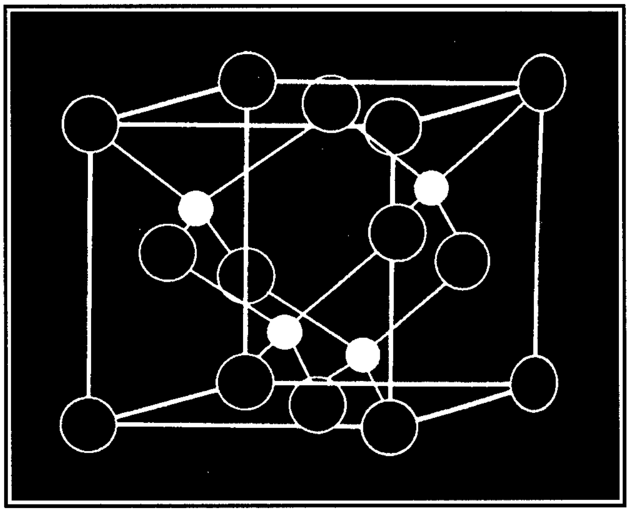
SCIENTIFIC PROGRAM & BOOK OF ABSTRACTS

ECSCRM'96



1st EUROPEAN CONFERENCE on SILICON CARBIDE and RELATED MATERIALS

◆

Fodele Beach Hotel
Heraklion, Crete, Greece
October 6 - 9, 1996

1st European Conference on Silicon Carbide and Related Materials (ECSCRM '96)

6 - 9 October, 1996

Fodele, Crete, Greece

ORGANIZING COMMITTEE

Chairman:

J. Stoemenos (Arist. Univ. Thessaloniki, GREECE)

Members:

G. Constantinidis (FORTH/IESL, GREECE)
S. Contreras (Univ. of Montpellier II, FRANCE)
R. Lossy (Techn. Univ. of Berlin, GERMANY)
P. Panayotatos (FORTH/IESL, Univ. of Crete, GREECE)
J. Pascual (Univ. Autonoma Barcelona, SPAIN)
K. Zekentes (FORTH/IESL, GREECE)

SCIENTIFIC PROGRAMME COMMITTEE

A. Christou (University of Maryland, USA)
E. Janzén (Linköping University, SWEDEN)
C. Jaussaud (CENG/LETI/DMEL, FRANCE)
M. T. Mora (Univ. Autonoma Barcelona, SPAIN)
E. Obermeier (Techn. Univ. Berlin, GERMANY)
G. Pensl (Erlangen Univ., GERMANY)
J.L. Robert (Universite de Montpellier II, FRANCE)
Y.M. Tairov (St. Petersbourg Univesity, RUSSIA)

SPONSORED BY:

- Training and Mobility of Researchers Programme (EuroConferences), Commission of the European Communities
- FOundation for Research & Technology-Hellas
- Greek Ministry of Culture
- General Secretariat of Research and Technology (Greece)
- Aristotle University of Thessaloniki (Greece)
- US Army/European Research office

1st European Conference on Silicon Carbide and Related Materials (ECSCRM '96)

6 - 9 October, 1996
Fodele Beach Hotel
Fodele, Crete, Greece

All sessions will be held in the Fodele Beach Hotel Conference Room. The Posters will be displayed during two sessions and it is kindly requested that the presenting author be at his/her poster during the session allocated to it.

Sunday, October 6, 1996

17:00 *Registration*

20: 00 *Welcome Reception at the Fodele Beach Hotel*

Conference Programme

Monday, October 7, 1996

08:30-08:45 Welcome

SESSION 1: INTRODUCTORY TALKS

Chairman: **J. L. Robert**

08:45-09:25 (1.1) W. J. Choyke and R.P. Devaty (invited)
Univ. of Pittsburgh, USA
"Progress on the study of optical and related properties of SiC since1992"

09:25-10:05 (1.2) J. Lasseur (invited)
EP Schlumberger, France
"Prospective of SiC applications in Europe"

10:05-10:20 *Coffee break*

SESSION 2: SiC BULK GROWTH

Chairman: **Yu. Tairov**

10:20-10:55 (2.1) M. Anikin, K. Chourou, M. Labeau, R. Madar (invited)
LMGP-ENSERG, France
"Relations between SiC single-crystal sublimation growth conditions and occurence of Defects"

10:55-11:15 (2.2) V. Heydemann, N. Schulze, D.L. Barrett, G. Pensl
Universität Erlangen-Nürnberg, Germany
"Sublimation growth of 6H- and 4H-Silicon Carbide boule crystals".

11:15-11:35 (2.3) D.D. Avrov, A.S. Bakin, S.I. Dorozhkin, V.P. Rastegaev, Yu.M. Tairov
St.-Petersburg Electrotechnical University, Russia
"Defect formation under 6H- and 4H-SiC sublimation growth".

11:35-11:55 (2.4) D. Hofmann, R. Eckstein, Y. Makarov*, M. Müller, St.G. Müller, E. Schmitt, A. Winnacker
University of Erlangen-Nürnberg, Germany
E.N. Mokhov, Yu.A. Vodakov
*A.F. Ioffe Physical Technical Institute, St. Petersburg, Russia
"Innovative aspects of SiC bulk growth technology".

11:55-12:15 (2.5) M. Syväjävri[1], R. Yakimova[1,2], E. Janzén[1]
[1] Linköping University, Sweden
[2] Outkompo Semitronic AB, Sweden
"Growth of Silicon Carbide from liquid phase: wetting and dissolution of Silicon Carbide".

12:15 *Lunch break*

POSTER SESSION (P.1): SiC MATERIAL (BULK AND EPITAXIAL) GROWTH AND CHARACTERIZATION

15:00-16:45

Poster Board No.:

1. M. Pons*, E. Blanquet*, J.M. Dedulle**, I. Garcon**, R. Madar** and C. Bernard*
*UMR CNRS/INPG/UJF, ENSEEG, France
** UMR CNRS/INPG-ENSPG, France
Modelling of the sublimation growth of Silicon Carbide crystals

2. J. Heindl, W. Dorsch, R. Eckstein*, D. Hofmann*, T. Marek, St.G. Müller*, H.P. Strunk, A. Winnacker*
Inst. für Werkstoffwissenschaften, Univ. Erlangen, Germany
Inst. für Werkstoffwissenschaften, Univ. Erlangen, Germany
The kinetic growth model applied to micropipes

3. G.V. Saparin, S.K. Obyden, P.V. Ivannikov
Moscow State University, Russia
E.N. Mokhov, A.D. Roenkov, M.G. Ramm, Yu.A. Vodakov
A.F.Ioffe Physical-Technical Inst., Russia
Polytypism of SiC epitaxial layers grown by sublimation sandwich method

4. C. Hallin, A.O. Konstantinov[1], B. Pecz[2], O. Kordina[3,4] and E. Janzén
Linköping University, Sweden
[1]Industrial Microelectrinics Center, Kista, Sweden
[2]Research Institute for Technical Physics, Budapest, Hungary
[3]ABB Corporate Research, Sweden
[4]Outokompu Semotronic, Sweden
The origin of 3C polytype inclusions in epitaxial layers of silicon carbide grown by chemical vapor deposition

5. A. Leycuras
CNRS, France
Optical monitoring of the growth of 3C SiC on Si in a CVD reactor

6. R. Beccard, D. Schmitz, E.G. Woelk, G. Strauch and H. Jürgensen
AIXTRON, Germany
SiC and group III nitride growth in MOVPE production reactors

7. J. Stoemenos[1], M.T. Clavaguera-Mora[2], J. Rodriguez-Viejo[2], Z. El Felk[2], E. Hurtos[2], S. Berberich[2], N. Clavaguera[2]
[1]Aristotle Univ. of Thessaloniki, Greece
[2]Universitat Autonoma de Barcelona, Spain
[3]Universitat de Barcelona
Growth of SiC films obtained by LPCVD

8. A. Fissel, K. Pfennighaus, U. Kaiser, B. Schröter, W. Richter
Universität Jena, Germany
Hexagonal and cubic SiC thin films on SiC(0001) deposited by solid source MBE

9. T. Stauden, J. Pezoldt, V. Cimalla, G. Eichhorn
TU Ilmenau, Germany
Chemical conversion of Si to SiC by solid source MBE and RTCVD

10. S. Yu. Davydov and S.K. Tikhonov
A.F. Ioffe Physico-Technical Institute, Russia
Bond orbital model approach to the pressure dependence of dielectric and optical properties of wide band gap semiconductors

11. S. Yu. Davidov and S.K. Tikhonov
A.F. Ioffe Physico-Technical Institute, Russia
Towards the calculation of the photoelastic moduli and quadratic dielectric susceptibility of wide band gap semiconductors

12. G. Wellenhofer and U. Rössler
Universität Regensburg, Germany
Valence band dispersion of hexagonal SiC

13. C. Persson[1] and U. Lindefelt[1,2]
[1]Dept. of Phys. & Measurement Technol., Linkoping Univ., Sweden
[2]ABB Corporate Research, Västeras, Sweden
Effective masses and carrier concentration for electrons and holes in intrinsic SiC polytypes

14. P. Käckell, J. Furthmüller and F. Bechstedt
Universität Jena, Germany
Polytypism and surface structure of SiC

15. U. Starke, J. Bernhardt, J. Schardt, K. Heinz
Universität Erlangen, Germany
Structure and morphology of SiC surfaces studied by LEED, AES, HREELS and STM

16. T. Balster[1], J.A. Schaefer[1], H. Ibach[2]
[1]TU Ilmenau, Germany
[2]Forschungszentrum Jülich, Germany
Control of modified 3C-SiC(100) by surface sensitive techniques

17. M. Hollering, A. Ziegler, R. Graupner, L. Ley
Universität Erlangen, Germany
A. Stampfl, J.D. Riley, R.C.G. Leckey
La Trobe Univ., Australia
Angle resolved photoemission on 6H-SiC(0001)

18. Ph. Komninou, G.P. Dimitrakopoulos, K. Zekentes*, V. Papaioannou, B. Pecz+, J. Stoemenos, and Th. Karakostas
Aristotle Univ. of Thessaloniki, Greece
* FORTH, Greece
+Hungarian Academy of Sciences, Hungary
Topology of twin interface junctions in epitaxial β-SiC

19. R. Scholz, U. Gösele
Max-Planck-Institut, Germany
E. Niemann, D. Leidich, F. Wischmeyer
Daimler-Benz, Germany
The new kind of micropipe defects and usual voids at β-SiC/Si(100) interfaces

20. A. Ellison[1], H. Radamson[1], C. Hallin[1], S. Milita[2], T. Tuomi[3], R. Yakimova[1,4], O. Kordina[1,4,5] and E. Janzén[1,4,5]
[1]Dept. of Phys. & Measurement Technol., Linkoping Univ., Sweden
[2]European Synchrotron Radiation Facility, Grenoble, France
[3]Optoelectronics Lab., Helsinski Univ, of Technology, Finland
[4]Ocmetic Ltd., Espoo, Finland
[5]ABB Corporate Research, Västeras, Sweden
Structural properties of 4H-SiC CVD layers

21. M. Tuominen[1], R. Yakimova[1,2], E. Prieur[3], T. Tuomi[4], A. Vehanen[2,5] and E. Janzén[1,5]
[1]Dept. of Phys. & Measurement Technol., IFM Linkoping University, Sweden
[2]Outokumpu Semitronic AB, Bromma, Sweden
[3]European Synchrotron Radiation Facility, Grenoble, France
[4]Optoelectronics Lab., Helsinski Univ, of Technology, Finland
[5]Ocmetic Ltd., Espoo, Finland
Growth related structural defects in seeded sublimation grown SiC

22. A.N. Andreev, A.S. Tregubova, M.P. Scheglov
A.F. Ioffe Physico-Technical Institute, Russia
Revealing of double position twins in cubic Silicon Carbide by X-ray topography

23. S.I. Dorozhkin, A.S. Bakin, D.D. Avrov, V.P. Rastegaev, A.O. Lebedev, Yu. M. Tairov
St.-Petersburg Electrotechnical Univ, Russia
Structural defects in the 6H- and 4H-SiC single crystals and layers

24. C. Meyer, G. Lüpke, E. Stein von Kamienski, A. Gölz, H. Kurz
RWTH Aachen, Germany
Nonlinear optical mapping of 3C-SiC inclusions in 6H-SiC-epilayers

25. N.T. Son, E. Sörman, M. Singh, W.M. Chen, C. Hallin, O. Kordina, B. Monemar and E. Janzén
Linköping University, Sweden
J.L. Lindström
National Defence Research Institute, Linköping, Sweden
Deep luminescent centres in electron-irradiated SiC

26. N.T. Son, E. Sörman, W.M. Chen, C. Hallin, O. Kordina B. Monemar and E. Janzen
Linköping University, Sweden
Optically detected magnetic resonance studies of defects in 3C SiC epitaxial layers

27. C. Peppermüller and R. Helbig,
University Erlangen-Nürnberg, Germany
A. Schöner, and K. Rottner
Industrial Microelectronics Center, Sweden
Hydrogen-, boron-, and hydogen-boron-related low temperatrue photoluminescence of 6H-SiC.

28. M. Frischholz, K. Rottner, and A. Schöner
IMC, Stockholm-Kista Sweden
OBIC studies on 6H-SiC Schottky rectifiers with different surface pretreatments

29. J.M. Bluet, J. Camassel and A. Leycuras[1]
G.E.S. Univ. Montpellier II, France
[1]CRHEA-CNRS, Valbonne, France
Optical investigation of thick 3C-SiC on Si grown by CVD

30. S. Greulich-Weber, M. März, J.-M. Spaeth, E.N. Kalabukhova* and S. Lukin*
Univeristy of Paderborn, Germany
The microscopic structure of shallow donors in silicon carbide

31. J.P. Doyle, M.O. Aboelfotoh, M.K. Linnarsson, and B.G. Svensson
Royal Institute of Technology, Kista-Stockholm, Sweden
Characterization of deep level defects in 4H and 6H SiC

32. T.S. Sudarshan[1], G. Gradinaru[1], S. Gradinaru[2], W. Mitchel[3], H. McD. Hobgood[4]
[1] Dept. Electrical & Computer Eng., Univ. South Carolina, USA
[2] Governor's Sch. Science & Mathematics, Harstville, USA
[3] Wright-Patterson AFB, USA
[4] Northrop Grumman Science & Tech. Center, Pittsburg, USA
Electrical performance of high resistivity silicon carbide under high temperature - high field stress

33. A.A. Lebedev
A.F. Ioffe Physico-Technical Institute, Russia
Comparative investigation by capacitance spectroscopy of the 6H-SiC epilayers and p-n junctions grown by sublimation epitaxy (SE) and chemical vapor deposition (CVD)

34. V.I. Sankin, I.A. Stolichnov
A.F. Ioffe Physico-Technical Institute, Russia
Wannier-Stark localization effects in the natural Silicon Carbide superlattices

16:45-17:00 *Coffee break*

SESSION 3: SiC EPITAXIAL GROWTH

Chairman: **C. Jaussaud**

17:00-17:35 (3.1) H. Matsunami (invited)
Kyoto University, Japan
"Progress in SiC epitaxy - Present and Future"

17:35-18:10 (3.2) R. F. Davis, R. S. Kern and S. Tanaka (invited)
Dept. Materials Science and Eng., North Carolina State Univ., USA
Growth and doping via Gas Source Molecular Beam Epitaxy and microstructural and electrical characterization of SiC and SiC/AlN heterostructrures"

18:10-18:30 (3.3) A. Henry*, I.G. Ivanov, T. Egilsson, C. Hallin, O. Kordina*, U. Lindefelt*, and E. Janzén
Linköping University, Sweden
* ABB Corporate Research, Sweden
"High quality 4H-SiC grown on various substrate orientations".

18:30-18:50 (3.4) A. Schöner[1], K. Rottner[1], N. Nordell[1], C. Peppermüller[2], R. Helbig[2], M. Linnarson[3]
[1] Industrial Microelectronics Center, Sweden
[2] University Erlangen-Nürnberg, Germany
[3] Royal Institute of Technology, Sweden
"Hydrogen incorporation in epitaxial layers of 6H- and 4H-Silicon Carbide grown by vapor phase epitaxy".

ROUND TABLE DISCUSSION: EUROPEAN EFFORT ON SiC WAFER PRODUCTION & SiC BULK AND EPITAXIAL GROWTH APPARATUS.

19:00 Chairman: **E. Janzén**

Dr. D. Brown (ATM), Dr. J.O. Fornell (Epigress AB), Dr. H. Juergensen (AIXTRON), Dr. M. Kanaya (Nippon Steel), Prof. R. Madar (INP Grenoble), Dr. J. Palmour (CREE), Prof. Y. Tairov (St. Petersburg Electrotech. Univ.), Dr. A. Vehanen (Okmetic Oy), Dr. J. Voelkl (Siemens), Prof. A. Winnacker (Erlangen Univ.).

Tuesday, October 8, 1996

SESSION 4: SiC CHARACTERIZATION: CRYSTAL STRUCTURE & DEFECTS; OPTICAL AND ELECTRONIC PROPERTIES

Chairman: **J. Camassel**

08:30-09:05 (4.1) P. Bergmann (invited)
Linköping University
"Carrier Lifetimes in SiC, studied by Time Resolved Photoluminescence Spectroscopy"

09:05-09:25 (4.2) S. Contreras, C. Dezauzier, P. Thomas, J.L. Robert
G.E.S., UM2-CNRS Montpellier, FRANCE
"Analysis of transport properties of β-SiC films: determination of donors density and compensation ratio".

09:25-09:45 (4.3) T. Dalibor[1], G.Pensl[1], T. Kimoto[2], H. Matsunami[2], S. Sridhara[3], R.P. Devaty[3], W.J. Choyke[3]
[1] University of Erlangen-Nürnberg, Germany
[2] Kyoto University, Japan
[3] University of Pittsburgh, USA
"Radiation-induced defect centers in 4H and 6H Silicon Carbide".

09:45-10:05 (4.4) C. Wagner, G. Krötz
Daimler-Benz AG, Germany
"Thermal properties of β-SiC epitaxial layers between RT and 600°C measured by using microstructures".

10:05-10:20 *Coffee break*

SESSION 5: SiC PROCESSING: OXIDATION, METALLIZATION, ION-IMPLANTATION AND ETCHING

Chairman: **W. J. Choyke**

10:20-10:55 (5.1) J. W. Palmour, L.A. Lipkin, R. Singh, D.B. Slater,Jr., and A.Suvorov (invited)
CREE Research Inc., USA
"SiC device technology: Remaining issues"

10:55-11:30 (5.2) C. Brylinski (invited)
Thomson-CSF-LCR, France
"SiC for Microwave Power Applications"

11:30-11:50 (5.3) N. Lundberg, P. Tägtström[1], U. Jansson[1] and M. Östling
Royal Institute of Technology, Sweden
[1]Uppsala University, Sweden
"CVD-based tungsten Carbide Schottky contacts to 6H-SiC for very high temperature operation".

11:50-12:10 (5.4) L. Spieß[1], O. Nennewitz[1], H. Weishart[2], J. Lindner[3], W. Skorupa[2], H. Romanus[1], F. Erler[1], J. Pezoldt[4]
[1] Technische Universität Ilmenau, Institut für Werkstoffe, Germany
[2] Forschungszentrum Rossendorf e.V, Germany
[3] Universität Augsburg, Germany
[4] Technische Universität Ilmenau, Institut für Festkörpelektronik, Germany
"Aluminium implantation of p-SiC for ohmic contacts".

12:10-12:30 (5.5) A. Gölz, R. Janssen, S. Groß, E. Stein von Kamienski, and H. Kurz
Institut für Halbleitertechnik, RWTH Aachen, Germany
"Fabrication of high-quality oxides on SiC by remote PECVD".

12:30 *Lunch break*

POSTER SESSION (P2): SiC-BASED DEVICE FABRICATION & CHARACTERIZATION. SiC-RELATED MATERIALS

15:00 - 16:45

Poster Board No.:

1. S. Kennou*, A. Siokou, I. Dontas and S. Ladas
Univ. of Patras, Greece
* Permanent address: Univ. of Ioanninna, Greece
An interface study of vapor-deposited rhenium with the (0001) and (0001) faces of single crystal 6H-SiC

2. B. Pécz, G. Radnoczi, G. Vincze, S. Cassette[1], C. Brylinski[1] and C. Arnodo[1]
Research Inst. for Technical Physics, Hungary
[1]THOMSON-CSF, France
TEM study of Ni and Ni_2Si Ohmic contacts to SiC

3. J. Kriz, K. Gottfried, Ch. Kaufmann, T. Gessner
Technische Universität Chemnitz-Zwickau, Germany
Determination of Ohmic contacts to n-type 6H- and polycristalline SiC using circular transmission line structures

4. H. Weishart, W. Matz and W. Skorupa
Institut für Ionenstrahlphysik and Materialforschung, Dresden, Germany
Ion beam assisted deposition of a tungsten compound layer on 6H-SiC

5. T. Licht, N. Achtziger, D. Forkel-Wirth*, J. Grillenberger, K. Freitag**, M. Kaltenhäuser, U. Reislöhner, M. Rüb, M. Uhrmacher***, W. Witthuhn and Isolde Collaboration*
Universität Jena, Germany
* CERN/PPE, Geneva, Switzerland
** Universität Bonn, Germany
*** Universität Göttingen, Germany
Hafnium, cadmium and indium impurities in 4H-SiC observed by perturbed angular correlation spectroscopy

6. H. Heissenstein, C. Peppermüller and R. Helbig
Univ. Erlangen-Nürnberg, Germany
Nuclear transmutation doping of 6H-SiC with phosphorous

7. W. Reichert, R. Lossy, M. Gonzalez Sirgo, E. Obermeier, and W. Skorupa*
TU Berlin, Germany
* FZ Rossendorf, Dresden, Germany
Investigation of the effects of high temperature implantation and post implantation annealing on the electrical behavior of nitrogen implanted β-SiC films

8. W. Reichert, E. Obermeier, and J. Stoemenos*
TU Berlin, Germany
* Aristotle Univ. of Thessaloniki, Greece
β-SiC films on SOI substrates for high temperature applications

9. N. Sieber, M. Hollering, A. Ziegler R. Graupner, L. Ley
Univ. Erlangen, Germany
Surface chemistry of 6H-SiC after reactive ion etching

10. R. Yakimova[1,2], A.-L. Hylén[1], M. Tuominen[1], M. Syväjärvi[1], and E. Janzén[1]
[1] Linköping University, Sweden
[2] Outokumpo Semitronic AB, Sweden
Preferential etching of SiC crystals

11. G. Constantinidis, K. Tsagaraki, M. Androulidaki and J. Kuzmik[1]
MRG-IESL-FORTH, Heraklion, Greece
[1]Inst. Electrical Eng., Slovak Academy of Sciences, Slovakia
Schottky barrier contacts on reactive ion etched 6H-SiC

12. K. Christiansen[1], R. Helbig[1], S. Christiansen[2], M. Albrecht[2] and H.P. Strunk[2]
[1]Inst. of Applied Physics, University Erlangen-Nürnberg
[2] Inst. of Microcharacterization, University Erlangen-Nürnberg
Anisotropic oxidation of 6H-Silicon Carbide

13. M. Bassler[1], G. Pensl[1] and V. Afanas'ev[2]
Univ. Erlangen-Nürnberg, Germany
Lab. voor Halfgeleiderfysica, KU Leuven, Belgium
"Carbon-cluster model" for electronic states at SiC/SiO_2 interfaces

14. Z. Ovuka and M. Bakowski
Industrial Microelectronic Center, Kista, Sweden
Investigation of walk-out phenomena in SiC mesa diodes with SiO_2/Si_3N_4 passivation

15. E. Stefanov, L. Bailon, and J. Barbolla
University of Valladolid, Spain
Analysis of blocking capabilities of α-SiC planar p-n junctions for power devices

16. L. Anghel, T. Ouisse, T. Billon*, P. Lassagne* and C. Jaussaud*
(LPCS) UMR-CNRS 5531, ENSERG, France
* LETI (CEA-Technologies Avancees), DMITEC-CEN/G, France
Low frequency noise in SiC Schottky diodes

17. P.A. Ivanov, K.I. Ignat'ev, T.P. Samsonova, V.N. Panteleev
A.F. Ioffe Physico-Technical Institute, Russia
A.A. Maltsev, A. Yu. Maksimov, and N.K. Yushin
FTIKKS Enterprise, Russia
Formation of inversion layer in 6H-SiC MOS structures made from SSM and CVD epitaxial films

18. E.G. Stein von Kamienski, C. Leonhard, S. Scharnholz, A. Gölz, and H. Kurz
RWTH Aachen, Germany
Passivation of interface traps in MOS-devices on n- and p-type 6H-Si

19. F. Schwierz
Tech. University Ilmenau, Ilmenau, Germany
The potential of SiC and GaN for application in high speed devices

20. V.E. Chelnokov and P.A. Ivanov
A.F. Ioffe Physico-Technical Institute, Russia
Depletion-mode SiC FETs for high power, high frequency applications (physical outlook)

21. C. Raynaud, C. Richier, G. Guillot, V. Séguier
UMR 5511 - INSA, Villeurbanne, France
Temperature dependence of electrical properties of 6H-SiC buried JFET

22. D. Korakakis, D. Doppalapudi[1] and T.D. Moustakas
Dept. Electrical & Comp. Eng. - Center for Photonics Res., Boston Un., USA
[1]Dept. Manufacturing Eng. - Center for Photonics Res., Boston Univ., USA
Growth of $Al_xGa_{1-x}N$ films on 6H-SiC by plasma assited MBE

23. Yu. M. Melnik, I.P. Nikitina, A.E.Nikolaev, D.V. Tsvetkov, A.A. Sitnikova and V.A. Dmitriev
Cree Research EED and A.F. Ioffe Institute, Russia
Structural properties of GaN grown on SiC substrates by hydride vapor phase epitaxy

24. E.V. Kalinina[1], N.I. Kuznetsov[1], A.I. Babanin[1], A.P. Kovarsky[2], A.V. Shchukarev[2]
[1]Cree Research EED and Ioffe Institute and
[2]Mekhanobr Analyt Co.
Structural and electrical properties of Schottky barriers on n-GaN

25. A.S. Zubrilov[1], D.V. Tsvetkov[1], V.I. Nikolaev[1], I.P. Nikitina[1], V.E. Bougrov[1], and V.A. Dmitriev[1,2]
[1] Cree Research EED & Ioffe Institute, Russia
[2] Cree Research, USA
Luminescent properties of AlGaN solid solutions grown on 6H-SiC

26. M. Katsikini[1,2], E.C. Paloura[1], T.S. Cheng[3], C.T. Foxon[3]
[1] Aristotle Univ. of Thessaloniki, Greece
[2] Hahn-Meitner Institute, Berlin, Germany
[3] Univ. of Nottingham, England
Angle resolved nexafs spectra of hexagonal and cubic GaN

27. H. Alause[1], C. Skierbiszewski[1], M. Dyakonov[1], W. Knap[1], M.L. Sadowski[2], S. Huant[2], J. Young[3], M. Asif-Khan[3], Q. Chen[3]
[1]G.E.S., UM2-CNRS Montpellier, FRANCE
[2]High Magnetic Field Lab., Grenoble, France
[3]A.P.A. Optics Inc,, Minnesota, USA
Contactless characterisation of 2D-electrons in GaN/AlGaN HFETs

28. K. Aguir, D. Lollman, B. Roumiguieres, & H. Carchano
Université d'Aix- Marseille III, France
Amorphous $GaAs_{1-x}N_x$ *thin films on crystalline Si substrates: growth and characterizations*

29. L.F. Marsal, J. Pallares, X. Correig, M. Dominguez*, D.Bardes*, J. Calderer* and R. Alcubilla*
Universitat Rovira i Virgili, Spain
* Universitat Politecnica de Catalunya, Barcelona, Spain
Electrical properties of PECVD amorphous silicon-carbon alloys from amorphous-crystalline heterojunctions

30. G. Viera, S.N. Sharma, R.Q. Zhang, J.L. Andujar and E. Bertran
LFCF, Universitat de Barcelona, Spain
Effects of thermal and laser annealing on silicon carbide nanopowder produced by rf glow discharge

31. M.C. Rossi, S. Salvatori, F. Galluzzi
Third Univ. of Rome, Italy
R.M. Montereali, ENEA, C.R. FRASCATI, (RM), ITALY
F. Somma, Third Univ. of Rome, Italy
Emission and excitation spectra of silicon-related luminescent centers in CVD-grown diamond films

32. M.E. Kompan, V.A. Lukoshkin, I.I. Novak, O.I. Konkov, E.I. Terukov, I.N. Trapeznikova
A.F. Ioffe Physico-Technical Institute, Russia
Observation of wave-length tunable luminescence from the variable thickness a-C:H film on the fused silica substrate

33. Sh.A. Nurmagomedov, M.K. Kurbanov, A.G. Magomedov, N.V. Oficerova, N.D. Sorokin, O.A. Omarov, G.K. Safaraliev and Yu. M. Tairov
Daghestan State University
The epitaxial growth and etching of large area solid solutions $(SiC)_{1-x}(AlN)_x$
The formation of solid solutions in systems with Silicon Carbide

34. E.I. Terukov, V. Kh. Kudoyarova, A.N. Kuznetsov, W. Fuhs*
A.F. Ioffe Physico-Technical Institute, Russia
Room-temperature photoluminescence of amorphous hydrogenated Silicon Carbide doped with erbium

35. A.P. Garshin
St. Petersburg St. Tech. University, Russia
Some tribological properties of reaction-sintering silicon carbide

16:45-17:00 *Coffee break*

SESSION 6: SiC-BASED DEVICES AND APPLICATIONS

Chairman: **A. Christou**

17:00-17:35 (6.1) D. Stephani (invited)
Siemens AG, Germany
"Recent progress on SiC-based devices"

17:35-18:10 (6.2) V. E. Chelnokov, A. L. Syrkin and V.A. Dmitriev (invited)
A.F. Ioffe Institute, Russia
"Overview on SiC power electronics"

18:10-18:30 (6.3) K.H. Rottner, A. Schöner, S.M. Savage and M. Frischholz
IMC, Sweden
"2.5 kV Ion-Implanted p^+n Diodes in 4H SiC".

18:30-18:50 (6.4) E. Bano, T. Ouisse, C. Leonhard*, A. Gölz* and E.G. Stein von Kamienski*
UMR-CNRS, France
* RWTH Aachen, Gemany
"High field and high temperature stress of n-SiC MOS capacitors".

18:50-19:10 (6.5) P. Tobias, A. Baranzahi, A.L. Spetz, P. Martensson, and I. Lundström
Linköping University, Sweden
"Platinum Metal - Insulator - Silicon Carbide Devices Operating up to 1000°C".

ROUND TABLE DISCUSSION: SiC APPLICATIONS AND EUROPEAN INDUSTRY

19:15 Chairman: **G. Pensl**

Dr. C. Brylinski (Thomson-CSF), Dr. S. Lande (MAGUS Research), Dr. J. Lasseur (Schlumberger Ind.), Dr. E. Niemann (Daimler Benz), Dr. A. Sénes (Schneider Electric), Dr. D. Stephani (Siemens).

21:00 *BBQ party*

Wednesday, October 9, 1996

SESSION 7: NITRIDES GROWTH AND CHARACTERIZATION

Chairman: **R. F. Davis**

08:30-09:05 (7.1) S. Porowski (invited)
High Pressure Research Center, Poland
"Bulk growth of GaN"

09:05-09:40 (7.2) T.D. Moustakas (invited)
Boston University, USA
"Molecular beam epitaxy of GaN"

09:40-10:00 (7.3) I.P. Nikitina*, M.P. Sheglov**, Yu.V. Melnik*, K.G. Irvine*, A.I.Babanin*, and V.A. Dmitriev*
* Cree Research and/or A.F. Ioffe Inst., St. Petersburg, Russia
** Ioffe Institute, St. Petersburg, Russia
"Residual strains in GaN grown on 6H-SiC".

10:00-10:20 *Coffee break*

SESSION 8: AMORPHOUS SiC AND OTHER SiC-RELATED MATERIALS

Chairman: **M.T. Mora**

10:20-10:55 (8.1) G. Muller (invited)
Daimler Benz AG, Germany
"Thin-Film-on-ASIC Applications of Hydrogenated Amorphous Silicon Carbide Alloys"

10:55-11:25 (8.2) J. Kalomiros[1], E.C. Paloura[1], C. Janowitz[2], and A. Anagnostopoulos[1]
[1]Aristotle Univ. of Thessaloniki, Greece
[2]Humboldt Univ. zu Berlin, Germany
"Surface and bulk effects in ex-situ hydrogenated α-SiC thick films"

11:25-11:45 (8.3) M.C. Polo[1], M. Ben el Mekki[2], J.L. Andujar[1] and J. Pascual[2]
[1]Universitat de Barcelona, Spain
[2]Universitat Autonoma de Barcelona, Spain
"Optical study of Boron Nitride thin films prepared by plasma-enhanced CVD"

11:45 *Lunch break*

16:45 Excursion to Knossos and FORTH
(Visit &Close of the Conference)

Monday, October 7, 1996 08:45-10:05

SESSION 1: INTRODUCTORY TALKS

Chairman: J. L. Robert

PROGRESS ON THE STUDY OF OPTICAL AND RELATED PROPERTIES OF SIC SINCE 1992

W.J.Choyke and R.P. Devaty
Department of Physics and Astronomy
University of Pittsburgh
Pittsburgh,PA . USA 15260
Phone: 001+(412) 624 9251
FAX: 001+(412) 624 1479

Since 1992 when we last reviewed this area very substantial progress has been made in the understanding of the physical properties of SiC. It was difficult then and impossible now to cover the field in completeness in the space and time allotted. We have chosen to discuss such progress as is closely related to our own areas of research and we in no way make a value judgement of much of the splendid work that we are forced to leave unmentioned.

We shall start our discussion by reviewing the latest data on phonon replicas in 4H and 6H SiC and how this relates to the latest calculated energy positions of these replicas and in turn what that says about the positions of the minima on the Brillouin zone boundary.

UV reflectivity experiments will be reviewed and compared with first principles band calculations
.

In 1992 the issue of the effective masses in 4H and 6H SiC was quite cloudy. With the advent of improved cyclotron resonance measurements and theory the picture today is much clearer.

There has been a constant striving to improve our understanding of various dopants in SiC. Some of the puzzles have been around for more than thirty years. New results since 1992 on boron, aluminum gallium and phosphorus in 6HSiC or 4H SiC will be discussed.

Very substantial progress has been made in the study of electron Raman scattering in SiC from heavily doped SiC and these experiments will be reported on.

Porous SiC has attracted some attention in these years following the great interest in porous Si. The luminescent results have been dissapointing but some rather novel features have been brought out by the use of FTIR-reflectivity in the restrahlen region.

Erbium implanted crystals of 3C, 6H, 4H and 15R SiC have shown very interesting sets of spectra ranging from the 1.54µm region to the visible . Photoluminescence as well as electroluminescence spectra will be discussed.

Transition metals have been under discussion for a long time in SiC but since 1992 beautiful experimental results have enhanced our appreciation of the nature of transition metal centers in SiC and some of the main features will be discussed.

Thermoluminescence has been observed in SiC since the fifties and possibly before then. However, not until now has a systematic study been made of this phenomena in SiC. New results ,especially on epitaxially grown films of SiC will be shown.

Finally, there are some interesting new results on the pressure dependence of the electronic energy bandgap of 6H SiC and we shall discuss them.

PROSPECTIVE SIC APPLICATIONS IN EUROPE

Jean Lasseur
EP Schlumberger
26 Rue de la Cavee
Clamart 92-140
France

Tel. 33-1-45-37-24-33 Fax 33-1-45-37-25-13 E-mail : lasseur@clamart.wireline.slb.com

MOTTO

The driving motto for the prospective SiC applications in Europe will be:
"Every time there is an harsh or severe environment, SiC has to be considered"
"Large savings can be obtained in many fields by pushing materials beyond the accepted limits".
The presentation will try to analyze and to put emphasis on the necessary role of Europe in that area.

GLOBAL SITUATION

Silicon carbide is an old material but to-day, silicon carbide is now a new technology and the future usage is still largely unknown. Electronician, sensors , optical and mechanical specialists are discovering it at the same time. All the applications are challenging but the main competitor is silicon for a while.
However the global situation is rather confusing and fuzzy: one main supplier world wide, no product available from Japan, strong governments support for activities in US and Japan. SBIR projects are numerous in U.S..
In Europe, some European projects as Tecsica, Sicoin are running or starting but the overall European industrial interest is not well defined or at least not well perceived by the community.

PROPERTIES OF MATERIAL

The success of SiC will reside in its outstanding material properties. In the mechanical field its stability, abrasion resistance, combination with ceramic or metallic composite materials, low specific density have to be considered.
Its chemical resistance and inertness are of premium in chemical plants. Optical people will be attracted by the thermal dimensional stability, polishability, UV and IR reflectivity or transparency.
But the main points will be the electrical behavior: wide energy band gap, high breakdown field, high thermal conductivity, high saturated electron drift velocity.

MARKET SEGMENTS

By using the above qualities of SiC, the market segments would be transportation [oil fuel cars, electric vehicle, hi-speed train, Maglev, More Electric Airplane] electric power control, industrial processes, nuclear plant, geothermal and oil well industries, optical, mechanical.

RISKS

A risk analysis will be performed in order to weigh the future of the SiC in Europe.

Monday, October 7, 1996 10:20-12:15

SESSION 2: SiC BULK GROWTH

Chairman: Y. Tairov

RELATIONS BETWEEN SiC SINGLE CRYSTAL SUBLIMATION GROWTH CONDITIONS AND OCCURENCE OF DEFECTS

M. Anikin, K. Chourou, M. Labeau, R. Madar

Laboratoire des Matériaux et du Génie Physique
UMR 5628 CNRS. ENSPG - BP 46
38402 Saint Martin d'Hères

tel : (33) 76 82 63 30
fax : (33) 76 82 63 94

Taking into account its intrinsic properties, silicon carbide SiC seems to be among the different wide band gap semiconductors, the material of choice for the new generation of high power and high frequency devices.

The progress in these fields is however quite low mainly because in spite of the work already done on this subject, the problems for making these devices are still related to the "quality" of available SiC substrates.

The method presently used in most laboratories to growth large size SiC ingots, called the Modified Lely method [1], was originally proposed by Yu. M. Tairov and V. F. Tsretkov in 1978. Despite the improvements which have been introduced since this original work, commercially available SiC substrates still contain a lot of defects, micropipes, dislocations, coexistence of different domains and polytypes, which are detrimental for device operation.

A perfect understanding of the origin of these defects in connection with crystal growth conditions is of prime importance for the future of SiC based electronic.

In the modified Lely method, the growth takes place by uncongruent sublimation from SiC powder on a monocrystalline SiC used at low pressure and high temperature. To suppress nucleation at low temperature which would result in underisable formation of many small crystals, the pressure in the furnace is first set at atmospheric level. A lot of defects are generated in this initial stage and these defects propagate in the growing ingot.

In order to remove damaged and contaminated surface layer, to suppress nucleation at low temperature and to start the crystal growth at high temperature but at slow growth rate, we have proposed [2] to begin the growth process at inversed sign of temperature gradient and low argon pressure. In these conditions, nucleation at low temperature is suppressed and sublimation polishing etching takes place. Then the sign of the temperature gradient is slowly inversed to start the growth.

The influence of these nucleation steps on the nature and quantity of defects has been determined by structural analysis using X-Ray diffraction, high resolution neutron diffraction, optical and electronic microscopy, atomic force microscopy and synchrotron white beam X-ray topography. The results will be discussed at the light of the present knowledge of the sublimation process.

[1] Yu. M. Tairov and V.F. Tsretkov, J. of Cryst. Growth, 43 (1978) 208.
[2] M. Anikin and R. Madar, Proc. of E-MRS (1996), Strasbourg (F).

SUBLIMATION GROWTH OF 6H- AND 4H-SILICON CARBIDE BOULE CRYSTALS

V. Heydemann, N. Schulze, D.L. Barrett[1], G. Pensl
Institut für Angewandte Physik, Universität Erlangen-Nürnberg, Staudtstrasse 7,
D-91058 Erlangen, Germany, Phone (+49) 9131 / 85 84 - 26, Fax - 23

Abstract

SiC boule material of great diameter and high crystalline quality is of great interest for device manufacturers. In order to study the SiC growth mechanism, we have set up a SiC bulk growth system that allows sublimation physicial vapor transport (PVT) according to the modified Lely process. A novel dual seed method is used to test the dependence of the growing polytype, the morphology and the residual nitrogen concentration on the face polarity, the polytype and the off-orientation of the seed crystal as well as the effects of a surplus of elementary silicon to the SiC source material.

The dual seed method allows to simultaneously overgrow two SiC seed crystals under identical growth conditions; the two seed crystals are cut from the same wafer, however, they may be provided with different face properties.

For the growth experiments, we varied the SiC source temperature in a range from 2200°C to 2400°C and achieved an axial temperature gradient to the seed crystal of 50K to 200K. The argon pressure was kept constant during each run (at min. 1mbar up to max. 50mbar).

SiC growth of the 4H polytype was achieved on 4H or 6H C-face seeds, when the growth rate exceeded a critical value of 1.0 g/h. Independent of the polarity and orientation of the seed face, we obtained the 6H polytype, when the growth rate was lower than this critical value.

A varying surplus of elementary silicon to the SiC source material was used in a series of growth experiments with identical growth conditions ($T_{Source} = 2260°C$, $T_{Seed} = 2160°C$, $p_{Argon} = 10mbar$, $t_{Growth} = 300min$, boule diameter = 26mm). The surplus of Si is defined by the parameter $R = m_{Si} / (m_{SiC} + m_{Si})$. Due to the Si addition the growth rate of SiC crystals increases in a range of 0.70 g/h (for R = 0) to 2.8 g/h (for R = 0.50). Monocrystalline SiC crystals grow without Si addition (R = 0) up to R < 0.15, the growth rate increases linearly with a slope of 5.2 g/h. In the range of R = 0.15 to R < 0.30 the growing crystals are found to be a mixture of mono- and polycrystalline SiC. For values $R \geq 0.30$ all the growing SiC is polycrystalline and the slope of the linear increase of the growth rate with the Si addition turns out to be 3.7 g/h.

Conductivity and Hall effect measurements in the temperature range of 70K to 600K were conducted on monocrystalline 6H and 4H samples grown in one run on a Si-face and a C-face of a 6H seed crystal. The concentration of nitrogen in samples grown on a C-face is 2 to 3 times higher than in samples grown on a Si-face regardless of the polytype. SiC crystals of the 6H and 4H polytype grown onto the C-face of a 6H seed with half the area orientated on-axis and 8° off-axis, respectively, resulted in identical nitrogen concentrations.

The Hall mobility of electrons in crystals grown on C-face seeds is higher by a factor of approximately 2 than the corresponding mobility in crystals grown on Si-face seeds. We believe that this reduction of the Hall mobility is caused by a higher density of crystalline defects, which are present in crystals grown on a Si-face.

---

[1] permanent address: 6141 Sanctuary Gardens Blvd., Port Orange, FL 32124, USA

DEFECT FORMATION UNDER 6H- and 4H-SiC SUBLIMATION GROWTH

Avrov D.D., Bakin A.S., Dorozhkin S.I., Rastegaev V.P., Tairov Yu.M.
Department of Microelectronics
St.-Petersburg Electrotechnical University
Prof. Popov Str. 5, 197376 St.-Petersburg, RUSSIA
Phone: +7 (812) 234-31-64
Fax: +7 (812) 234-31-64
E-mail: root@me.etu.spb.ru

Silicon carbide device application strongly depends on material quality. Micropipe defects in silicon carbide single crystals are performance limiting defects for devices on their base and micropipe defects in substrates serve as the sources for the formation of defects in epitaxial layers grown on them. First results on the silicon carbide sublimation growth using Modified-Lely method (LETI method) elaborated at the St.Petersburg Electrotechnical University were reported by Yu.M.Tairov and V.F.Tsvetkov in 1976 at the 1st European Conference of Crystal Growth in Zurich. But till now the problem of micropipe defects control is not solved. Formation of 3C-SiC (β-SiC) on the initial stages of 6H- and 4H-SiC growth as well as during further growth process is one of the problems of sublimation crystal growth and one of the reasons of the formation of other types of defects. At the same time cubic silicon carbide is one of the most promising polytypes for device applications. The aim of the present paper is to make overview of our previous and recent studies of 3C-SiC formation study under the SiC sublimation growth and of the influence of the sublimation growth conditions on the micropipe defects formation and behaviour in 6H- and 4H-SiC crystals and layers.

The sublimation growth was carried out by the Modified Lely method (LETI method) [1, 2]. Optical microscopy, scanning electron microscopy, selective etching, X-ray topography and photoluminescence were employed for investigations of samples obtained. The influence of the growth temperature, temperature gradient, vapour phase composition, vapour pressure, the step limiting the growth rate, argon pressure, orientation of substrate's surface; pumping time on the formation and behaviour of micropipe defects and dislocations and on the formation of certain polytype on a different SiC facets have been investigated. Results obtained make possible to control the yield of the required SiC polytype, to avoid formation of defects which are caused by the growth of metastable 3C-SiC, to consider the reasons of micropipes and dislocations formation and to reduce formation of defects which are formed at the different stages of SiC sublimation growth and to reduce replication of substrate's defects.

References

[1] Tairov Yu.M. J. of Crystal Growth, Vol.52, 1981, p.146.

[2] Tairov Y.M. and V.F. Tsvetkov, in Progress in Crystal Growth and Characterization, Vol. 7, Pergamon, London, 1983, p.111-162.

INNOVATIVE ASPECTS OF SIC BULK GROWTH TECHNOLOGY

D. Hofmann, R. Eckstein, Y. Makarov*, M. Müller, St.G. Müller, E. Schmitt, A. Winnacker
Institutes of Materials Science 6 and Fluid Mechanics *, University of Erlangen-Nürnberg
Martensstr. 7 and Cauerstr. 4*, D-91058 Erlangen, Germany

E.N. Mokhov, Yu.A. Vodakov
Ioffe Physical Technical Institute, Russian Academy of Sciences
Polytechnitcheskaya 26, 194021 St. Petersburg, Russia

Tel.: +49-9131-85-7634
Fax: +49-9131-85-8495

Considerable progress in SiC materials science and semiconductor technology has been achieved in the last years giving perspectives for a commercial realization of SiC devices in power and high temperature electronics and III-V nitride based optelectronic devices emitting in the blue/UV spectral range, respectively. But several aspects related to SiC substrate crystals represent obstacles decelerating the dynamics of the starting activities in SiC device production:

(i) SiC single crystals exhibit still a high density of micropipes and dislocations and highly strained areas. Also the formation of parasitic crystallographic modifications and phases is frequently observed. The avoidance of defect generation is shown to become more and more complicated with increasing crystal diameter.

(ii) The present status of the SiC bulk growth process by sublimation according to the modified Lely technique (MLT) does not permit the preparation of large diameter and long SiC boules at high growth rates. It is not evident whether all demands of future large-scale SiC wafer production will be fulfilled by MLT processing, both technically and economically.

In this paper analysis on recent developments of the SiC sublimation growth process and new approaches for bulk growth are performed and discussed with respect to improving the deficiencies described in (i)-(ii).

The MLT technique is investigated theoretically to evaluate upper limits of the crystallization rate for maintaining morphological stable growth conditions and structural quality. Heat and mass tranfer including chemical reactions are calculated numerically. Excess phases formation is also predicted. Theoretical results are compared to experimental SiC growth studies.
The use of container materials (e.g. tantalum) as alternative to graphite is studied for the improvement of process conditions for high rate, low defect SiC growth.

Recently Kordina et al. presented at the ICSCRM 1995, Kyoto (Japan) first experimental results on chemical vapor deposition of SiC layers at elevated temperatures as possible growth method for SiC bulk crystals, the so called HT-CVD method. This new approach will be analyzed by numerical simulations focussing on technological questions, e.g. the correlation of gas composition and flow rate (silane, propane, hydrogen) and growth velocity and possible measures to increase the efficiency of silicon up-take from the gas phase into the growing crystal.

Finally SiC bulk growth from the liquid phase is studied. Possibilities for solution growth of SiC at elevated crystallization rates are proposed. A new growth reactor design is introduced to prepare large diameter SiC boules from the liquid at high temperatures and pressures. This approach looks also promising for the economic preparation of thick (>100 μm), low defect SiC epitaxial layers for applications in high power electronics.

GROWTH OF SILICON CARBIDE FROM LIQUID PHASE: WETTING AND DISSOLUTION OF SILICON CARBIDE

M. Syväjärvi[1], R. Yakimova[1,2], and E. Janzén[1]

[1] Dept. Physics and Measurement Technology, Linköping University, S-581 83 Linköping, Sweden
[2] Outkompo Semitronic AB, S-161 11 Bromma, Sweden

Linköping University, Dept. Physics and Measurement Technology, S-58183 Linköping, Sweden
Phone: +46 13 28 25 28; Fax: +46 13 14 23 37; e-mail: roy@ifm.liu.se

Silicon carbide (SiC) is a wide bandgap semiconductor well suited for high-power, high-temperature, and high-frequency applications. However, the quality of the material still has to be improved before commercial devices are manufactured. When semiconductor materials are grown from the liquid phase it is a standard procedure to dissolve the surface of the substrate prior to growth. This improves the structural quality since preparation damages of the substrate surface will not be present and will consequently not affect the growth. However, by this meltback procedure a new surface is exposed on which the subsequent growth will be performed. Thus, the dissolution process is a critical step when growing from the liquid phase. Due to this, the wetting property of the solution is also very important when SiC is grown from the liquid phase.

We have studied the wetting and dissolution of α-SiC from solutions using different compositions in the Si-Sc system. This system has shown to be suitable for growth of SiC from the liquid phase [1,2]. The studies are carried out on both on-axis and off-axis substrates. The Si-face and C-face of SiC are also compared. The wetting and dissolution properties in vacuum and in an inert ambient are reported. The surface morphology of α-SiC after dissolution is studied. A relation between growth and dissolution has been observed.

The dissolution proceeds with different behaviour and rate comparing a pure Si-melt and a melt containing Sc. This is explained by the difference of the solubility of SiC in the different solvents. Dissolution proceeds fast with pure Sc and the surface morphology is rough with well expressed patterns following the hexagonal symmetry of the SiC crystal. The dissolution from a pure Si-melt is slower exhibiting small circular and hexagonal pits. The dissoluion morphology from a Si-Sc alloy changes with the composition.

The wetting properties improve when Sc is added to the Si-melt. The wetting angle is not affected by the ambient used. The mixing of the alloy, however, improves in vacuum. From these studies the wetting angles are deduced. The angle is larger for the pure Si-melt. The surface energy of α-SiC is discussed. Possible growth mechanism, based on the surface and interface energy, is discussed as well.

[1] R.T Yakimova and A.A. Kalnin, Phys. Stat. Sol. (a) **32**, 297 (1975).
[2] R. Yakimova, M. Tuominen, A.S. Bakin, J-O. Fornell, A. Vehanen, and E. Janzén, Proc. ICSCRM-95, Sep. 18-21, Kyoto, Japan (1995), in press.

Monday, October 7, 1996 15:00-16:45

POSTER SESSION (P.1): SiC MATERIAL (BULK AND EPITAXIAL) GROWTH AND CHARACTERIZATION

MODELLING OF THE SUBLIMATION GROWTH OF SILICON CARBIDE CRYSTALS

M. PONS*, E. BLANQUET*, J.M. DEDULLE, I. GARCON**, R. MADAR** and C. BERNARD***

* Laboratoire de Thermodynamique et Physicochimie Métallurgiques, UMR CNRS/INPG/UJF 5614 - ENSEEG, Institut National Polytechnique de Grenoble, BP 75, 38402 Saint Martin D'Hères, France (Tel. 33 76826532 ; Fax 33 76826677 ; e-mail tsrpons@ccomm.grenet.fr)
** Laboratoire de Matériaux et de Génie Physique, UMR CNRS/INPG 5628 - ENSPG
Institut National Polytechnique de Grenoble, BP 46, 38402 Saint Martin D'Hères, France

Single silicon carbide crystals have been grown from the vapour phase by sublimation inside a sealed enclosure at temperature above 2300 K and pressure lower than $5x10^{-3}$ Pa [1]. The development of different macroscopic modelling approaches to simulate the process growth is discussed with a special emphasis on their coupling mechanism. Thermodynamic equilibrium, heat transfer and mass transport were carried out with different levels of complexity. On the basis of the results of the thermodynamic analysis, the composition (i) of the gas phase above silicon carbide (mainly Si, Si_2C and SiC_2) and (ii) of the resulting crystal were determined in a perfectly mixed reactor. The thermal field inside the growth chamber is difficult to control because sensors cannot be used in such experimental conditions. The heat transfer was determined by linking conduction, convection, radiation and induction heating modes in the different materials of the reactor. Actual temperatures inside the reaction chamber were determined. The calculated temperature field was compared to experimental pyrometric measurements. Mass transport modelling linked with thermochemical equilibrium arguments and known temperature field has provided the growth rate which was found to be closed the experimental one. Figure 1 clearly shows this agreement. It is important to note that no fitting parameters have been used. The transport properties have been calculated from the kinetic theory of gases for multicomponent systems and the thermodynamic data (Si, Si_2C, SiC_2, Si_2, Si_3, C_1, C_2, C_3, SiC and Ar) measured or estimated in previous work [2]. Despite the complexity of the SiC growth process, the different results of the different modelling routes suggest their potentialities to represent the actual phenomena involved inside the crucible.

[1] I. Garcon, A. Rouault, M. Anikin, C. Jaussaud, R. Madar, Mat. Sci. Eng., 1995, B29, 90-93.
[2] P. Rocabois, C. Chatillon, C. Bernard, F. Genet, High Temp. High Pres., 1995, in press.

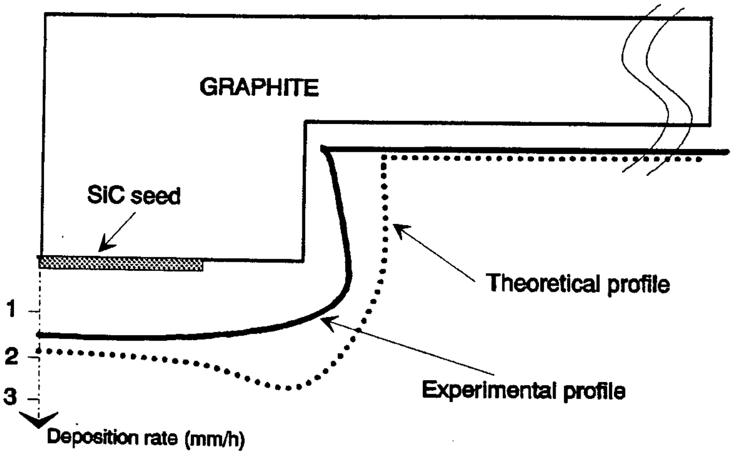


Figure 1 : Radial uniformity of the deposition rate.

THE KINETIC GROWTH MODEL APPLIED TO MICROPIPES

J. Heindl, W. Dorsch, R. Eckstein*, D. Hofmann*, T. Marek, St.G. Müller*, H.P. Strunk, A. Winnacker*

Institut für Werkstoffwissenschaften - Mikrocharakterisierung
Universität Erlangen - Nürnberg
Cauerstraße 6; 91058 Erlangen; Germany
phone: +49-9131-858610; fax: +49-9131-858602
e-mail: heindl@ww.uni-erlangen.de

*Institut für Werkstoffwissenschaften - Werkstoffe der Elektrotechnik
Universität Erlangen - Nürnberg
Martensstraße 7; 91058 Erlangen; Germany

We investigate the as-grown {0001} Si surface of modified Lely grown 6H-SiC by using atomic force microscopy. The crystals are grown in a resistively heated reactor at temperatures 2350K < T < 2450K and a pressure of 30 mbar. We measure the radii of micropipes and the total step heights of the accompanying growth spiral. We find micropipes in the center of the growth spirals with total step heights ranging from 1 to 21 unit-cells (corresponding to 1.5 - 31.5 nm) and radii ranging from 25 nm to 4600 nm.

One possible explanation of micropipes was given by Frank [1], who suggested the model of the hollow core dislocation. Following this, a dislocations with a Burgers vector exceeding a critical value (approximately 1 nm) can obtain an energetically more favourable state by removing the highly-strained dislocation core and generating an additional free surface. If we assume that the hollow core dislocation is of pure screw type, we can identify the total step height of the growth spiral with the Burgers vector of this dislocation. The equilibrium radius of the micropipe is obtained by minimizing the total energy of this hollow core dislocation. According to Frank this total energy is given as a sum of the surface energy of the inner wall of the micropipe and the strain energy of the dislocation. The micropipe radius is identical with the radius of the dislocation core. This leads to a linear dependency of the square of the Burgers vector and the micropipe radius. A better fit to our measured data can be obtained if Frank's approach is extended with a kinetic term according to Cabrera and Levine [2]. This extended approach considers the fact that the solid crystal is in contact with a gaseous state of 'SiC' which consists mainly of Si, Si_2C and SiC_2. This phase change involves a Gibbs free energy which has to be added to the total energy used above. A minimization of this modified total energy leads to a relation which fits our data well if we assume a surface energy of 0.15 J/m^2 at the inner side of the micropipe and a supersaturation of $1.4 \cdot 10^{-24}$ J at the growth surface.

[1] F.C. Frank, Acta. Cryst. **4** (1951) 497

[2] N. Cabrera, M.M. Levine, Phil. Mag. **1** (1956) 450

POLYTYPISM OF SiC EPITAXIAL LAYERS GROWN BY SUBLIMATION SANDWICH METHOD

Saparin G.V., Obyden S.K., Ivannikov P.V
Department of Physics, Moscow State University, Moscow,
119899, Russia.Fax:7-095-932-8820,Phone:7-095-939-4829.
Mokhov E.N., Roenkov A.D., Ramm M.G., Vodakov Yu.A.
A.F.Ioffe Physical-Technical Institute, St.Petersburg,
194021, Russia. Phone:7-812-515-9273,Fax:7-812-515-67

Silicon carbide (SiC) is known to refer to polytypic materials. However a growth of homogenious SiC crystals of required polytype (without of other polytypes inclusions) are still difficult and not clearly solved problem. In the present work we have been studied polytypism of SiC epitaxial layers (EL) grown under different crystallization conditions on the substrate surfaces both vicinal and singular types. The growth of layers was carried out by sublimation sandwich-method in inert gas or vacuum media at temperature from 1700 to 2500^{0}C. Usually the substrates of {0001} SiC of 21R polytype were used. The singular type surface was formed on the profiled substrates having separate elevated platforms (like a mesa structure) with the linear sizes about of 0,1-1 mm, during special heat treatment (method of artifical local surface singularization). A color cathodoluminescence scanning electron miocroscopy was used for detection of the information about the polytypes in thin layers (from 0.1 up to 3 microns). The electron beam energy was varied from 2 kV up to 20 kV that provided a way to perform the 3D-analysis by layer by layer manner.

The probability of the polytype transformation on the singular type surface was shown to be much higher than that on the vicinal type ones especially at low supersaturation in growth system. SiC grown films were defined frequently as a set of various polytype interlayers having thickness about 0.1 microns or more. The alternation of polytype layers was observed both on (0001)C and (0001)Si surfaces, though the probability of occurrence one or other polytypes on the polar {0001} surfaces was distinguished. The amount of mesa-structures with singular type of the surface is sharply reduced with increase of dislocation and crystal defects density having in a substrate or introduced specially by using diamond indentor that promotes to substrate polytype stabilization during growth process. Introduction of some impurity results in dominant growth of the distinctive polytype both on vicinal and singular types. However in the later case the transformation is observed at lower growth temperatures and supersaturations. Problems of SiC polytypism in the connection with the growth mechanisms are discussed.

THE ORIGIN OF 3C POLYTYPE INCLUSIONS IN EPITAXIAL LAYERS OF SILICON CARBIDE GROWN BY CHEMICAL VAPOR DEPOSITION

C.Hallin, A.O.Konstantinov[a), B.Pétz[b), O.Kordina[c),d) and E.Janzén.

Department of Physics and Measurement Technology
Linköping University, S-581 83 Linköping, Sweden.
fax: +46 13 14 23 37
[a) Industrial Microelectronics Center, Box 1084, S-164 21 Kista, Sweden.
[b) Research Institute for Technical Physics, H-1325 Budapest, Hungary.
[c) ABB Corporate Research, 721 78 Västerås, Sweden.
[d) Outokompu Semitronic AB, S-161 11 Bromma, Sweden.

A serious problem of SiC device technology is a spontaneous nucleation of cubic material (the 3C polytype of silicon carbide) upon epitaxial growth. Those inclusions are fatal defects for critical device applications, such as SiC power devices. The basic technique used to prevent the 3C incorporation into epilayers is to use off-axis substrates. Besides, the off-axis substrates are yet no panacea, particularly for growing epilayers onto the substrates of the 4H polytype, the most attractive polytype from viewpoint of its electrical properties. In the paper we investigate the origin of 3C polytype inclusions in 4H SiC and the techniques to prevent its nucleation.

The epitaxial growth is carried out in an atmospheric-pressure hot-wall CVD reactor with a SiC-coated susceptor. Silane and propane are used as precursor gases. The growth temperature range is 1450-1600°C. The substrates are (0001) Si-face off-axis wafers grown by the modified Lely technique. A few sublimation-grown epilayers were studied for the purpose of comparison. The structure of the imperfections are investigated by optical and scanning electron microscopy using defect-revealing techniques and by cross-section transmission electron microscopy. The defect revealing techniques used in the present study are the polytype decoration by oxidation, polytype-selective photo-electrochemical etching, hydrogen-etching and chemical etching in KOH.

Both the substrate imperfections and the growth regimes are important for the nucleation of 3C. We could either suppress or totally avoid the 3C nucleation using "milder" growth regimes with a low growth rate and a low C/Si ratio. The substrate imperfections are critical for the 3C nucleation, as was established an in investigation of the inclusion structure.

The results of the study suggest that the 3C nucleation occurs predominantly via the intermediate stage of triangular stacking fault (TSF) formation. The TSFs are the twinned crystal domains which appear due to glide along the {0001} crystal planes as induced by substrates defects. The formation of TSFs results in a suppression of step-flow growth and in development of large on-axis terraces on initially off-axis crystals. Given the large terraces appear on the surface, the formation of 3C occurs in a similar manner as for on-axis substrates, via homogeneous nucleation. The spontaneous 2D nucleation on {0001} crystal planes has a very high yield of 3C for typical growth conditions employed in CVD. Dealing with non-perfect substrate crystals the elimination of 3C inclusions requires to minimize the supersaturation through a control of process parameters, using an elevated growth temperature, a moderate growth rate and a low C/Si precursor ratio.

OPTICAL MONITORING OF THE GROWTH OF 3C SIC ON SI IN A CVD REACTOR

André Leycuras

Centre de Recherche sur l'Hétéroépitaxie et ses Applications, CNRS, rue Bernard Gregory 06560 Valbonne
(France). Tel (33) 93 95 42 02, Fax (33) 93 95 83 61.

The crystalline quality of 3C SiC grown on Si substrates is very sensitive to parameters such as the carbonization layer thickness, the growth rate the C/Si ratio, the substrate temperature etc... Contrary to MBE reactors in which electron beams are extensively used to monitor and characterize the growth, the surface structure and its chemical composition, in a CVD reactor, light is the only tool which can be used to monitor the growth. The substrate can be active and in this case its light emission is recorded, or passive if its rôle consists of reflecting a laser beam, and both roles can be utilized simultaneously.

A vertical CVD reactor has been equiped with an axial window. The beam of a pulsed laser diode (λ=655.2nm) with a 1mm diameter is directed toward the Si substrate and the reflected beam is directed toward a large area photovoltaic diode and synchronously detected in phase with the laser pulse in order to discriminate between the reflected signal and the substrate radiation. The refractive index of 3C SiC is sufficiently smaller than the Si one to provide large contraste time dependent fringes during the layer growth. An interfringe represents a thickness of ~125 nm. Growth rates have been obtained in the range 0.01 to 20 μm h^{-1} . 3C SiC is transparent at the laser wavelength which has allowed to record up to 140 fringes (17.5 μm).

The carbonization of the Si substrate before the growth has been monitored as a function of the substrate temperature and the C_3H_8 partial pressure in purified H_2 . It shows the time dependence of the SiC thickness increase and its sharp stop when the layer is completed.

Lateral growth has also be monitored showing the increase of the area of the dots by an increase of the amplitude of the reflected intensity at each new fringe until the area of the laser spot is entirely covered by SiC.

The large area of the photovoltaic diode is necessary to intercept the reflected laser spot because under certain growth conditions the stress between the layer and the substrate can induce a curvature which leads to a displacement of the laser spot up to ~1 cm at the diode surface in the experimental set up geometry. The measurement of this displacement has been made during some growths.

Good quality layers have been obtained with FWHM of 140 arcsec for the (400) rocking curve of a 18 μm thick layer and very sharp photoluminescence features in the donnor-acceptor pairs spectra.

SIC AND GROUP III NITRIDE GROWTH IN MOVPE PRODUCTION REACTORS

R. Beccard, D. Schmitz, E. G. Woelk, G. Strauch and H. Jürgensen
AIXTRON GmbH, Kackertstr. 15 - 17, D-52072 Aachen, Germany
Tel: +49 (241) 8909-22, Fax: +49 (241) 8909-40

Silicon Carbide is presently gaining much attention as a material for high temperature, high speed and high power devices. However, fabricating epitaxial SiC films is still a challenge since very high growth temperatures (up to 1600 °C) must be used. This requires a carefully adapted design of reactors to ensure laminar flow conditions and a controlled depletion of the reactants inside the reactor.

A second class of materials that is also playing a more and more important role today are the group III nitrides (AlN, GaN, InN and alloys consisting of these). These materials are also grown at high deposition temperatures (up to 1300 °C). Furthermore, these materials are grown on special buffer layers and are typically part of complex heterostructures which require abrupt changes of the growth temperature. In general, both nitrides and SiC are similar in their challenges to the growth equipment.

This study uses a family of high temperature reactors to grow SiC and Nitrides. The load capacity ranges from single wafer machines to multiple wafer mass production reactors. All these reactors have a two flow injection system allowing a separated inlet of the various reactants. To achieve maximum uniformity of the growth, the Gas Foil Rotation® principle is applied. The multiwafer reactors are Planetary Reactors® with a double rotation of the substrates. Extensive modeling has been used in order to find the optimum reactor geometries. Thus an optimization of uniformity and efficiency and a minimization of undesired parasitic reactions has been obtained.

The results obtained in these reactors confirm the predictions mentioned above. State-of-the-art SiC can be grown both in the single wafer and in the multiple wafer systems. We will present results of 3C-SiC growth both on Si and 6H-SiC substrates. The same type of reactors have been used for the growth of various nitride compounds. GaN grown on sapphire substrates shows sharp x-ray diffraction peaks (30 arcsec) and background carrier concentrations below 10^{18} cm^{-3}. p and n-type doping is successfully employed. Extensive ptical and x-ray mapping studies reveal uniformities below $\Delta\lambda$=1nm and $\Delta a \leq \pm 150$ ppm.

The results to be presented demonstrate that a set of various reactors for high temperature applications has been designed allowing the growth of SiC as well as group III nitrides. The results obtained in growth experiments fit with the modeling of the fluid dynamics and the thermal conditions inside the reactors. Using these reactors, large-scale production of these compounds is possible in a reproducible and efficient way.

GROWTH OF SiC FILMS OBTAINED BY LPCVD

J. Stoemenos
Physics Department, Aristotle University of Thessaloniki, 54006 Thessaloniki, Greece

M. T. Clavaguera-Mora, J. Rodríguez-Viejo, Z. El Felk, E. Hurtós, S. Berberich
Grup de Física de Materials I, Departament de Física, Universitat Autònoma de Barcelona, 08193-Bellaterra, Spain. Telephone: +34-3-5811564 / 5811769 Fax: +34-3-5812155

N. Clavaguera
Grup de Física de l'Estat Sòlid, Departament ECM, Facultat de Física, Universitat de Barcelona, Diagonal 647, 08028-Barcelona, Spain

3C-SiC is a promising semiconductor for high temperature, high frequency and high power device applications due to its large band-gap, high-saturated electron velocity and high breakdown electric field. Moreover, its intrinsic resistance to oxidation, corrosion and creep at high temperature makes it also useful for protective coatings of aerospace engines.

This paper reports on results obtained using Tetramethylsilane $Si(CH_3)_4$ in the SiC growth by hot wall LPCVD in the temperature range of 900-1150 °C in order to establish the growth conditions using this precursor in hot wall environments. The deposition temperatures were chosen to perform a systematic study of the influence of deposition conditions on the morphology of the films. In particular, most of the SiC films were deposited on a thin a-SiO_2 layer, thermally grown on Si(001) wafers. Characterization of the SiC films was performed by X-ray diffraction (XRD) using Cu K_α radiation, scanning electron microscopy (SEM), transmission electron microscopy (TEM), ellipsometry, profilometry, electron microprobe analysis with a wavelength dispersive spectrometry detection system (EPMA/WDS) and X-ray photoelectron spectroscopy (XPS). The results obtained on the kinetics of growth concern the change of the growth rate with: *i)* the distance of the wafer from the reactor entrance; *ii)* the deposition temperature; *iii)* the respective values of the H_2 and TMS flows, and the evolution of the preferential (111) orientation of the polycrystalline films with *a)* temperature; *b)* film thickness; *c)* presence and thickness of the SiO_2 interlayer. The general characteristics of the polycrystalline films are their columnar structure, which is related with the very strong (111) preferred orientation, and the formation of microtwins, having the twin planes perpendicular to the direction of growth.

Financial support from CEE BRITE/EURAM by Contract N° BRE-CT92-0211, from CIRIT by Project N° GRQ-2.048 and from CICYT by Project N° MAT95-0875 is acknowledged.

HEXAGONAL AND CUBIC SiC THIN FILMS ON SiC(0001) DEPOSITED BY SOLID SOURCE MBE

A. Fissel, K. Pfennighaus, U. Kaiser, B. Schröter, W. Richter
Friedrich-Schiller-Universität Jena, Institut für Festkörperphysik, Max-Wien-Platz 1, D-07743 Jena
Tel/Fax: (049) 03641-635749; e-mail: richter@pinet.uni-jena.de

The deposition of heterostructures on the base of SiC with different polytypes is an interesting goal because of the possibility to built devices from one semiconducting material with confined electrons in a two dimensional gas [1]. This can be used for example for devices with resonant tunneling effect. Molecular beam epitaxy (MBE) is the usual method to grow quantum wells. Therefore we have used this deposition method. The first task for us is to learn how to grow defined SiC polytype heterostructures. For the reason of simplicity of the growth process we avoid in the MBE machine all gases, especially hydrogen. Therefore we deposite the SiC by means of solid sources.

The SiC films were grown in a RIBER MBE system (EVA 32). Source materials of high-purity polycristalline silicon and pyrolitic graphite were coevaporated with separate electron-beam guns. Si_2 and C_2 fluxes are regulated with a quadrupol mass spectrometer (HIDEN-HAL). At temperatures of 850 - 970 °C stoichiometric films were obtained at a 10 -30 % excess Si flux with groth rates of about 1 nm/min. At on-axis SiC(0001) layer-by-layer growth mode is obtained between 900 and 970 °C. At continuous deposition the growing films consist of laminae of the hexagonal and the cubic polytypes. The occurrence of such laminae maybe attributed to fluctuations in the Si adlayer thickness.

For Si excess flux the SiC(0001) surface shows the following sequence of Si determined superstructures with increasing Si caplayer thickness: 1x1; $(\sqrt{3}x\sqrt{3})$R30°; 1x1; 3x3. Above 970°C this superstructures disappear because of the high kinetic energy of the Si atoms. For elucidation of the atomic and electronic structure of these SiC surface superstructures we are using LEED and angle-resolved photoemission.

We find, that the growing polytype can be modified by the Si surface adlayer, the superstructure of which depends on the Si excess. We believe, that this adlayer determines the nucleation on terraces and therefore the growing polytype. The Si determined superstructure is controlled with RHEED pattern in the case of migration enhanced epitaxy (MEE) [2]. In this case alternating monolayers of Si and C were deposited. This alters the Si rich surface superstructure periodic between two definite states. The growth of the cubic polytype is favoured at a thick Si adlayer forming a 3x3 superstructure, whereas 6H-SiC is growing on the $(\sqrt{3}x\sqrt{3})$R30° surface. These impressions are under test and are verified by means of high resolution TEM.

[1] F. Bechstedt, P. Käckell: "Heterocrystalline structures: New types of superlattices"
Phys. Rev. Lett. **75** (1995) 2180

[2] A. Fissel, U. Kaiser, E. Ducke, B. Schröter, W. Richter: "Epitaxial growth of SiC thin films on Si-stabilized α-SiC(0001) at low temperatures by solid source molecular beam epitaxy",
J. of Crystal Growth **154** (1995) 72-80

CHEMICAL CONVERSION OF Si TO SiC BY SOLID SOURCE MBE AND RTCVD

T. Stauden, J. Pezoldt, V. Cimalla, G. Eichhorn
TU Ilmenau, Institut für Festkörperelektronik, Postfach 0565, D-98684 Ilmenau,
Phone: ++49 3677 691669, Fax +49 3677 691674, e-mail: spiess@e-technik.tu-ilmenau.de

Despite the rapidly increasing interest in the wide band gap semiconductor Silicon Carbide (SiC) for high temperature, high power and high frequency applications the crystal growth of SiC remains still one of the most serious problems. In the case of the deposition on foreign substrates commonly a thin buffer layer is used to reduce the effects of large lattice and thermal expansion mismatch. It acts as a pseudo-substrate for the further growth process. On the other hand silicon carbide buffer layers are useful for the hetereoepitaxial growth of a wide range of wide band gap semiconductors, for example Aluminium Nitride, Gallium Nitride and Diamond.

The carbonization is a typical process to form such a buffer layer. However, this chemical conversion of Si to SiC is highly nonlinear and can lead to the formation of voids beneath the growing SiC layers. This voids are able to grow further during the following epitaxial growth affecting both film morphology and structure. Up to now methods for suppressing the void formation are of empirical nature because the growth and mass transport mechanisms are not completely understood.

The carbonization process was investigated using different methods with typical ranges of process parameters in the carbon-flux-temperature-diagram (fig.1). In the case of solid source molecular beam epitaxy the investigations are focused on the growth of single crystalline SiC at very low temperatures [3].

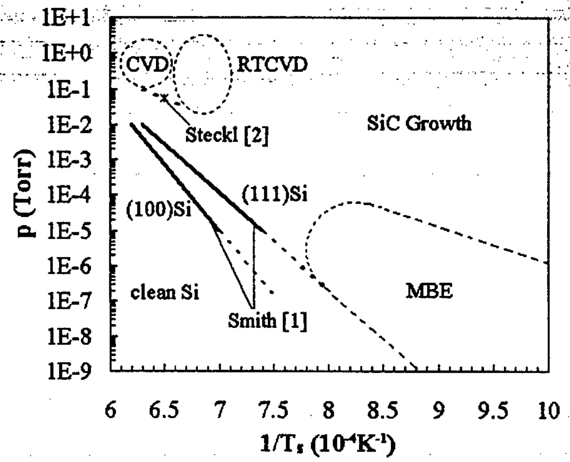


Fig.1 Critical conditions for the growth of SiC by carbonization of SiC and common used growth conditions

The aim of this work was the study of the carbonization process in a wider range of carbon fluxes and substrate temperatures and the comparison with previously obtained results growing SiC on Si by Rapid Thermal Chemical Vapour Deposition (RTCVD) [4]. Additional attention was drawn on the influence of different surface treatments as well as the influence of temperature ramping of the resulting structure of the grown SiC layer. The grown layers were characterized by Reflection High Energy Electron Diffraction (RHEED), Atomic Force Microscopy and Ellipsometry. While the RTCVD processes had to be interrupted to investigate selected stages of the time dependent SiC growth by *ex situ* analysis MBE system offers the possibility to observe the growth dynamics by *in situ* RHEED.

[1] F.W. Smith, Surf. Sci. **80** 388 (1979).
[2] A.J. Steckl and J.P. Li, IEEE Trans. Electr. Dev. **39** 65 (1992).
[3] K. Zekentes, R. Callec, K. Tsagaraki, B. Sagnes, G. Arnaud, J. Pascal and J. Camassel, Mater. Sci. Eng. **B29** 138 (1995).
[4] V. Cimalla, K.V. Karagodina, J. Pezoldt and G. Eichhorn; Mater. Sci. Eng. **B29** 170 (1995).

BOND ORBITAL MODEL APPROACH TO THE PRESSURE DEPENDENCE OF DIELECTRIC AND OPTICAL PROPERTIES OF WIDE BAND GAP SEMICONDUCTORS

S. Yu. Davydov and S. K. Tikhonov. A. F. Ioffe Physico-Technical Institute, Russian Academy of Sciences, 194021 St.Petersburg, Russia. Tel.: (812) 273-94-93, Fax.:

Within the scope of Harrison bond orbital model the response of static and high frequency dielectric permittivities as well as the phonon frequencies $\omega_{TO}(0)$ and $\omega_{LO}(0)$ to the externally applied pressure has been analysed. Calculations have been fulfilled for SiC, BN, AlN, and GaN.

Harrison first principle model of the semiconductors properties permits one to analyse a great number of the characteristics using only two independent parameters: the bond length of compound and the $|s\rangle$ and $|p\rangle$ states atomic energies. Earlier we have calculated the dielectric and optical characteristics for the cubic modifications [1]. In this paper we present a further step of analysis - the pressure dependence of these characteristics.

To calculate the pressure derivatives of the dielectric permittivities we have use the analytical expressions from [1]. Unfortunately, experimental information on the subject is fairly scanty. Nevertheless, the first principle calculations based on the density functional formalism [2] gives nearly the same results as the presented one. Our calculations also show that the high frequency permittivity derivative changes its sign with the increasing of ionicity. In terms of Phillips ionicity scale this inversion of sign takes place for the ionicity value $f_i \cong 0.46$.

For the calculation of the phonon frequencies pressure derivatives we have used the Lyddane-Sachs-Teller formula and the previously calculated [1] value of $\omega_{TO}(0)$. It has been found that the consecutive calculation from the first principles give the correct interrelation between the parameters under study. However, it is better to use the experimental values of bulk modulus and phonon frequencies than the straightforward calculated.

This work was supported in part by the University of Arizona.

References.

1. S.Yu.Davydov and S.K.Tikhonov. Phys. Sol. State. 37, 1677 (1995).
S.Yu.Davydov and S.K.Tikhonov. E-MRS 1996 Spring Meeting Conf. Proc. (Strasbourg, France, 1996), to be published.
2. K.Karch, A.Zywietz, F.Bechstedt, et al. In: International Conference on Silicon Carbide and Related Materials-1995 (ICSCRM-95). Technical Digest (Kyoto, Japan, 1995), 87.

TOWARDS THE CALCULATION OF THE PHOTOELASTIC MODULI AND QUADRATIC DIELECTRIC SUSCEPTIBILITY OF WIDE BAND GAP SEMICONDUCTORS

S. Yu. Davydov and S. K. Tikhonov. A. F. Ioffe Physico-Technical Institute, Russian Academy of Sciences, 194021 St.Petersburg, Russia. Tel.: (812) 273-9493, Fax.:

On the basis of Keating-Harrison model of semiconductor elastic properties [1] and Phillips idea of elastic to photoelastic interrelation we have obtained for the cubic crystals the following expressions for the photoelastic moduli p_{ij}:

$$p_{11} = -\frac{1}{3}\eta\frac{1+8\lambda}{8+\lambda}\Omega\ ,$$

$$p_{12} = -\frac{1}{3}\eta\frac{1-4\lambda}{8+\lambda}\Omega\ ,$$

$$p_{44} = -\eta\frac{33\lambda}{(8+\lambda)(8+3\lambda)}\Omega,$$

where $\Omega=(\varepsilon_\infty-1)/\varepsilon_\infty^2$, $\eta=2\text{-}6\alpha_p^2$, ε_∞ is the high frequency permittivity, α_p is polarity, $\lambda=0.85$. We have verified these expressions by comparison of the calculated values with the available experimental data for diamond. Such a verification leads us to the conclusion that the predicted values of p_{ij} for other wide band gap materials are also reasonable. Photoelastic moduli of SiC and BN are of the same order and sign as those for diamond but for the compounds with higher ionicity (AlN and GaN) p_{ij} are an order smaller and positive.

By using the well-known method of sphalerite-wurtzite elastic constants transformation we have also calculated p_{ij} for hexagonal modification. The same method has been used for the estimation of the quadratic dielectric susceptibility X_{ij} (X_{ij} for cubic modification were obtained earlier [2]). The comparison of the calculated value $X_{33}=3.04\cdot10^{-8}$ CGSE for GaN is in good agreement with the experimental value $2.88\cdot10^{-8}$ CGSE [3].

This work was supported in part by the University of Arizona.

References.

1. S.Yu.Davydov and S.K.Tikhonov. Semiconductors. (1996), to be pulished.
2. S.Yu.Davydov and S.K.Tikhonov. Phys. Sol. State. **37**, 1677 (1995).
   S.Yu.Davydov and S.K.Tikhonov. E-MRS 1996 Spring Meeting Conf .Proc. (Strasbourg, France, 1996), to be published.
3. J.Miragliotta, W.A.Bryden, T.J.Kistenmacher, et al. In: Silicon Carbide and Related Materials. Proc. Fifth Conf., ed. by M.G.Spencer et al, Inst. Phys. Conf. Series, No.137 (Bristol and Philadelphia, 1993), 537.

VALENCE BAND DISPERSION OF HEXAGONAL SIC

G. Wellenhofer and U. Rößler
Institut für Theoretische Physik
Universität Regensburg
D-93040 Regensburg
phone: 0049-9421/9432026
fax: 0049-9421/9434382

We describe the spin-dependent electronic dispersion close to the valence-band maximum of 2H, 4H, and 6H SiC using **k**·**p** theory.[1] First, we perform spin-less band structure calculations within the density functional theory (DFT) in the local density approximation (LDA). Thus we determine all parameters of the **k**·**p** Hamiltonian—except for the value of the spin-orbit coupling which we take from Ref. [2]. In Fig. 1 we show the typical hole dispersion of SiC in the case of 2H SiC along ΓM. Without the spin-orbit coupling the DFT-LDA calculations (solid lines) yield at the valence-band maximum Γ two degenerate bands and a third band split off by the crystal field. Close to valence-band maximum those bands can be approximated by a parabolic fit (dashed lines) and, hence, by effective hole masses. In our work, we compare these effective hole masses and the crystal field splitting for different polytypes and discuss their dependence on hexagonality. The inclusion of the spin-orbit coupling results in the dotted dispersion. It can be analyzed in detail by **k**·**p** theory.

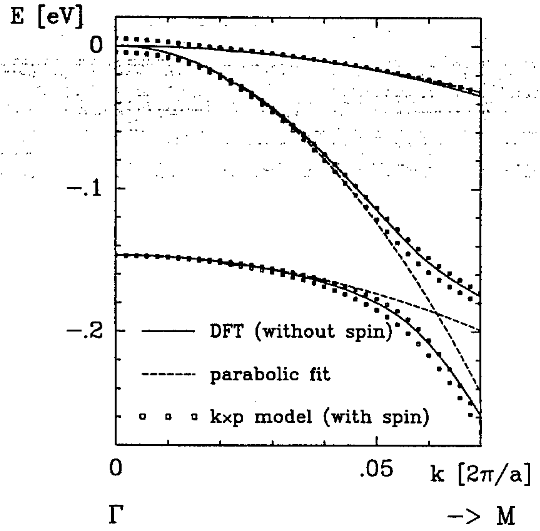


Fig. 1 Hole dispersion of 2H SiC.

Using the spin-dependent hole dispersion we calculate the density of states with the quadratic tetrahedron method. We discuss the energy dependence of the density of states and—due to the non-parabolic behavior of the bands—provide a parameterization of the energy dependence of the density of states mass. Finally, referring to previous results for effective electron masses in SiC we calculate the intrinsic carrier concentration via the neutrality condition and determine their temperature dependence.

[1] M. Suzuki, T. Uenoyama und A. Yanase, Phys. Rev. B **52**, 8132 (1995).
[2] M. Willatzen, M. Cardona und N.E. Christensen, unpublished.

EFFECTIVE MASSES AND CARRIER CONCENTRATIONS FOR ELECTRONS AND HOLES IN INTRINSIC SIC POLYTYPES.

C. Persson[1] and U. Lindefelt[1,2]

[1] Department of Physics and Measurement Technology, Linköping University,
S-581 83 Linköping, Sweden, phone: +46 -13 281000, fax: +46 -13 137568
[2] ABB Corporate Research, S-721 78 Västerås, Sweden, phone: +46 -21 323177

ABSTRACT:

A full-potential bandstructure calculation, within the local density approximation to the density functional theory, has been performed for 3C-, 2H-, 4H-, and 6H-SiC. From **kp**-parameterization of the conduction band minima and the valence band maxima, the effective electron and hole masses were determined. The resulting masses are in agreement with experimental values, when available, to an excellent precision and the hole masses indicate similar hole mobilities for the three hexagonal polytypes. The great importance of including the spin-orbit interaction in order to determine the hole masses is demonstrated. Presuming parabolic energy dispersion of the bands, the carrier concentrations as a function of temperature have been worked out and the corresponding effective density of state masses are presented. The parabolic approximation describes the bands only in the vicinity of the band minima or maxima and the carrier concentrations are expected to be valid for modest temperatures.

Polytypism and surface structure of SiC

P. KÄCKELL, J. FURTHMÜLLER and F. BECHSTEDT,
Institut für Festkörpertheorie und Theoretische Optik,
Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, D 07743 Jena
Phone: +49-3641-635910 FAX: +49-3641-635182

The controlled epitaxial growth of high–quality SiC thin films or SiC heterostructures of *defined polytypes* is of vital interest for many electronic, optoelectronic or optical applications. Though the SiC wafers which can be produced nowadays match more and more standards which make them somehow suitable for electronic device technology, there is still a lack of full control of the SiC growth process. The films grown have too many defects and the control of the polytype grown on any substrate is still too poor. One key ingredient for understanding the growth of SiC crystals is the understanding of the chemical bonding (i.e. the atomic and electronic structure) of SiC surfaces. Before one does not understand the basic steps of the growth process one will never understand how to control the growth of a specific polytype or how to "switch" from one polytype to another polytype during the growth process.

We present *ab–initio* calculations within the framework of density functional theory in the local density approximation using ultrasoft Vanderbilt–pseudopotentials in a plane wave basis. We performed calculations for Si–terminated and C–terminated 3C SiC(001) surfaces as well as for Si–terminated 3C SiC(111) and nH SiC(0001) surfaces. The latter ones are of particular interest because their normals represent the natural growth direction of SiC. However, more experimental data were available for 3C SiC(001). We explored the 2×1 reconstruction on Si-terminated 3C SiC(001) (finding a very weak dimer formation — in contrast to experiment where a strong dimerisation was found) and several 2×2 reconstructions on C-terminated 3C SiC(001) (finding a triple–bonded C–dimer in a Si brigde position to be slightly more stable than a "staggered dimer" model). On 3C SiC(111) and nH SiC(0001) we are currently interested in $\sqrt{3} \times \sqrt{3}$ reconstructions. In experiments one usually observes a 3×3 reconstruction for very Si–rich surfaces. With decreasing Si contents of the surface one finds then usually a (yet unidentified) state showing a 1×1 LEED–pattern (and sometimes also other reconstructions). But finally one always ends up with a $\sqrt{3} \times \sqrt{3}$ reconstruction. The most stable $\sqrt{3} \times \sqrt{3}$ structure found is a T_4 site Si adatom structure. But we can also not rule out (metastable) trimer structures (the most stable trimer structure being a planar "trimer network" which is expected to be perfectly π–bonded and which consists of fully symmetric trimers being centered above a T_4 site). The trimers show a slight "twisting" with respect to the substrate (a rotation of order 20^o). The question is whether such a rotation could be interpreted as some kind of precursor for tendencies towards "polytype changes" during the SiC growth. Furthermore there exist several trimer structures of almost identical energy and the total energy surface seems to be rather "flat". Our suspicion is that this "flatness" could give rise to thermal structural fluctuations which might effectively result in the "1×1" structure observed as an intermediate state when reducing the amount of Si.

STRUCTURE AND MORPHOLOGY OF SiC SURFACES STUDIED BY LEED, AES, HREELS AND STM

U. Starke, J. Bernhardt, J. Schardt, K. Heinz
Lehrstuhl für Festkörperphysik, Universität Erlangen-Nürnberg, Staudtstr. 7, D-91080 Erlangen, Germany
Phone: +49 - 9131 - 858405
Facsimile: +49 - 9131 - 858400

Atomic structure, stoichiometry and step morphology of different SiC surfaces in hexagonal orientation were investigated by means of low-energy electron diffraction (LEED), Auger electron spectroscopy (AES), high resolution electron energy loss spectroscopy (HREELS) and scanning tunneling microscopy (STM). We used bulk grown samples as well as CVD grown epilayers. Immediately after *ex situ* preparation, involving oxidation and HF etching, and introduction into vacuum via a load lock mechanism a sharp LEED pattern can be observed on all kinds of samples. The surface periodicity as judged from the diffraction angles corresponds to the SiC bulk structure.

The morphology of a 6H-SiC(0001) surface had been previously studied using STM, HRRELS and LEED [1,2]. We found large steps of multiple triple bilayer height equivalent to odd or even numbers of half 6H unit cells. Correspondingly, the LEED pattern has six-fold symmetry because both possible stacking orientations are present on the surface. The surface of a 6H-sample may be terminated by three different topmost layer stacking sequences, equivalent to different cuts in the ABCACBA... stacking of the crystal. From a new, detailed intensity analysis of LEED diffraction spots we have identified the "A" layers to be the predominant (80%) surface layer of the sample, in agreement with the n*3 bilayer step heights found in STM. Atomic distances, i.e. bilayer thickness and bilayer spacing were determined to be similar to the geometry in a bulk crystal. An additional layer of oxygen on top of the topmost silicon atoms was found in the LEED analysis. This oxygen obviously represents hydroxyl species that were detected by vibrational analysis using HREELS. The OH-groups are sensitive to electron beam irradiation which causes the LEED pattern to disappear after a few minutes of measurement.

We have studied the morphology and atomic structure of different polytypes and surface orientations using LEED and AES. As mentioned above, the predominant stacking sequence ABCACB found on the 6H-SiC(0001) surface is in accordance with step bunching observed with STM. To the contrary, on the 6H-SiC(000$\bar{1}$) surface all possible stacking sequences are present in equal amounts. This indicates a single step morphology for the carbon rich orientation. On a 3C-SiC sample grown in (111) orientation on Si(111) the linear stacking sequence of the bulk crystal structure is found to be extended to the surface. The three-fold symmetry of the LEED pattern indicates that the crystal contains exclusively one stacking orientation which is corroborated by the LEED intensity analysis.

All *ex situ* prepared and load locked samples contain oxygen as determined by AES. This was found to be the case for 6H-, 4H- and 3C-polytypes. The oxygen remains on the surface even after prolonged electron irradiation and can only be removed by heating to approximately 800° C. A detailed analysis of the surface geometry and stoichiometry of the 6H and 3C-surfaces using the Tensor LEED approximation and automated fit algorithms revealed a typical oxygen coverage of about 50% for the 3C-sample and a full oxygen coverage for 6H-SiC(0001). The topmost bilayer is slightly compressed due to the anisotropic bond coordination of the topmost silicon atom. All other atomic distances are equal to the SiC-bulk values within the limits of error. On the carbon side of 6H, i.e. SiC(000$\bar{1}$) no oxygen is found in the diffraction analysis. Obviously, the oxygen detected by AES is present in a disordered fashion.

[1] U. Starke, Ch. Bram, P.-R. Steiner, W. Hartner, L. Hammer, K. Heinz and K. Müller, Appl. Surf. Sci. **89**, p175 (1995).

[2] J. Schardt, Ch. Bram, S. Müller, K. Heinz and K. Müller, Surf. Sci. **337**, p232 (1995).

Control of modified 3C-SiC(100) by surface sensitive techniques

T. Balster[1], J.A. Schaefer[1], H. Ibach[2]

[1] Institut für Physik, TU Ilmenau, D-98684 Ilmenau

[2] Institut für Grenzflächenforschung und Vakuumphysik, Forschungszentrum Jülich,
D-52425 Jülich

We studied the preparation of 3C-SiC(100) - surfaces via heating with and without deposition of silicon from a flux, created by a silicon source, by high resolution electron energy loss spectroscopy (HREELS), Auger electron- and X-ray photoelectron spectroscopy, and low-energy electron-diffration. After annealing at 1325 K the oxygen desorbed and a silicon-terminated (2x1)-surface is obtained. Subsequent annealing leads to the sublimation of silicon which results in a carbon-rich c(2x2)-surface. We exposed the surfaces with different stoichiometries - (3x2), c(4x2), (2x1) and c(2x2) in order of decreasing Si-surface concentration - to atomic hydrogen. First results will be presented at the conference.

ANGLE RESOLVED PHOTOEMISSION ON 6H-SiC(000$\bar{1}$)

M.Hollering, A.Ziegler, R.Graupner, L.Ley (Universität Erlangen, Institut für
Technische Physik II, Erwin-Rommel-Str. 1, 91058 Erlangen,
Tel. +49 9131/85 7080, FAX: +49 9131/85 7889)

A.Stampfl, J.D.Riley, R.C.G.Leckey (La Trobe University, Australia)

Despite considerable efforts comparatively little is known experimentally about the bulk and surface electronic structure of the SiC polytypes [1]. We have recently succeeded in preparing well ordered C-terminated surfaces of 6H-SiC from which bandstructure information has been obtained using angle resolved photoemission. The preparation proceedure encompasses first a dry etching step in a hydrogen plasma followed by an HF-dip and finally an in situ annealing up to 700°C under ultra high vacuum conditions. This yields a well ordered surface that exhibits a low background 1x1 LEED pattern for electron beam energies down to 20eV. Core level spectra show a weak O 1s contamination signal corresponding to an average coverage of one monolayer which seems to be concentrated in in localized scratches.

Angle resolved valence band spectra were acquired on the beamline TGM4 at the Berlin synchrotron radiation facility BESSY with an overall energy resolution of 0.2 eV and an angular resolution of ±1°.

Normal emission valence band spectra taken with photon energies between 16 and 80 eV probe the valence band dispersion along $\Gamma-A$ in the Brillouinzone (BZ) of 6H-SiC. From these spectra we are able to derive the energies of at the critical points Γ and A covering the top 15 eV of the valence bands which we compare with pertinent band structure calculations [2,3].

Off normal spectra taken along the $\overline{\Gamma K}$ and $\overline{\Gamma M}$ azimuths for several photon energies exhibit an energy dispersion of peaks with $k_{||}$. Most of the peaks can be identified as due to transitions from bulk valence states. Two sets of transitions which fall into the experimentally determined ionic gap between 9.3(1) and 10.9(1) eV below the valence band maximum and into a gap in the projected bulk band structure around 13.5 eV, respectively, are ascribed to occupied surface states for which the dispersion has been determined.

References:

[1] Johansson et al., Phys. Rev. B**53**, ? (1996)
[2] Käckell et al., Phys. Rev. B**50**, 10761 (1994)
[3] Wenzien et al., Phys. Rev. B**52**, 10897 (1995)

TOPOLOGY OF TWIN INTERFACE JUNCTIONS IN EPITAXIAL β-SiC.

Ph. Komninou, G.P. Dimitrakopulos, K. Zekentes, V. Papaioannou, B. Pecz+, J. Stoemenos, and Th. Karakostas.*
Aristotle University of Thessaloniki, Department of Physics, Solid State Section 313-1, 540 06 Thessaloniki, Greece.
**Foundation for Research and Technology, Heraclio, Crete, Greece.*
+Research Institute for Technical Physics, Hungarian Academy of Sciences, P.O. Box 76, H-1325 Budapest, Hungary.

The nucleation and growth of β-SiC on vicinal (001) Si has been studied by HREM, TEM, and AFM. The material exhibits island growth and the initial nuclei have the morphology of tetragonal pyramids corresponding to half-octahedra. Growth proceeds by a dendritic mechanism, and, as a result, a large density of primary twins and stacking faults develops. The density of planar defects is reduced dramatically with increasing distance from the substrate. Using a recently developed topological theory, we have studied mutual twin annihilation, taking into account interfacial connectivity principles. The secondary defects that are geometrically-necessary for such a mechanism have been identified. It has been shown that, for the formation of closed topologies, it is required to have triple lines of planar defects that form nodes. This conclusion has been verified using computer simulation of HREM images.

THE NEW KIND OF MICROPIPE DEFECTS AND USUAL VOIDS AT β-SiC/Si(100) INTERFACES

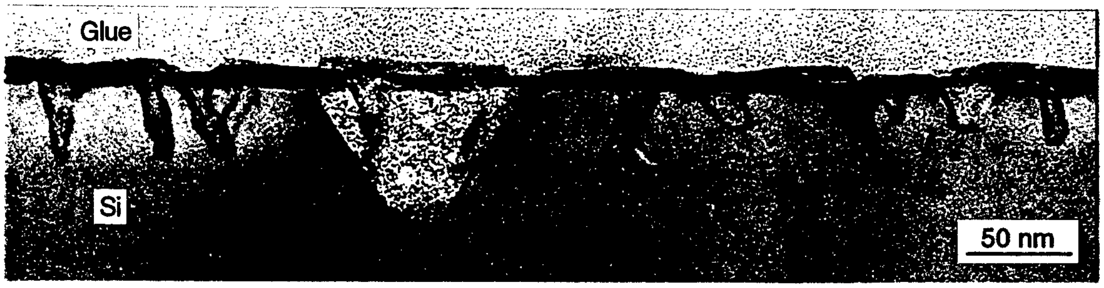
R. Scholz, U. Gösele, Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, D-06120 Halle/Saale, Germany. Phone: +49-345-5582-626, Fax: +49-345-5511223
E. Niemann, D. Leidich, F. Wischmeyer, Daimler-Benz Forschungsinstitut, D-60528 Frankfurt/Main, Germany

Voids in the shape of inverted pyramids are well known to occur underneath SiC layers within silicon substrate surfaces. They are undesired growth defects, which form during most deposition processes of SiC layer growth on silicon. Their formation by silicon outdiffusion during initial reactions of carbon-containing species with hot silicon surfaces seems to be largely understood in connection with SiC nucleation and layer growth. Nevertheless, because of the many experimental factors involved in growth processes of SiC on Si, the voids are hard to prevent reproducibly.

Voids described in the literature have mainly been studied by light or scanning electron microscopy, revealing sizes of about 100 nm up to several µm in edge length and surface densities between about 10^5 and 10^8 cm^{-2}. Transmission electron microscopy (TEM) as a method of higher local resolution has rarely been applied, though, occasionally smaller defect features of higher densities were supposed at the interfaces.

Recent systematic TEM studies* on various cross-sectional and planar specimens of β-SiC/Si(100) samples fabricated by a chemical vapor deposition (CVD) method, proved a new kind of micropipe defects of extremely high densities (up to 2.4 x 10^{10} cm^{-2}) to occur at the interfaces in addition to relatively small pyramidal voids (up to about 250 nm in edge length) of usual densities. The presence of nanocrystalline SiC within these micropipes indicates that the latter form by silicon outdiffusion with SiC simultaneously growing from the interface region into the substrate. The voids, on the other hand, grow, remaining empty during carbonization. Subsequent SiC layer growth causes the inner {111} walls of the voids to be covered with SiC, with micropipes developing also at these walls. The gradual closing of the micropipe top openings may cause the formation of bubble-like bulges at their ends within the substrate.

In order to find an explanation for the formation of the two types of Si outdiffusion defects in our samples further investigations were carried out. As a possible reason for the micropipe formation a similarly high density of SiC contamination nuclei at substrate surfaces was observed after pretreatments before carbonization. Short-time carbonization experiments of 10 s and 1 s reactions of hydrocarbon gas with substrate surfaces have not clear elucidated the cause of void formation in certain places.



TEM cross section micrograph of a pyramidal void and several micropipes under a thin SiC layer grown during CVD carbonization for 10 s at 1220°C.

---

* R. Scholz, U. Gösele, E. Niemann, D. Leidich, Appl. Phys. Lett. 67, 1453 (1995)

STRUCTURAL PROPERTIES OF 4H-SIC CVD LAYERS

A. Ellison[1], H. Radamson[1], C. Hallin[1], S. Milita[2], T. Tuomi[3], R. Yakimova[1,4], O. Kordina[1,4,5] and E. Janzén[1,4,5].

[1] Dept. of Physics and Measurement Technology, IFM Linköping University, 581 83 Linköping, Sweden
Tel: +46 13 28 25 32, Fax: +46 13 14 23 37, e-mail: ale@ifm.liu.se
[2] European Synchrotron Radiation Facility, Grenoble, France
[3] Optoelectronics Laboratory, Helsinki University of Technology, Espoo, Finland
[4] Okmetic Ltd., Espoo, Finland
[5] ABB Corporate Research, Västeras, Sweden

The physical and electronic properties of SiC epilayers are expected to be influenced to some extent by structural defects found in current SiC wafers, such as micropipes, dislocations, planar faults and domain boundaries. Some of these features are investigated in the present wortk.

CVD growth was realised in a hot-wall reactor at 1550°C using propane and silane diluted in hydrogen. Commercial off-axis, Si (0001) face, n-type 4H-SiC substrates were used. The layers thickness ranged from 15 to 60 μm, with N doping in the low 10^{15} cm^{-3}, the morphology being smooth except for some macroscopic step bunching and triangular features related to TSFs.
Structural defects are investigated using different white beam synchrotron X-ray topography techniques. The transmission and grazing incidence reflection geometries are used to respectively reveal substrate and epilayer defects. The section geometry allows to individually image both the substrate and the layer, thus eventually determining the origin of some epitaxial features. High resolution X-ray diffraction mapping is carried out to study long range defects, whereas KOH etching performed on sections of the epitaxied wafers is used to reveal features of the layer-substrate interface.

Substrate features: domain boundaries, wafer bending
Besides micropipes, screw and basal plane dislocations, commercial SiC wafers mainly contain low-angle boundaries misoriented domains. Transmission topographs show that the boundaries contain high density of edge type dislocations with Burger vector **b** in $< 11\bar{2}0 >$ directions, thus confirming recent results obtained by Takahashi et al. Together with screw dislocations or micropipes, such boundaries are expected to introduce intrinsic lattice tilts, which may lead to long range crystal bending and eventually increase the wafer's capacity to warp. Although precautions should be taken, owing to overlapping of intrinsic bending with post-growth stresses introduced by wafer preparation, XRD maps show that as-received wafers generally have a severe, non uniform, crystal curvature with an average of 4 to 10 meters, even if the surface of the substrate may be flat within a few microns or less. 4H substrates bend towards the Si face, whereas 6H wafers generally bend towards the C face, thus suggesting a crystal bending for one part related to the bulk growth. Relationship with mosaicity in terms of polygonisation and influence of epitaxy in terms of wafer warpage are investigated.

Consequences on structural features of the epilayer
As reported earlier by Wang et al. for 6H-SiC, screw dislocations are found to be replicated into the 4H layers. Section topographs of thick (60 μm) epilayers show that defect occurence is however decreased and modified: mainly line defects and inclined planar faults are imaged in the layer. Much higher density of line and various planar defects are present in the substrate. Planar faults in the basal plane are also found in most parts of the interface. Lattice tilts reduction after epitaxy is confirmed by improvement of the FWHM of X-ray diffraction peaks, when the shape of the profile is not controlled by mosaicity or wafer bending. Little or none improvement is observed in scans sensitive to lattice strain, presumably owing to replicated screw dislocations. The role of the epi-substrate interface is investigated by KOH etching on cleaved and/or polished sections of the epitaxied wafer. A preferential and uniform etching rate is oberved along the entire interface, the etched region extending roughly linearly in time into the underlying substrate. The relationship with layer-substrate doping difference is investigated.

GROWTH RELATED STRUCTURAL DEFECTS IN SEEDED SUBLIMATION GROWN SiC

M.Tuominen[1,2], R.Yakimova[1,2], E.Prieur[3], T.Tuomi[4], A.Vehanen[2,5] and E.Janzén[1,5]

[1]Department for Physics and measurement Technology, IFM, Linköping University,
S-581 83 Linköping, Sweden.
Tel: +46 13 28 25 31, Fax: +46 13 14 23 37, Internet: mat@ifm.liu.se.
[2]Outokumpu Semitronic AB, P.O.Box 111 92, S-161 11 Bromma, Sweden.
[3]European Synchrotron Radiation Facility, BP 220, F-38043 Grenoble Cedex, France.
[4]Optoelectronics Laboratory, Helsinki University of Technology, FIN-02150 Espoo, Finland.
[5]Okmetic Ltd., P.O.Box 44, FIN-02631 Espoo, Finland.

In the present work structural defects in 4H and 6H SiC wafers have been studied by means of synchrotron X-ray topography and optical microscopy. The optical microscopy serves in obtaining general picture of the wafer. Because of the transparency of the material the defects can, in principle, be followed through the wafer. Projection and section topographs as well as grazing incidence reflection topographs were made with synchrotron radiation in order to get the overall picture of the defects, strain fields and misorientations in the material.

The studied material has been grown using the seeded sublimation technique. In this technique the SiC seed crystal and source powder are placed in a graphite crucible. The seed crystal is fixed on a graphite lid above the powder. The seed is either 4H or 6H polytype. The growth takes place when the system is heated to a temperature over 2000°C and a temperature gradient is applied between source and seed. The system is inductively heated with a RF-coil and the temperature gradient is achieved by changing the coil position. Growing either on the C- or the Si-face of the seed, non-dependent on the polytype, results in 4H or 6H polytypes, respectively. For the growth of the long boule several runs with reloading of the source is needed.

In the studied wafers macro-defects are observed due to the seed attachment, initial stages of the growth, spiral growth mechanism and the growth front shape. The rigid seed crystal attachment can bend the seed crystal which causes defect formation. The crystal may divide into domains. This leads to misorientation and formation of micropipes. In addition nonuniformities in the seed attachment may lead to growth disturbances. The disturbances cause uneven surface with inhomogeneous defect distribution and doping. In connection with doping inhomogeneities misorientations are observed as well. The interfaces between different growth runs are also sources of macro-defects, especially micropipes. Off-axis growth seems to have slightly different defect appearance compared to the on-axis growth. Line defects are also observed lying parallel to the steps. Comparison between 4H and 6H crystals shows clear difference in the micropipe and domain appearance. The micropipes seem to be bigger and the domain misorientation larger in the 6H wafers.

Revealing of Double Position Twins in Cubic Silicon Carbide by X-ray Topography

A.N.Andreev, A.S.Tregubova, M.P.Scheglov

A.F.Ioffe Physico-Technical Institute of Russian Academy of Sciences
26, Politechnicheskaya st., 124021, St.-Petersburg, Russia
Phone: (812) 247-99-88; Fax: (812) 247-10-17; E-mail: Postman@shuttle.ioffe.rssi.su

It is well known that double position (DP) twinning occurs during 3C-SiC growth. For example, the boundaries between different type twins (so called double position boundaries - DPB) are the one of main defects in 3C-SiC epitaxial layers grown on 6H-SiC substrates [1,2]. Revealing and studing of such defects are very important for estimation of structural perfection of cubic epitaxial films and crystals. The optical microscopy is widespread now for detection of DPB on the surface after its preliminary etching. Such methods are quit suitable, however the ones have not enough in many cases.

In this report we shown that X-ray topography methods are can be successively used also for revealing of DP twins in 3C-SiC. For definitness let us consider the condition of X-ray diffraction in 3C-SiC/6H-SiC structures with DP twinning. Elementary cells of crystal lattice in DP twins of different types are slewed each other around $[111]_{3C}$ (or $[0001]_{6H}$) direction by 180°. As a result, the some systems of crystal planes (for example $(113)_{3C}$) can be chosen so that conditions of the diffracted intensity maximum can be not fulfilled simultaneously for this systems in different type twins. This fact provides formation of diffraction image from DP twins of one of the type only. Therefore, the regions of white and black contrast can be seen on the topograms and this regions will be correspond to different type twins. Besides, fulfilling of conditions of maximum of diffracted intensity for another twin type can be provide by 180° crystal rotation around $[111]_{3C}$ and white and black regions on topograms varies its contrast on opposite. It can be noted that for hexagonal crystal lattice such method don't reveal black and white contrast regions and possible inclusions of another politypes in 3C-SiC epitaxial films can be easily seen. It is preferable difference from optical methods.

The DP twins in 3C-SiC(epilayer)/6H-SiC(substrate) structures grown by vacuum sublimation were studied in this way with using asymmetric Bregg reflections of $(113)_{3C}$ type on Cu $K_{\alpha 1}$ radiation and by optical microscopy also. Contours of DP twins obtained from topograms and optical pictures were in a full agreement. The Bregg reflections $(1.0.\text{-}1.15)_{6H}$ were used for investigation of structural perfection of epilayer-substrate interface region. There is not similar system of crystal planes in cubic crystal lattice and diffraction image of layers located under 3C-SiC films can be obtained. It can be noted that contour of DPB remains across all thickness of epilayer on such pictures. Thus, studing of DP twinning in 3C-SiC can be provided by X-ray topography without layer-by-layer removing of epilayer.

The work was partly supported by Arizona University (USA).

References

1. K.Nishino, T.Kimoto, H.Matsunami. Institute of Phys. Conf. Ser. 137 (Proceedings of 5th SiC and Related Materials Conf., Washington, D.C., 1993), Institute of Physics Publishing, Bristol and Philadelphia, 1994, p.33
2. J.Yang, S.Nishino, J.Powell, D.Pizouz. Institute of Phys. Conf. Ser. 137 (Proceedings of 5th SiC and Related Materials Conf., Washington, D.C., 1993), Institute of Physics Publishing, Bristol and Philadelphia, 1994, p.25

STRUCTURAL DEFECTS IN THE
6H- and 4H-SiC SINGLE CRYSTALS AND LAYERS

Dorozhkin S.I., Bakin A.S., Avrov D.D., Rastegaev V.P., Lebedev A.O., Tairov Yu.M.
Department of Microelectronics
St.-Petersburg Electrotechnical University
Prof. Popov Str. 5, 197376 St.-Petersburg, RUSSIA
Phone: +7 (812) 234-31-64
Fax: +7 (812) 234-31-64
E-mail: root@me.etu.spb.ru

Commercial use of SiC for device applications especially for high power devices is still seriously limited by the not high enough quality of substrate material.

In this paper we summarize our previous and recent results on the investigations of structural defects (dislocations, blocks, grains, lattice strain, pinholes, inclusions) in large silicon carbide crystals and layers using x-ray topography, SEM, selective etching, x-ray diffractometry, optical microscopy.

The 6H- and 4H-SiC boules and epitaxial layers were grown by the Modified Lely method elaborated at the St.-Petersburg Electrotechnical University (LETI method) [1, 2]. X-ray topography was carried out using Berg-Barrett and Modified Schultz methods. Etching in molten KOH was employed for selective etching. The influence of growth parameters (growth temperature, vapour phase composition and pressure, supersaturation, kinetics of growth process, step limiting the growth rate etc.) on the formation of above mentioned defects have been investigated and discussed.

References

[1] Tairov Yu.M. J. of Crystal Growth, Vol.52, 1981, p.146.

[2] Tairov Y.M. and V.F. Tsvetkov, in Progress in Crystal Growth and Characterization, Vol. 7, Pergamon, London, 1983, p.111-162.

NONLINEAR OPTICAL MAPPING OF 3C-SiC INCLUSIONS IN 6H-SiC-EPILAYERS

C. Meyer, G. Lüpke, E. Stein von Kamienski, A. Gölz, H. Kurz
Institute of Semiconductor Electronics II, RWTH Aachen, 52056 Aachen, Germany,
Phone: +49-241-807895, Fax: +49-241-8888246, email: Meyer@basl.rwth-aachen.de

The growth of defect free epilayers is of primary importance for the realization of SiC–based devices. The most promising approach to achieve high quality material is the growth of 6H–SiC monocrystalline films on 6H–SiC substrates. However, defects such as micropipes, microfacets and crystalline inclusions of different polytypes limit the performance of devices fabricated on those films. Reducing the density of stacking faults by lowering the growth temperature leads to the growth of 3C–SiC islands in the epilayers [1].

We demonstrate that optical second–harmonic generation (SHG) can be used to identify different polytypes of SiC. As a second order effect it is governed by the second–order nonlinearity tensor $\chi^{(2)}$, determined by the crystalline symmetry of the material. In this way, different polytypes can be distinguished by the rotational anisotropy of the reflected SH radiation. Since 6H–SiC exhibits a sixfold rotational symmetry which cannot be resolved by the third-rank tensor $\chi^{(2)}$ governing SHG, the SH–reflection from 6H–SiC is isotropic. 3C–SiC has a threefold–symmetric structure which also shows up in the SH rotational anisotropy. The figure shows xy–scans of a $200\times150\,\mu m^2$ area of a 6H–SiC epilayer at two different angular positions, taken in about 8 min each. The dark background shows the 6H–SiC epilayer. Two other polytypes labeled I and II can be clearly distinguished by their SHG rotational anisotropy. From a quantitative analysis of the SHG anisotropy these could be identified as 3C–polytypes of different crystalline orientations [2].

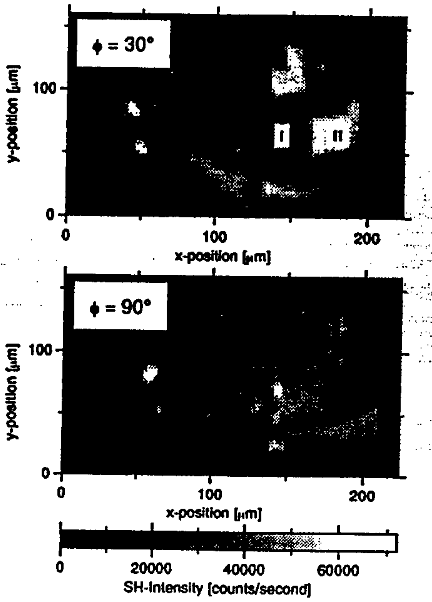


Figure 1: xy–scan of a 6H–SiC surface area

The huge signal difference of one order of magnitude between 3C– and 6H–SiC allows a fast mapping of different polytypes in SiC–epilayers. As an optical technique SHG is usable *in situ* and offers lateral resolutions in the μm–regime.

[1] Y. C. Wang and R. F. Davis, Journal of Electronic Materials 20, 869 (1991).
[2] C. Meyer, G. Lüpke, E. Stein von Kamienski, A. Gölz, and H. Kurz, submitted to Appl. Phys. Lett.

DEEP LUMINESCENT CENTRES IN ELECTRON-IRRADIATED SiC

N.T. Son, E. Sörman, M. Singh, W.M. Chen, C. Hallin, O.Kordina, B. Monemar
and E. Janzén
Department of Physics and Measurement Technology, Linköping University
S-581 83 Linköping, Sweden
Tel: 46. 13. 282531, Fax: 46. 13. 142337, e-mail: son@ifm.liu.se

J.L. Lindström
National Defence Research Institute
P.O. Box 1165, S-581 11 Linköping, Sweden

In modern semiconductor technology, electron irradiation is a standard technique for lifetime control, which seems to be a suitable choice for SiC since alternatives such as diffusion of impurities seem too difficult in the material. The implementation of the technique then requires significant knowledge on radiation-induced defects, especially deep level centres, which often play an important role in carrier recombination. In this work, photoluminescence (PL) was used to study deep level defects in 4H and 6H SiC irradiated by 2.5 MeV electrons at room temperature.

Irradiation with a wide range of electron doses (5×10^{13}–10^{18} cm^{-2}) was performed to study the formation of PL centres in the near-infrared region. In all 4H and 6H SiC CVD (chemical vapour deposition) layers irradiated with doses below 10^{15} cm^{-2}, the near-infrared PL is similar to that in as-grown material, i.e., only the well-known vanadium related PL spectrum could be observed. At a dose of 10^{16} cm^{-2}, two new broad PL bands accompanied by several sharp lines were observed in the regions 1.08-1.15 eV and 1.36-1.44 eV for n- and p-type 6H SiC. For 4H SiC, only the low energy band was weakly detected. Increasing the electron dose leads to the observation of numerous PL lines in the deeper region. A short anneal at 750 °C removed most of these PL lines, and a PL band with five very sharp no-phonon lines ranging from 1.088 to 1.134 eV was detected in 6H SiC. The spectrum can still be observed after annealing at ≈1000 °C. In the 4H polytype, a PL band with three no-phonon lines at 1.097, 1.119 and 1.150 eV was also observed after annealing. From the energy position of these two spectra in 4H and 6H SiC and their annealing behaviour, it is suggested that they are related to the same defect but in different polytypes. Its annealing behaviour also indicates that the defect is a complex probably involving a silicon vacancy. Optically detected magnetic resonance (ODMR) at X-band (≈9.23 GHz) was also carried out on annealed 4H and 6H SiC samples. However, only the negative signals from the isolated nitrogen and the X centre [1] were observed. The defect associated to this PL band is either non-paramagnetic or its ODMR was obscured by the strong negative signals of the nitrogen and X centres.

In the bulk material (substrates from CREE), besides the above mentioned PL bands, a group of eight sharp PL lines were observed in the deeper region (0.99-1.08 eV) after irradiation. Since the spectrum was not observed in any layer but only in the substrates, the involvement of impurities may be considered in this case.

[1] N.T. Son, E. Sörman, W.M. Chen, O. Kordina, B. Monemar and E. Janzén, Appl. Phys. Lett. **65**, 2687 (1994).

OPTICALLY DETECTED MAGNETIC RESONANCE STUDIES OF DEFECTS IN 3C SiC EPITAXIAL LAYERS

N.T. Son, E. Sörman, W.M. Chen, C. Hallin, O.Kordina, B. Monemar and E. Janzén
Department of Physics and Measurement Technology, Linköping University
S-581 83 Linköping, Sweden
Tel: 46. 13. 282531, Fax: 46. 13. 142337, e-mail: son@ifm.liu.se

Defects in 3C SiC epitaxial layers grown at high temperatures (1550 °C) by chemical vapour deposition (CVD) on a free-standing 3C SiC film substrate were studied by optically detected magnetic resonance (ODMR). In such a film, sharp photoluminescence (PL) peaks from the nitrogen bound exciton could be observed, indicating a high crystalline quality. In addition, two new near-infrared PL bands were detected in the regions 0.8-1.05 eV and 1.2-1.6 eV. An isotropic, broad (more than 20 Gauss at half maximum) and asymmetric ODMR line with a g value of about 2.009 was observed under ultraviolet light (351.1-363.8 nm) excitation [Fig.1(a)]. This asymmetric and broad linewidth was shown to be due to the overlapping of two different isotropic spectra as revealed from magnetic field modulation measurements [Fig.1(b)]. Both spectra can be described by an effective electron spin S=1/2. The high field peak has the same g value (g=2.0061) as the L2 centre [1] observed in the electron-irradiated material, which probably related to a silicon vacancy. Using the 514 nm laser line as the excitation source, this high field line was not efficiently excited, and consequently, a low field component with a symmetric line shape and a g value of 2.012 was detected. With near-infrared excitation (720 nm), this line was weakly observed and seems to be due to a hyperfine structure of a nuclear spin-1 impurity. However, the hyperfine constant is smaller than that of the isolated nitrogen centre and the signal was too weak to conclusively identify the impurity involved.

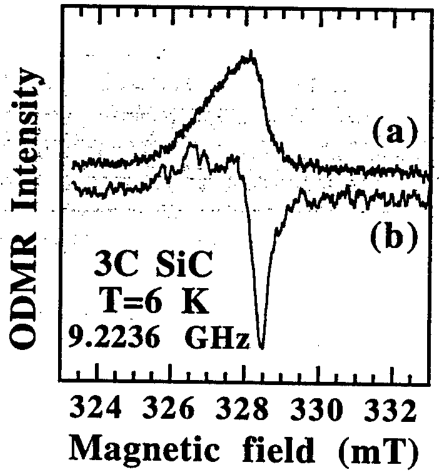


Figure 1: ODMR spectrum observed in a 3C SiC layer grown by CVD on a free-standing 3C SiC film at a microwave frequency ν=9.2236 GHz with (a) microwave modulation and (b) magnetic field modulation.

Both ODMR spectra can be observed through any luminescence bands in the sample, e.g, the nitrogen bound exciton, the donor-acceptor pairs and the two new near-infrared PL bands. This indicates that the defects act as very efficient recombination centres in the material.

[1] N.T. Son, E. Sörman, W.M. Chen, M. Singh, C. Hallin, O. Kordina, B. Monemar, E. Janzén and J.L. Lindström, J. Appl. Phys. **79**, 3784 (1996).

HYDROGEN-, BORON-, AND HYDROGEN-BORON-RELATED LOW TEMPERATURE PHOTOLUMINESCENCE OF 6H-SIC

C.Peppermüller, and R. Helbig
Institute of Applied Physics, University Erlangen-Nürnberg
Staudtstr. 7 A3, D-91058 Erlangen, Germany
Phone +49 9131 85 84 34, fax +49 9131 85 84 23

Adolf Schöner, and Kurt Rottner
Industrial Microelectronics Center (IMC)
P.O. Box 1084, Isafjordsgatan 22, S-16421 Kista, Sweden
Phone +46 8 752 10 00, fax +46 8 750 54 30

ABSTRACT

In order to examine the role of hydrogen in SiC, we investigated the low temperature ($T<2K$) photoluminescence (LTPL) emission of 6H-SiC samples after implantation of hydrogen, boron or boron together with hydrogen. In former experiments we detected that the hydrogen-related LTPL lines appear only in a few samples. The aim of this investigation was to find the conditions leading reproducible to hydrogen-related LTPL.

Samples were prepared by dividing different wafers (with or without epilayers) into four parts, each part was prepared differently as described below. Energies of ion implantations were chosen using the program TRIM to get optimal coincidence of concentration profiles of boron and hydrogen.

The first part was annealed at 1700°C for 30 minutes. The LTPL spectrum of this part did not change after the annealing. This part was used as reference.

The second part was implanted with hydrogen at room temperature with a dose of $10^{14}cm^{-2}$ and an energy of 80 keV. No additional annealing was done. The LTPL spectra of this part showed in some of the samples the well-known hydrogen-related LTPL lines H_3 and H_3^s.

The third part was implanted with boron at room temperature with a dose of $10^{14}cm^{-2}$ and an energy of 350keV. After this implantation the same annealing process was done as for the first part. The LTPL spectra of this part shows three new LTPL emission lines at about 4205Å.

The fourth part was first treated as the third part and afterwards treated as the second part. We detected in this part another LTPL emission line at 4183Å, but not the emission lines at 4205Å. Only for samples that showed hydrogen-related LTPL lines in part two these lines could be observed in part four also.

A sample with a higher boron concentration ($10^{15}cm^{-2}$) was prepared also. This sample was annealed after ion implantation of hydrogen at 600°C for 5min. This revealed a very intense LTPL line at 4183Å together with ist phonon replica. Two additional peaks are vibrational modes of the 4183Å emission with energie shifts of 86meV and 118meV.

Samples treated with aluminum instead of boron revealed intense D_I-defect LTPL and another LTPL line at 4557Å that appears after implantation of heavy elements and annealing at temperatures above 1000°C. In these samples no LTPL emission specific to aluminum was detected.

OBIC STUDIES ON 6H-SIC SCHOTTKY RECTIFIERS WITH DIFFERENT SURFACE PRETREATMENTS

Manfred Frischholz, Kurt Rottner, and Adolf Schöner
IMC, P.O. Box 1084, S-164 21 Stockholm-Kista, Sweden
Phone: +46 8 752 1061 Fax: +46 8 750 5430

Thomas Dalibor and Gerhard Pensl
Institute of Applied Physics, University Erlangen-Nürnberg
Staudtstr. 7, A3, D-91058 Erlangen, Germany
Phone: +49 9131 85 8427 Fax: +49 9131 85 8423

The high breakdown electric field strength of SiC makes it one of the most promising candidates to replace silicon in power semiconductor applications. However, in order to utilise the advantage in electric field strength over other materials a proper design of the junction termination is crucial to avoid premature breakdown at the surface. The reduction of the surface electric field is also essential to be able to use the established passivation schemes developed for silicon power devices.

The experimentally observed breakdown voltage of SiC rectifiers exceeded the value predicted by numerical two-dimensional device simulations for the specific design and approached the value of the parallel plane case. This fact was confirmed not only for SiC mesa diodes [1] but for Schottky diodes as well [2]. In the previous studies the authors found evidence for negative surface charge on n-type and positive surface charge on p-type 6H-SiC, respectively. In both cases the surface charge led to a significantly increased lateral depletion layer width mapped using the optical beam induced current (OBIC) technique. This expansion of the depletion layer width caused a reduction in the surface electric field thus increasing the breakdown voltage.

This effect was likewise observed on as-grown and processed surfaces, however differently pronounced. Therefore the present work concentrated on studying the influence of different surface treatments on the device characteristics of Schottky rectifiers in order to be able control the precise amount of surface charge. Prior to the formation of Schottky barrier contacts the SiC surface was either thermally annealed in hydrogen atmosphere, etched using O_2 or a mixture of Ar, H_2 and CF_4 as reactive gases or sputtered with Ar. The devices were characterised by measuring the current-voltage characteristics and the spatial variation of the photocurrent.

The current-voltage characteristics of these diodes showed differences in reverse current densities of several orders of magnitude for devices subject to different surface treatments. This indicates a large influence of surface treatment on the electrical characteristics of devices. Using the OBIC technique for spatially resolved measurements of the photocurrent we were able to determine the actual effective area contributing to the electrical characteristics of the device. For all surface treatment we used in our study we observed an expansion of the depletion layer width along the surface. This observation confirmed that the device area is not precisely rendered by the area of the metal contact but also by the additional depletion layer area induced by the presence of surface charge. The size of this additional area depends on the surface treatment as well as on the doping concentration. In our case we chose a relatively high doping concentration in order to keep the influence of the increased depletion region small. The behaviour of the reverse current density for different surface treatments was also reflected in the photocurrent density we compared for similar regions of differently treated devices. Our results indicate the importance of an optimised surface treatment in order to control the quality and the size of the actual surface region for achieving optimum device performance.

REFERENCES

[1] K. Rottner, A. Schöner, M. Frischholz, and R. Helbig presented at the MRS Spring Meeting April 8-12, 1996 in San Francisco; Proceedings published as Vol. 423 of the MRS Symp. Proc. Series.

[2] K. Rottner, S. Savage, J. André, L. Ramberg, M. Frischholz, and R. Helbig in Proc. 6th Int. Conf. on Silicon Carbide and Related Materials - 1995 , Sept. 18-21, 1995, Kyoto, Japan.

OPTICAL INVESTIGATION OF THICK 3C-SiC ON Si GROWN BY CVD

J.M. Bluet[1], J. Camassel[1] and A. Leycuras[2]

[1] Groupe d'Etude des Semiconducteurs, Université de Montpellier II, cc074, 34095 Montpellier Cedex 5, France.
[2] Centre de Recherche sur l'Hétéroépitaxie et ses Applications, CNRS, Rue Bernard Gregory 06560 Valbonne

The fabrication of thick (~ 20 µm) 3C-SiC epitaxial layer on Si is a goal for microsensors working in hostile environments as well as for quasi-substrate applications. Along this line, one of us reported in the same conference [1] on the growth of 3C-SiC sample on silicon by optically monitored CVD. The sample thickness range from 11 µm to 18 µm. In this work, we investigate the influence of the carbonization conditions (substrate temperature and C_3H_8 flux) on the interfacial strain and the layer flatness. We have performed infrared reflectivity and micro-Raman measurements.

The infrared reflectivity measurements provide macroscopic informations on the layer structure They give the following results :

i) the upper surface roughness is about 120 nm for a carbonization temperature of 1400°C. It decreases to 70 nm when lowering the substrate temperature to 1380°C;

ii) a lower interface roughness of about 300 nm is systematically found on the full series of sample. It does not come from the SiC layer but from pyramidal voids in the silicon substrate revealed by SEM investigation;

iii) the homogeneity of the layer thickness increases when enhancing the C_3H_8 flux;

iv) a finite infrared activity of the LO frequency arises from a breakdown of the selection rules. It is induced by the finite value of the bulk residual strain.

Micro-Raman performedon a cleaved sample edge allowed us to investigate the strain relaxation. Starting from the interface to the topmost layer, we find the following :

i) there is a strong residual strain near the interface in both the SiC layer and the Si substrate. This manifests by a shift of about 1 cm^{-1} of the silicon mode and by a splitting of the SiC TO mode and corresponds well to the curvature optically detected during the growth.

ii) this feature disappears after typically 2 µm when coming to the SiC surface revealing a good strain relaxation in the SiC layer.

[1] A. Leycuras, this conference.

THE MICROSCOPIC STRUCTURE OF SHALLOW DONORS IN SILICON

S. Greulich-Weber, M. März, J.-M. Spaeth, E.N. Kalabukhova* and S. Lukin*

University of Paderborn, Fachbereich Physik, Germany
FAX +49 5251 603247 TEL +49 5251 602740
Institute of Semiconductors, Kiev, Uraine

Although the nitrogen donors in SiC are known since years, there still remain open some important questions. It is not understood so far, why the hexagonal site donors in 4H- and 6H-SiC show more than 10 times smaller hyperfine (hf) interactions than the donors on the quasi-cubic sites. Moreover it is astonishing that the hf interaction of the cubic site donor in 3C-SiC shows a 10 times smaller hf interaction than the quasi-cubic site donors in 4H- and 6H-SiC. We therefore investigated the shallow nitrogen donors in 3C, 4H- and 6H-SiC with electron paramagnetic resonance (EPR) and electron nuclear double resonance (ENDOR). For all three polytypes ^{14}N hf interactions and ^{29}Si and ^{13}C superhyperfine (shf) interactions are observed with ENDOR. The ^{29}Si and ^{13}C ligand shf interactions were analysed with the effective mass theory (EMT) taking into account the layer structure of the SiC polytypes. New results on the Bohr radii, the wavefunctions and the spin density distribution on the Si sublattice and the C sublattice were obtained. From the temperature dependence of the EPR spectra the orbit valley splitting is obtained as a transition between the EPR of the E ground state and A_1 ground state of the donor. From the EPR temperature dependence and ENDOR measurements it could be decided, which state is lowest for the quasi-cubic and hexagonal site donors in 3C-, 4H- and 6H-SiC. Microscopic models of the nitrogen donors in SiC will be proposed.

CHARACTERIZATION OF DEEP LEVEL DEFECTS IN 4H AND 6H SiC

J.P. Doyle , M.O. Aboelfotoh, M.K. Linnarsson, and
B.G. Svensson
Royal Institute of Technology, Solid State Electronics
P.O. Box 229, Electrum, 164 40 Kista-Stockholm, Sweden
Phone: 46-8-752-1409
Fax : 46-8-752-7782
e-mail: jdoyle@ele.kth.se

A.Schöner and N. Nordell
Swedish Industrial Microelectronic Center
Electrum, Kista-Stockholm, Sweden

Electrically active defects in both 4H and 6H polytypes of SiC have been observed through the use of deep level transient spectroscopy (DLTS) and admittance spectroscopy utilizing Schottky barrier contacts. The epitaxial layers were grown by vapor phase epitaxy (VPE). In n-type samples the defect concentrations in the as-grown material are typically below $1x10^{13}$ cm^{-3}. Secondary ion mass spectrometry (SIMS) was used to quantify the concentration of vanadium and titanium as these metallic species are known impurities in bulk material and can produce electrically active defect levels in the electronic bandgap. Coupled with MeV electron beam irradiation of the samples, we have attempted to correlate the observed levels in the as-grown state to structural defects and metallic impurities.

ELECTRICAL PERFORMANCE OF HIGH RESISTIVITY SILICON CARBIDE UNDER HIGH TEMPERATURE - HIGH FIELD STRESS

T. S. Sudarshan and G. Gradinaru
Depart. of Electrical and Computer Engg., Univ. of South Carolina, Columbia, SC 29208
Tel: (803)777-7302; Fax: (803)777-8045
Stefan A. Gradinaru
Governor's School for Science and Mathematics, 306 East Avenue, Harstville, SC 29550
Tel: (803)383-3900; Fax: (803)383-3903
W. Mitchel
WL/MLPO Bldg. 651, 3005 P St. Ste 6, Wright-Patterson AFB, OH 45433-7707
Tel: (513)255-4474x3252; Fax: (513)255-4913
H. McD. Hobgood
Northrop Grumman Science&Tech. Center, 1310 Beulah Rd, Pittsburgh, PA 15235
Tel: (412)256-1991; Fax: (412)256-1331

ABSTRACT

The influence of high temperature-high field stress on the electrical properties of high resistivity, single crystal, undoped and vanadium-compensated 6H-SiC is reported. Room temperature current density vs. electric field (J-E) measurements on lateral and vertical metal-semiconductor-metal (MSM) test structures indicate a strong influence of defect activation at relatively low fields on the current response in vertical devices. It is supposed that micropipes in high resistivity 6H-SiC, especially in the vanadium compensated material, are highly activated in parallel electric fields (vertical devices). No activation of micropipes was observed in high fields (up to 120 kV/cm) when the field is perpendicular to micropipes (lateral devices), even at high ambient temperatures.

Due to a perfect ohmic response over a wide range of fields (1-100 kV/cm), and having J-E characteristics free of micropipe influence, the lateral MSM test structures were used to investigate the influence of ambient temperature (295 - 750 K) on the material resistivity, using pulsed electric fields. A high rate of decrease of the electrical resistivity (ρ) of the material is observed even for small increase of the ambient temperature of 5-10 degrees, especially in the relatively low temperature range above the room temperature (295-350 K). J-E and ρ-E characteristics at T= constant and ρ-T and ($\ln\rho$)-(1000/T) characteristics at E= constant, both experimental and theoretical, are presented for different high resistivity 6H-SiC samples.

It is shown that the strong temperature variation of the undoped SiC is mainly dominated by the activation of the boron acceptor level with $E_a = 0.33 - 0.35$ eV. It is concluded that the undoped material is impractical as a substrate material for microwave integrated circuits for high temperature applications. Vanadium-compensated 6H-SiC semi-insulating (70-150 kΩcm) and insulating (> 10^{12} Ωcm) materials indicate a much more complex behavior at high temperatures, due to the presence of multiple impurity levels in the material. The response of the insulating material at different temperatures is difficult to evaluate due to the complexity in the separation of very low bulk and surface currents. New research work is in progress.

COMPARATIVE INVESTIGATION BY CAPACITANCE SPECTROSCOPY OF THE 6H - SIC EPILAYERS AND P-N JUNCTIONS GROWN BY SUBLIMATION EPITAXY (SE) AND CHEMICAL VAPOR DEPOSITION (CVD).

A.A.Lebedev

A.F.Ioffe Physico-Technikal Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia. Phone: (812) 247 93 14, Fax: (812) 247 10 17, E-mail: VChelnokov@optl.pti.spb.su

In the present work investigation were made by DLTS and capacitance - voltage method. All p-n structures studied in this work were grown on the (0001) Si face of single crystal silicon carbide substrates of polytype 6H. It were investigated CVD n-type layers and p-n junctions prepared by CREE Inc. USA [1], n-type epilayers and p-n structures fabricated by sublimation sandwich method [2] and p-n structures fabricated by sublimation growth of p+ emitter on base of the CVD n-type epilayers [3].

On CVD epilayers the Schottky barrier heights (φ_b) were studied for various types of metals (Ti, Al, Au, Mo) and after the following treatments of the surface of epitaxial. It was found that the value of φ_b strongly depends on the type of treatment, being equal from ~1.2 - 1.4 eV to ~0.4 eV , with the dependence of φ_b on the work function of a metal (see figure) becoming weaker with increasing φ_b .During investigation of the Schottky diodes on base of n-type 6H-SiC grown by sublimation epitaxy, we did not see so strong dependence of the barrier height on the type of surface treatment [4]. This diodes has higher value of the φ_b for the same metals. And this value is like φ_b value for CVD epilayers after plasma-ion etching ~ 1.2 - 1.4 eV.

Value of the diffusion potentials (U_d) of the 6H-SiC p-n structures produced by different technological methods were investigated at temperature range 300 K.. It was shown that calculated value for Ud for all types of p-n structures has better agreement with experiments with using for forbidden gap value 2.86 eV, but not usual value equal to 3.02 eV.

In CVD p-n structures it was found presents of the same deep acceptor levels (L-center ,Ev + 0,24 eV and D-center, Ev + 0.58eV), which were early founded in SE grown samples [5]. But the net concentration of the deep acceptor centers in CVD p-n structures was found to be consistently smaller by 2-3 orders of magnitude than in SE p-n structures with the same value of Nd - Na.

This work was partly supported by Arizona University (USA) and INTAS grant 93-543.

References.

1. J.W.Palmor, J.A.Edmond, H.S.Kong and C.H.Carter Jr. *Physica B 185* (1993) p. 461.
2. M.M.Anikin, A.A.Lebedev, S.N.Pyatko, A.M.Strel'chuk and A.L.Syrkin, *Mater.Sci.Eng, B11*,(1992) 113
3. N.S.Savkina, A.A.Lebedev,A.A.Mal'tsev, N.K.Poletaev, M.G.Rastegaeva, A.M.Strel'chuk and V.E.Chelnokov, ***Technical Digest of Int'l Conf. n SiC and Related Materials - ICSCRM -95- Kyoto,Japan,Sept*** *1995*, p 160.
4. A.L.Syrkin,A.N.Andreev,A.A.Lebedev,M.G.Rastegaeva and V.E.Chelnokov, Matter.Sci.Eng B29 (1995) p198.
5. A.A.Lebedev and V.E.Chelnokov. Diamond films and Related Materials V 3, (1994) p 1393.

WANNIER-STARK LOCALIZATION EFFECTS IN THE NATURAL SILICON CARBIDE SUPERLATTICE

Sankin V.I., Stolichnov I.A.
A.F.Ioffe Physico-Technical Institute, Russian Academy of Sciences
26, Politekhnicheskaya, St.Petersburg, 194021, Russia
Fax: (812) 515 6747, (812) 247 1017
E-mail: sankin@widegap.ioffe.rssi.ru

A very low rate of electron impact ionization was discovered in silicon carbide (SiC) polytypes 4H, 6H, 8H, 15R, 21R and others when the electric field was directed along the axis of natural superlattice. This phenomenon was explained by the narrow conduction band or miniband in the electronic spectrum of these polytypes. The electric field induced the Wannier-Stark localization (WSL) in the miniband and therefore electron heating was suppressed as high as electric field 2500 kV/cm. But the mechanism of this phenomenon was unclear.

The detailed investigation of WSL process on special experimental structures with electron conduction allowed to obtain unusually interesting results concerning various effects which were discovered within a large range of electric fields from 100 to 2500 kV/cm. Three SiC polytypes: 4H, 6H and 8H with different superlattice parameters were used for investigation of electron transport effects connected with the WSL. The data obtained describe different phases of WSL process which arise as the field increasing in SiC crystals. Each of these phases is characterized by the negative differential conduction (NDC). The direct observation of these NDC effects and their analysis based on the system parameters and threshold field values are a subject the paper is focused on.

The first WSL phase is the Bragg reflection of electrons known as the Bloch oscillations. In this case the electronic spectrum is quasicontinuous. The threshold fields of NDC observed for polytypes 4H, 6H, 8H correlates well with the superlattice periods of these polytypes. The second phase is the formation of discrete spectrum and hopping conduction via phonons. For this phase the electron-phonon current resonances as a result of interaction of electrons with the acoustic and optic phonons were observed. The next phase is full localization of low miniband and its transformation in a single level near the middle of the vanished miniband. Strong current drop was observed for this phase. The value of the threshold field allowed to make a reasonable estimation of the low miniband width. This process is completed by the resonant electron tunneling into an upper band that releases electron from confinement of WSL in low miniband and allows to get it into quasicontinuous wide band. There the electron increases its ionization rate abruptly by a very large field. The threshold field of the effect was used for interminiband gap estimation.

Therefore in the space charge region of p-n junction the electron impact ionization will be suppressed until electron tunnels into the upper band. This field delay induces the anomalous increase of breakdown field in SiC polytypes for the fields directed along the superlattice axis.

In conclusion it should be noted that besides the scientific significance the discovered NDC creates very promising basis for the new SiC application in the area of super-high frequency waves generation.

1st European Conference on Silicon Carbide and Related Materials

Monday, October 7, 1996 17:00-18:50

SESSION 3: SiC EPITAXIAL GROWTH

Chairman: C. Jaussaud

Progress in SiC Epitaxy – Present and Future

Hiroyuki MATSUNAMI

Department of Electronic Science and Engineering, Kyoto University
Yoshidahonmachi, Sakyo, Kyoto 606–01, Japan

Step-flow growth on off-oriented SiC{0001} substrates ensures the polytype replication in SiC epilayers by CVD even at relatively low temperatures well below 1600°C (step-controlled epitaxy) [1]. There exist two competitive processes on a growing surface, step-flow and two-dimensional nucleation. The supersaturation of chemical species on substrate terraces, which determines the growth mode, strongly depends on growth temperature, gas supply, C/Si ratio, and step structures. Besides, the nucleation rate and surface migration are different for substrate surface polarity (Si or C faces). It is, therefore, critical to control the supersaturation on a surface to get high-quality epilayers without any other polytype inclusions. In this paper, surface morphology, step structure, and surface kinetics in 6H- and 4H-SiC epitaxial growth are discussed in detail. Characterization of epilayers is also presented.

6H- and 4H-SiC epilayers were grown by atmospheric pressure CVD in a SiH_4–C_3H_8–H_2 system. The typical growth temperature and growth rate were 1500°C and 2.5μm/h, respectively. In 6H-SiC growth, almost all surface morphological defects come from micropipes in substrates. 4H-SiC growth, however, is very sensitive to polishing damage and substrate defects, especially on a Si face: 3C-SiC nucleation and macrostep formation easily occur during CVD growth. A cross-sectional transmission electron microscopy (TEM) analysis revealed that the average terrace width is larger on 4H-SiC than on 6H-SiC with an identical off-angle (3.5~5°), due to the higher step height for 4H-SiC [2]. The use of 4H-SiC substrates with a larger off-angle (8°-off) is effective to reduce surface defects [3]. The author's group found that surface morphology is excellent on C faces even for 4H, although optimum growth conditions involving the C/Si ratio is narrower on C faces. In a TEM analysis, epilayers on C faces exhibited fewer bunched steps and smaller average terrace width, which favors step-flow growth.

The background doping level of unintentionally doped epilayers can be reduced down to $5\times10^{13}\sim1\times10^{14}\mathrm{cm}^{-3}$ by the growth under C-rich conditions [4]. With lowering the doping level, the intensity of free exciton peaks in low-temperature photoluminescence and mobility significantly increase. The highest electron mobility (in the {0001} basal plane) at room temperature we obtained is $431\mathrm{cm}^2/\mathrm{Vs}$ for 6H-SiC and $851\mathrm{cm}^2/\mathrm{Vs}$ for 4H-SiC. A deep level analysis showed that trap concentrations are in the $10^{12}\mathrm{cm}^{-3}$ range for both 6H- and 4H-SiC, indicating high quality of epilayers.

The authors wish to thank Prof.W.J.Choyke (University of Pittsburgh) and Dr.G.Pensl (University of Erlangen-Nürnberg) for collaborative works on characterization of epilayers.

[1] N.Kuroda *et al.*, Ext. Abstr. 19th Solid State Devices and Materials, Tokyo, 1987, p.227.
[2] T.Kimoto *et al.*, Appl. Phys. Lett. **66**, 3645(1995).
[3] V.F.Tsvetkov *et al.*, Silicon Carbide and Related Materials 1995 (IOP, Bristol, 1996), p.17.
[4] D.J.Larkin *et al.*, Appl. Phys. Lett. **65**, 1659(1994).

GROWTH AND DOPING VIA GAS SOURCE MOLECULAR BEAM EPITAXY OF SiC AND SiC/AlN HETEROSTRUCTURES AND THEIR MICROSTRUCTURAL AND ELECTRICAL CHARACTERIZATION

R. F. Davis, R. S. Kern and S. Tanaka, Department of Materials Science and Engineering, North Carolina State University, Box 7907, Raleigh, NC, United States of America, 27695-7907, (Telephone: 919-515-3272; FAX: 919-515-7724)

Monocrystalline thin films, multilayer heterostructures and solid solutions of SiC and AlN have been grown in the range of 1000 - 1500°C on 6H-SiC(0001) substrates via gas-source molecular beam epitaxy. Growth mechanisms, defect formation, donor and acceptor doping, metal-insulator-semiconductor diodes and pseudomorphic structures have been investigated. Polytype control was achieved via changes in the substrate orientation, substrate temperature and gas phase chemistry. Step flow and resulting homoepitaxial growth of 6H-SiC films were achieved on vicinal substrates at 1350°C and higher temperatures using the SiH_4-C_2H_4-H_2 gas system. Step bunching, nucleation of cubic (3C- or beta-) SiC and double position boundaries were observed at all temperatures when H_2 was removed from the system or the temperature of growth was <1350°C. Kinetic analysis of the deposition indicated that the deposition was surface reaction controlled. Residual, unintentionally incorporated nitrogen impurity levels were affected by changing the SiH_4/C_2H_4 gas flow ratio, in agreement with the "site-competition epitaxy" model. Films intentionally doped with NH_3 or N_2 were n-type; with Al they were p-type. Uniform, controlled doping levels between 10^{15} and 10^{19} cm^{-3} were achieved for both polytypes. The electron mobility in undoped 6H was 434 $cm^2/V{\bullet}s$.

Monocrystalline AlN was deposited using evaporated Al and ECR plasma derived N or NH3. Very thin (<50Å) films grown on vicinal 6H-SiC(0001) had a higher defect density than those deposited on on-axis substrates due to inversion boundaries forming at most SiC steps. Metal-insulator-semiconductor diodes of Al/AlN/6H-SiC were fabricated using 100 nm AlN. These structures exhibited very little hysteresis and very low interface charge (acceptor-like) traps density ($\approx 1 \times 10^{11}$ cm^{-3}) at room temperature. Accumulation, depletion and deep depletion were observed; inversion was not achieved due to low minority carrier generation.

Superior single crystal AlN/SiC heterostructures were achieved when very thin AlN was deposited on the on-axis substrates. Single phase monocrystalline solid solutions of $(AlN)_x(SiC)_{1-x}$ were deposited between $0.2 \leq x \leq 0.8$. A structural transition from zindblende to wurtzite was observed at $x \approx 0.25$.

The presentation will detail the results of the growth and characterization of the various films and heterostructures.

Note: This abstract replaces the preliminary abstract submit earlier.

HIGH QUALITY 4H- SIC GROWN ON VARIOUS SUBSTRATE ORIENTATIONS

A. Henry*, I.G. Ivanov, T. Egilsson, C. Hallin, O. Kordina*, U. Lindefelt and E. Janzén

Department of Physics and Measurement Technology, Linköping University,
S-581 83 Linköping, Sweden
** also: ABB Corporate Research, S-721 78 Västerås, Sweden*

tel : (46) 13 28 24 14 fax: (46) 13 14 23 37 e-mail: ahy@ifm.liu.se

Growth of high quality 4H epilayers has been achieved with chemical vapour deposition using the concept of the hot-wall reactor [1]. The following substrate orientations were used for this study: (1) on-(0001) oriented (c-axis, Si face), (2) off-axis (3.5 and 8 deg off from the c-axis towards the $(11\bar{2}0)$ direction) Si face n-type and (3) a-cut materials ($11\bar{2}0$ and $10\bar{1}0$ oriented) substrate grown by the modified Lely method. Particular preparation of the substrate was done prior the growth such as long etching at the growth temperature in order to get a very good quality interface between the epilayer and the substrate. The effects of growth conditions such as temperature, growth rate and C/Si ratio were investigated and depending on the orientation of the substrate they were adjusted to get state-of-the-art epilayers with low doping concentration. Various characterisation techniques were used to control the quality of the epilayers: optical microscopy with Normarski optics, X-ray diffraction, Raman spectroscopy and mainly low-temperature photoluminescence (PL).

A decrease of the growth-rate accompanied by an increase of the growth temperature was found to decrease the fraction of 3C growth on the on-axis (0001) oriented 4H material as observed with the different characterisation techniques. However the quality of the remaining 3C-inclusions which were in very small proportion compared to the 4H-growth, was extremely high showing multi-bound exciton lines of the nitrogen donor in the PL spectrum. For the 4H c-axis samples only the near band gap emission of the 4H polytype was observed in the PL spectra without contribution of donor-acceptor pair or other deep emission. Strong free-exciton (FE) lines were observed and the nitrogen concentration was in the range $2 - 6 \cdot 10^{14}$ cm^{-3}. With the specified growth conditions samples showing either strong FE or donor bound-excitons (BE) lines were grown and we have performed a detailed study of their phonon replicas. They involve phonon from the M-point of the Brillouin zone (BZ) where the conduction band minium is positioned, and they exhibit well distinguished polarisation with respect to the c-axis. Namely, among the 24 phonon replicas, 12 are polarised // to the c-axis and 12 are $\perp$ to this axis, as predicted by a theorical-group model. We observe 22 of these 24 phonon replicas. The PL spectrum of a (0001) oriented sample recorded in the usual near backscaterring geometry exhibits mainly the $\perp$ to the c-axis phonon replicas. The zero-phonon lines of the BE are polarised $\perp$ to the c-axis, behaviour which agrees with the theorical analysis.

The a-axis samples were grown at a temperature of 1550°C with a ratio Si/C = 2 and a growth rate of about 2.5 µm/h. Photoluminescence was recorded for both $(10\bar{1}0)$ and $(11\bar{2}0)$ oriented samples. The observed PL spectra show BE and FE lines with both // and $\perp$ to the c-axis polarisation. For the first time the $(10\bar{1}0)$ and $(11\bar{2}0)$ oriented samples are of the same high quality, as estimated by the small linewidths of the PL peaks and their intensity.

For the various samples Raman spectra were recorded with polarisation study to be used as the source of the energies of the fundamental phonons in the center of the BZ.

[1] O. Kordina, A. Henry, C. Hallin, R.C. Glass, A.O. Konstantinov, C. Hemmingsson, N.T. Son and E. Janzén, Mat. Res. Soc. Symp. Proc. Vol. **339** (1994 Materials Research Society), p.405-410

HYDROGEN INCORPORATION IN EPITAXIAL LAYERS OF 6H - AND 4H - SILICON CARBIDE GROWN BY VAPOR PHASE EPITAXY

Adolf Schöner, Kurt Rottner, and Nils Nordell
Industrial Microelectronics Center (IMC)
P.O. Box 1084, Isafjordsgatan 22, S-16421 Kista, Sweden
Phone +46 8 752 10 00, fax +46 8 750 54 30

Christian Peppermüller, and Reinhard Helbig
Institute of Applied Physics, University Erlangen-Nürnberg
Staudtstr. 7, A3, D-91058 Erlangen, Germany
Phone +49 9131 85 84 34, fax +49 9131 85 84 23

Margareta Linnarson
Royal Institute of Technology, Depart. of Electronics, Solid State Electronics
P.O. Box Electrum 229, Isafjordsgatan 22-26, S-164 40 Kista, Sweden
Phone + 46 8 752 14 00, fax +46 8 752 77 82

In order to use silicon carbide (SiC) as a semiconductor material for electronic devices the incorporation of acceptor and donor dopants during growth has to be controlled in a wide concentration range. Because hydrogen is used as a carrier gas in epitaxial growth processes and is therefore present in high concentrations, the interaction of hydrogen with doping atoms like aluminium, boron, and nitrogen has to be studied carefully and is important for the electrical properties of epitaxial grown device material. From other semiconductors like silicon for example it is well known that hydrogen passivates acceptor dopants.

We have investigated the incorporation of hydrogen in epitaxial 4H- and 6H-SiC layers. The films were grown in a horizontal reactor for vapor phase epitaxy (VPE), with an inner cell entirely made of graphite. Besides the standard precursors silane and propane, precursors for aluminium, boron, and nitrogen doping were used to achieve p- and n-type conductivity, respectively. In addition using SiC coated susceptors the carbon (C) and silicon (Si) content of the gas phase inside the reactor could be varied.

The VPE-grown layers were characterized by different electrical, optical and structural methods. In particular we used low temperature photoluminescence (LTPL), secondary ion mass spectroscopy (SIMS), and capacitance voltage (CV) measurements.

In our investigations we found a strong dependence of the hydrogen incorporation on the C:Si-ratio. In LTPL-spectra of nitrogen doped n-type epitaxial layers, which are usually grown at low C:Si-ratios (site competition epitaxy), the hydrogen related LTPL is weak and the strongest hydrogen lines (in 6H-SiC the H_3-line at a wavelength of 419.4nm) are hardly seen. On the other hand, growth of aluminium doped p-type epitaxial layers, normally carried out under C-rich conditions (high C:Si-ratio), results in a bright hydrogen related luminescence. By annealing the p-type layers at different temperatures in the range of 600°C to 1600°C we found that at annealing temperatures above 800°C the hydrogen related luminescence decreased strongly and the donor acceptor pair spectrum was more pronounced.

By measuring the CV-characteristic of titanium Schottky contacts on epitaxial layers intentionally grown to have p-type conductivity we obtained in some samples unexpectedly n-type behavior, although acceptor dopants were added to the VPE growth process. P-type conductivity was not achieved before the samples were annealed in argon atmosphere at temperatures above 900°C.

SIMS investigations on epitaxial layers, doped during the growth with stair-like concentration profiles of acceptors (aluminium or boron), showed, that the hydrogen profile follows the profile of the acceptor dopants. Steps in the hydrogen profile were found at the same depth where the acceptor concentration was intentionally increased or decreased by changing the C:Si-ratio or the dopant supply.

Our investigations showed an enhanced incorporation of hydrogen in p-type 4H- and 6H-SiC layers indicating an interaction of hydrogen with acceptor dopants like boron and aluminium. A hydrogen passivation of the acceptor dopants during the VPE growth process was observed. The passivation effect could be reduced by a heat treatment at temperatures above 900°C in argon atmosphere.

Monday, October 7, 1996 19:00

ROUND TABLE DISCUSSION: EUROPEAN EFFORT ON SiC WAFER PRODUCTION & SiC BULK AND EPITAXIAL GROWTH APPARATUS.

Chairman: E. Janzén

Dr. D. Brown (ATM), Dr. J.O. Fornell (Epigress AB), Dr. H. Juergensen (AIXTRON), Dr. M. Kanaya (Nippon Steel), Prof. R. Madar (INP Grenoble), Dr. J. Palmour (CREE), Prof. Y. Tairov (St. Petersburg Electrotech. Univ.), Dr. A. Vehanen (Okmetic Oy), Dr. J. Voelkl (Siemens), Prof. A. Winnacker (Erlangen Univ.).

1st European Conference on Silicon Carbide and Related Materials

Tuesday, October 8, 1996 08:30-10:05

SESSION 4: SiC CHARACTERIZATION: CRYSTAL STRUCTURE & DEFECTS; OPTICAL AND ELECTRONIC PROPERTIES

Chairman: J. Camassel

CARRIER LIFETIMES IN SiC, STUDIED BY TIME RESOLVED PHOTOLUMINESCENCE SPECTROSCOPY

P. Bergmann

Department of Physics and Measurement Technology, Linköping University, S-581 83 Linköping, Sweden

fax : +46 13 14 23 37

Abstract not available

ANALYSIS OF TRANSPORT PROPERTIES OF β-SiC FILMS DETERMINATION OF DONORS DENSITY AND COMPENSATION RATIO

S.Contreras, C.Dezauzier, P.Thomas, J.L.Robert

G.E.S, cc074, UM2-CNRS, 34095 Montpellier cedex 5, France.

We present an interpretation of the electrical behaviour of n-type β-silicon carbide films deposited on silicon or on SOI (SIMOX) taking into account the parallel conduction at the interface and the role of the substrate. Conductivity and Hall measurements have been performed over a wide range of temperatures (4.2 K-600 K).

Different conductions regimes have been observed as a function of the temperature:

i) In the case of SiC/Si films, the conduction, at low temperature, is due to a highly degenerated layer located at the interface SiC/Si. At high temperature, leakage currents occuring at the p-n heterojunction are observed, and the conduction is dominated by the substrate. In the intermediate temperature range, only the SiC film controls the conduction.

ii) In the case of SiC/SIMOX films, the temperature at which the conduction by the substrate appears, is moved towards higher temperatures; this is because of the presence of the SiO_2 insulating layer.

Considering the behaviour of the SiC films observed in the intermediate temperature range, the analysis of the electrical properties have been made taking into account the following modes:

- Deformation potential and acoustic phonons scattering,
- Piezoelectric and polar optical scattering.
- Neutral impurities scattering.
- Ionized impurities scattering : Quantum correction to the first Born approximation must be introduced to determine this scattering time in highly degenerate samples.

In the proposed model, Hall effect and mobility behaviors as a function of temperature are simultaneously analyzed. By this way, we are able to determine both the density of the donors and the compensation ratio of our samples.

Particulary, we show that in the case of non-degenerate samples, the density of donors is about $5\ 10^{17}$ cm^{-3}, whatever the origin of the material. As a result, low carrier density at room temperature ($n \approx 2\ 10^{16}$ cm^{-3}) can be only obtained by increasing the compensation ratio up to 96 %.

RADIATION-INDUCED DEFECT CENTERS IN 4H AND 6H SILICON CARBIDE

T. Dalibor[1], G. Pensl[1], T. Kimoto[2], H. Matsunami[2], S. Sridhara[3], R.P. Devaty[3], W.J. Choyke[3]
1: Institute of Applied Physics, University of Erlangen-Nürnberg, Staudtstraße 7, D-91058 Erlangen, Germany, Phone: +(49)-9131-858426, Fax: +(49)-9131-858423.
2: Department of Electrical Engineering, Kyoto University, Kyoto 606-01, Japan.
3: Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15260, USA.

Ion implantation is one of the key technologies in the processing of silicon carbide (SiC) based devices. Due to very small diffusion coefficients, ion implantation is the favored technique for n- and p-type doping of SiC, when more complex structures are needed. Quite recently, remarkable progress could be achieved applying ion implantation for the doping of SiC with different dopants. However, these reports concentrate on the electrical activation of the dopant and the structural characterization of the implanted layer rather than on electrically active radiation-induced defect centers and their thermal stability.

For this purpose, we implanted n-type 4H and 6H SiC epilayers with helium ions (total fluence of He^+ ions equal to $9 \cdot 10^{10}$ cm^{-2}) to achieve a rectangular vacancy profile with a mean vacancy concentration of $4.5 \cdot 10^{16}$ cm^{-3} to a depth of 1.6μm (according to TRIM_C). The SiC epilayers we used were grown by chemical vapor deposition (CVD) in a SiH_4-C_3H_8-H_2 system. They were unintentionally n-type doped with a net doping concentration in the range of $(1\text{–}2) \cdot 10^{16}$ cm^{-3} as evaluated from capacitance-voltage measurements. The thickness of the epilayers was about 8μm; growth temperature and C:Si ratio were 1500°C and 3.0, respectively. Deep level transient spectroscopy (DLTS) and low temperature photoluminescence (LTPL) were applied to characterize the 4H and 6H SiC epilayers in their as-grown state and subsequent to the implantation with He^+ ions.

The DLTS spectra of the as-grown 4H and 6H samples reveal a rather low concentration of deep defect levels of $2 \cdot 10^{13}$ cm^{-3} in the investigated temperature range from 100–700K. In the DLTS spectra of the 4H SiC epilayers, we can only observe one peak at E_C–(0.63-0.68) eV (assuming $\sigma = \text{const.}$ and $\sigma \propto T^{-2}$, respectively) due to the Z_1-center. Two features are detectable in the 6H SiC epilayers: a peak with a shoulder on its low temperature flank at 200 K and a second peak at 575 K providing ionization energies of (391-426) meV and (1.17-1.27) eV, respectively, related to the conduction band. However, we would like to point out that we could not observe the Z_1/Z_2-center in the 6H polytype. As expected from the DLTS results, the LTPL spectra of the as-grown 4H SiC epilayers show a small L_1-line due to the D_1-center, which is correlated with the Z_1-center; the spectra of the 6H polytype do not show any L-lines.

After implantation of the 4H and 6H SiC epilayers with He^+ ions and no special heat treatment other than measuring DLTS up to approx. 430°C several new peaks and lines can be observed in the DLTS and LTPL spectra, respectively. In the 4H polytype samples, the concentration of the Z_1-center increases to about $4 \cdot 10^{15}$ cm^{-3} and a shoulder appears on its low temperature flank. Whereas the Z_1-center withstands annealing even at 2000°C, the shoulder disappears after an anneal at 1000°C. Three other peaks can be observed in the He^+-implanted 4H SiC epilayers with ionization energies of (888-970) meV, (981-1076) meV and (1.49-1.60) eV. The latter peak is of special interest, because its energy level is close to mid-bandgap and its capture cross section for electrons of $(1\text{-}9) \cdot 10^{-14}$ cm^2 is rather high. This trap might be able to act as an efficient recombination center in ion-implanted 4H SiC. However, it can be annealed at a temperature of around 1700°C. The LTPL spectra show a great number of new lines after the He^+-implantation, which are due to intrinsic defect centers. Most of these lines anneal at temperatures below 1700°C except for the L_1-line.

The DLTS spectra of the He^+-implanted 6H SiC epilayers indicate an increase of the concentration of the two features already observed in the as-grown state to about $3 \cdot 10^{15}$ cm^{-3} and $4 \cdot 10^{15}$ cm^{-3}, respectively. This clearly shows that the related defect centers are of intrinsic nature. In addition, a double peak appears with a concentration of approx. $9 \cdot 10^{14}$ cm^{-3}, which can be assigned to the Z_1/Z_2-center. Also for the 6H polytype, the LTPL spectra reveal a great number of new lines after the He^+-implantation, which can be attributed to intrinsic defect centers. Both DLTS and LTPL spectra show similar features to those of electron-irradiated samples.

Thermal properties of ß-SiC epitaxial layers between RT and 600°C measured by using microstructures

C. Wagner, G. Krötz
Forschung und Technik, Daimler-Benz AG, Postfach 80 04 65, 81663 München, Germany

Usually SiC is known as an attractive wide bandgap material for high temperature and high power electronics. The chemical inertness and the good elastic behaviour even at high temperatures make it also a good candidate for microsensor applications in harsh environments. For thermal simulations of microsensor concepts reliable data on the thermal properties of SiC are necessary.

In the present paper thermal properties of CVD grown epitaxial SiC layers on silicon were systematically studied. A novel arrangement of micromachined SiC bridges as depicted in the figure below together with a thermal imaging system was used to determine the heat conductivity and the thermal diffusion velocity in dependence on the temperature.

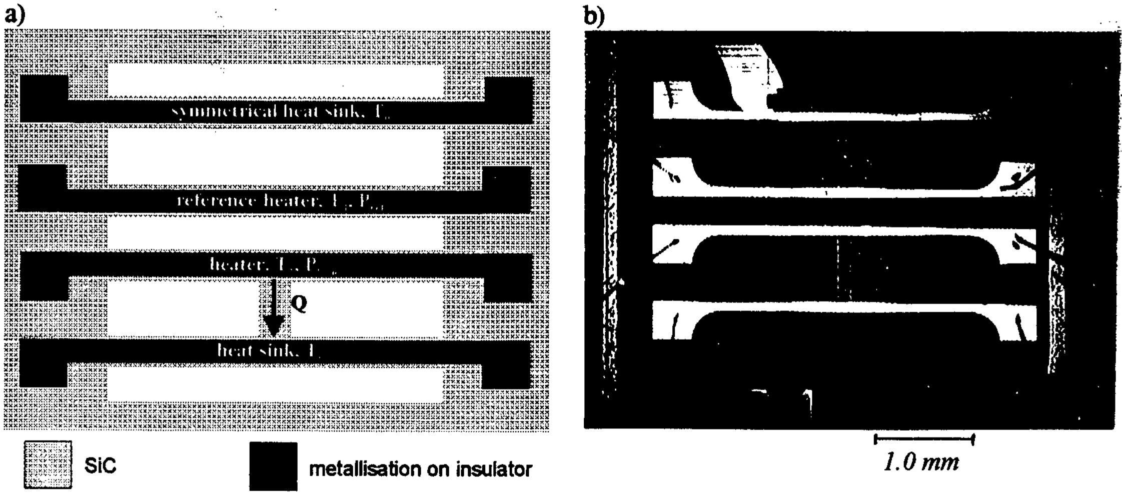
The measurement principles are as follows:

1. To measure the thermal conductivity both the heater and the reference heater are heated up to the same temperature T_1, the heat sinks to T_0. The temperatures are measured by the thermal imaging system. The thermal loss across the SiC bridge between the heater and the heat sink causes a higher power consumption of the first (P_{heat}) compared to the latter (P_{ref}). The measured difference $Q = P_{heat} - P_{ref}$ is used to derive the heat conductivity κ from the equation $Q = -\kappa$ grad T.
2. For measuring the heat diffusion velocity heat pulses are applied to the heater. The heat flow across the SiC bridge between the heater and the heat sink causes a time delayed temperature variation in the heat sink. The thermal diffusion velocity can be derived from the phase shift between heater and heat sink signal measured by an oscilloscope.

The advantages of the described method are:

1. The chosen microstructure design allows a simple evaluation procedure avoiding complicated model calculations.
2. Heat losses along the metallisation are compensated as well as uncertainties caused by the thermal contact resistance between metallisation and SiC.
3. A symmetrical heat sink was included to get very similar radiation equilibria both for the heater and the reference heater. Thus radiation losses along the heaters can be eliminated. Such of the SiC bridge connecting the heater and the heat sink can be considered in the evaluation of the measurement results.

At the conference the measurement principle will be explained in detail and extensive data concerning the thermal conductivity and the heat diffusion velocity of SiC epitaxial thin films in dependence on the layer quality and the temperature will be presented.



Microstructure for measuring thermal conductivity and heat diffusion velocity of epitaxial SiC layers: a) schematic sketch, b) photograph;

1st European Conference on Silicon Carbide and Related Materials

Tuesday, October 8, 1996 10:20-12:30

SESSION 5: SiC PROCESSING: OXIDATION, METALLIZATION, ION-IMPLANTATION AND ETCHING

Chairman: W. J. Choyke

SiC DEVICE TECHNOLOGY: REMAINING ISSUES

J.W. Palmour, L.A. Lipkin, R. Singh, D.B. Slater, Jr., and A. Suvorov
Cree Research, Inc.
4022 Stirrup Creek Drive, Suite 322
Durham, NC 27713
USA
Tel.: 1 (919) 361-4770
FAX: 1 (919) 361-2266, e-mail: john_palmour@cree.com

Silicon carbide technology has made tremendous strides in the last 5-7 years, with a variety of encouraging device and circuit demonstrations. The commercial availability of relatively large, high quality wafers of the 6H and 4H polytypes of SiC for device development has facilitated these exciting breakthroughs in laboratories throughout the world. These have occurred in numerous application areas, including high power devices, high temperature devices, and high power/high frequency devices. However, there are still a number of factors that are limiting the commercialization of devices in these areas. Some of the areas receiving the most attention currently are insulator/SiC interface quality, high temperature reliability, high voltage terminations, and ion implantation. This paper will discuss efforts in these areas, the impact of processes on the devices, as well as some of the material related issues.

Thermal oxides grown on p-type 6H-SiC have been shown to improve with a combination of low oxidation temperature (1050°C) followed by a 950°C re-oxidation anneal. Using this process, interface state densities of 1.0×10^{11} cm^{-2}/eV^{-1} have been achieved. This improved process produced the highest SiC surface channel mobility, 72 cm^2/V-s, reported to date for 6H-SiC MOSFETs. It is believed that we must further reduce the D_{it}, as well as the oxide charge (Q_{ox}), by another factor of five to make these devices commercially viable.

Oxide reliability is another area of concern for SiC devices. At high fields and high temperatures, SiO_2 layers have been reported to have poor lifetimes. However, recent work has begun to show some promise. As oxide quality and device processing techniques improve, the lifetimes have been significantly increased. Time-dependent dielectric breakdown (TDDB) results indicate that thermal oxides grown on p-type SiC have lifetimes as high as 700 years at 2 MV/cm and 350°C. However, samples fabricated on heavily doped material demonstrate a reduced high temperature lifetime. Additionally, TDDB data on SiO_2 on n-type SiC show much worse lifetimes, indicating an area of concern to be studied much more thoroughly. Device lifetimes measured on n-channel MOSFETs have also shown a large increase, with devices operating in air at 350°C for >70 hours without failure. The projected lifetime for n-channel MOSFETs is about 5 years at 350°C, and is projected to be longer for p-channel MOSFETs.

While a number of demonstrations of high voltage devices have been made in SiC, most of these have relied on the use of dielectric liquids or gases to prevent lower voltage failures. For commercially viable devices, high voltage termination techniques must be developed that allow for standard packaging of parts and allow higher temperature operation than can be obtained with the dielectric liquids. Efforts are now underway to develop these terminations. Promising results have been obtained with the use of field plates, self-aligned amorphizing implants, and boron p-type implants for Schottky diodes. Likewise, some improvements have also been obtained for mesa terminated devices.

The area of ion implantation of dopants into SiC has also begun to receive increased attention because of its importance to power devices and high temperature circuits. While reliable, low resistance N^+ implants seem to be relatively easily attained through the use of high temperature implantation followed by high temperature annealing, reliable processes for p-type ion implantation have been more difficult to obtain. Recent efforts have resulted in significant increases in activation of Al and B implants and reduction of sheet resistivities of Al^+ implanted layers. Sheet resistivities less than 10 kΩ/square and contact resistivities in the 10^{-5} Ω-cm^2 range have been obtained for Al implants in 6H-SiC.

Finally, one of the most important areas for power devices still depends on material quality issues. Micropipe defect densities as low as 3.5 cm^{-2} have now been demonstrated in research, but production levels are significantly higher. These levels must be reduced to <1 cm^{-2} in production quantities for viable power devices. Wafer diameter must also be increased to decrease fabrication costs.

SILICON CARBIDE for MICROWAVE POWER APPLICATIONS

Christian BRYLINSKI, tel + 33 1 69 33 92 51, fax: + 33 1 69 33 08 66
THOMSON CSF LCR, Domaine de Corbeville 91404 ORSAY CEDEX

Global comparison of dynamic electrical performances of devices with similar geometry but made out of different semiconducting materials can be made using "figures of merit" only depending on the material physical properties.

For short pulse applications, with thermal problems out of consideration, the most relevant figure of merit is the Johnson's one (JFM) which varies as $(Eb \times vs)^2$ (Eb breakdown field, v_s carriers saturated velocity). With the improvement of the silicon technology, present silicon device performances (power, frequency, output impedance level) are now approaching this fundamental limit. For further improvement, better materials are required.

Semiconductor materials made of light elements present high values of E_b and v_s and subsequent JFM. Moreover, they also exhibit higher thermal conductivities, which means that at least part of the pulse performances improvement can be maintained in a CW regime.

Diamond and BN should exhibit the highest possible JFM values, but many theoretical and technological problems related to them (doping for instance) remain unsolved. And so today, SiC, GaN and related compounds, are the lightest available semiconductors. SiC is the only one that is known to be matched to an existing substrate (itself). This is the main reason why, as soon as SiC substrates were made available, research has started in order to demonstrate experimentally the outstanding predicted performances of SiC based microwave power devices.

Regarding device structure, unfortunately MOS interface on SiC is still very far from perfection and generally unusable for practical applications in the microwave area. On the other hand, bipolar structures are quite difficult to make, mainly due to problems encountered with the p-type SiC doping and contacting.

In the early nineties, at a stage during which only conductive substrates were available, the main pioneer in this area, Westinghouse, has chosen to work with a vertical MESFET trench structure called Static Induction transistor (SIT) or Permeable Base Transistor (PBT).

For this kind of device, very fine trenches width is needed to get low output conductance. For more classical lithography dimensions, the relative inefficiency of the SIT current control by the gate electrostatic influence makes necessary a compromise between the current density and the control efficiency. The result is a device which exhibit "triode-like" characteristics with low current density and high output conductance.

Despite those basic drawbacks, today's Westinghouse (presently Northrop Grumann) SiC SIT microwave amplification power results in the UHF range (> 1kW at 600 MHz) and even in the S-band (pulse 36W at 3GHz) are already impressive and contribute to establish the reality of SiC interest for this range of applications.

On the other hand, the demonstration of semi-insulating sustrates has opened the way to successful high performances MESFETs which do not exhibit the same basic limitations as SIT, although more sensitive to other possible parasitic effects such as electron traps and surface effects. A first series of encouraging power results in the (2-4 Watts) range has been obtained at Westinghouse, Motorola and Thomson, although it seems that only Westinghouse has been able to successfully use semi-insulating substrates for making real power MESFETs today.

CVD-BASED TUNGSTEN CARBIDE SCHOTTKY CONTACTS TO 6H-SIC FOR VERY HIGH TEMPERATURE OPERATION

Nils Lundberg, Per Tägtström[a)], Ulf Jansson[a)] and Mikael Östling

Royal Institute of Technology, Department of Electronics

E229, S-164 40 Kista-Stockholm, Sweden

[a)] Uppsala University, Department of Chemistry, Uppsala, Sweden

Phone: +46 8 752 14 09, **Fax:** +46 8 752 77 82, **e-mail:** nils@ele.kth.se

ABSTRACT: Silicon carbide (SiC) devices are presently being developed for use in high temperature (≥ 500 °C) and high power environments under which conventional semiconductors hardly can perform. An obstacle to SiC's ability to function under such extreme conditions is the lack of reliable electrical contacts. Some metals react / intermix with SiC at elevated temperatures (Au at 500 °C [1], Pt at 450 °C [2] and Co at 600 °C [3]) resulting in increasing leakage currents for the Schottky contacts. An exception is Re which has been proven to be thermally stable up to at least 1100 °C [4] but no electrical characteristics were presented. Refractory metal silicides have been suggested because of their thermal stability and metal carbides because of their outstanding adhesion properties.

In this study, tungsten carbide, with its hardness, chemical inertness, thermal stability and low resistivity (25 μΩcm) [5] is shown as a reliable contact material to n- and p-type 6H-SiC for very high temperature applications. WC films with thicknesses of 100 - 150 nm were deposited by chemical vapour deposition (CVD) from a WF_6 / C_3H_8 / H_2 mixture at 900 °C. A method to pattern CVD-tungsten carbide is suggested. TEM analysis of as deposited samples displayed a clear and unreacted interface. The electrical investigations of the p-type 6H-SiC Schottky contacts revealed a high rectification ratio and a low reverse current density (6.1×10^{-5} A cm^{-2}, -10 V) up to 500 °C. We will show a temperature dependence for the barrier height of tungsten carbide contacts that can be related to the simultaneous change in the energy bandgap which should be considered when designing SiC devices intended for high temperature operation. On n-type a low barrier ($\Phi_{Bn} = 0.79$ eV) at room temperature was observed. The low Φ_{Bn} suggests WC to be promising as an ohmic contact material on highly doped n-type epi-layers.

[1] D. E. Ioannou, N. A. Papanicolaou, P. E. Nordquist Jr., IEEE Trans. Electr. Dev., **ED-34**, 1694 (1987)

[2] N. A. Papanicolaou, A. Christou, M. L. Gipe, J. Appl. Phys., **65** , 3526 (1989)

[3] N. Lundberg, C.-M. Zetterling, M. Östling, Appl. Surf. Sci., **73,** 316 (1993)

[4] J. S. Chen, E. Kolawa, M.-A. Nicolet, L. Baud, C. Jaussaud, R. Madar, C. Bernard, J. Appl. Phys. **75**, 897 (1994)

[5] H. J. Goldschmidt, *Interstitial Alloys*, Butterworth & Co, London (1967), p. 97

Aluminium implantation of p-SiC for ohmic contacts

Spieß, L.(1); Nennewitz, O.(1); Weishart, H.(2); Lindner, J.(3); Skorupa, W.(2); Romanus, H.(1); Erler, F.(1); Pezoldt, J.(4)

(1) Technische Universtät Ilmenau, Institut für Werkstoffe, PF 0565 ; **D-98684 Ilmenau**, Germany
(2) Forschungszentrum Rossendorf e.V.; PF 510119; **D-01314 Dresden**, Germany
(3) Universität Augsburg, Institut für Physik; Memminger Str. 6; **D-86135 Augsburg**, Germany
(4) Technische Universtät Ilmenau, Institut für Festkörperelektronik, PF 0565 ; **D-98684 Ilmenau**, Germany

SiC is a prospective material for electronic devices in future, but many problems still have to be solved. An important problem is the formation of low resistance ohmic contacts, especially for p-type SiC. One possibility to reduce contact resistance is the implantation of p-dopands into SiC. Up to now, no detail investigations of the formed layer structure were carried out.

It is impossible to produce an enhancement p-type contact in SiC. No metal or metal like material with a workfunction of about 6 eV is known. Fig.1 shows the theoretical band bending that occur in metal-semiconductor contact. This shows the existence of a Shottky barrier Φ_{Bn}. If no other effects influence the metal-semiconductor contact, one can ideal write $\Phi_{Bn}=\Phi_S-\Phi_m$. All known metals produce depletion p-type contacts in p-type SiC. A depletion zone of holes is observed on the interface. To obtain ohmic contacts the depletion zone has to be decreased. This is achieved e. g. by p-dopand implantation of the near surface on semiconductor. We will report on experiments using ion implantation of Al for doping. The implantation dosage ranged from $1*10^{13}cm^{-2}$ to $5*10^{15}cm^{-2}$ with an implantation energy of 50 keV. The annealing was performed at 1650°C for 20 min. in Argon atmosphere. Metallization was performed using Al/Ti contacts.

The estimated barrier heights ranged between 0,65 eV and 0,52 eV. The implanted samples (dose $>1*10^{14}cm^{-2}$) have an idiality factor $n>1$ (ohmic). Thus, no barrier height could be estimate.

An other aim was to study structural and chemical evolution of the surface, the interface and the SiC bulk after implantation, annealing and contact formation. Complex solid state analysis methods like Atomic Force Microscopy (AFM), Reflection of High Energy Electron Diffraction (RHEED), Transmission Electron Microscopy (TEM) and Rutherford Backscattering (RBS) were used.

Fig. 2 shows the surface after annealing. The roughness R_a is 0,46nm, the maximum height is 4,2 nm. Fig. 3 shows the RHEED pattern after annealing. It resumes to be a perfect 6H SiC surface. The TEM image shows a perfect surface, but in a region of 30nm under the surface some damage was found. In TEM and AFM investigations a step formation due to the annealing procedure was observed.

These investigations show that it is possible to obtain good ohmic contacts on p-type SiC material ($\rho_c < 5*10^{-4}\Omega cm^{-2}$) without introducing substantial damage to influence the interface behaviour of the SiC semiconductor.

This work was supported by the BMBF under contract No. 01 BM 303/8. The authors would like to thank SIEMENS Erlangen for the annealing.

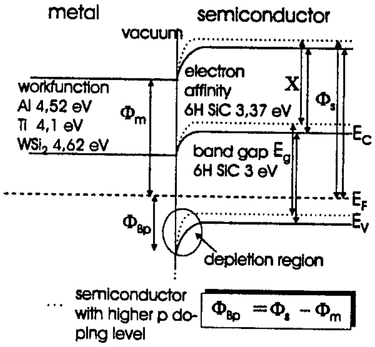


Fig. 1: band model

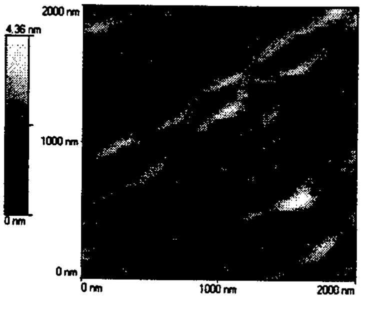


Fig. 2: AFM-Topographie

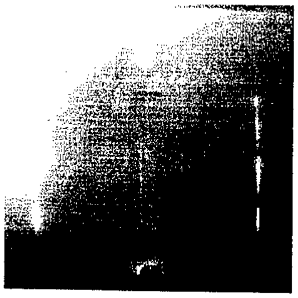


Fig. 3: RHEED pattern 6H SiC

Tel.: +49-3677-693234 Fax.: +49-3677-693171 E-mail: Lothar.Spiess@e-technik.tu-ilmenau.de

FABRICATION OF HIGH-QUALITY OXIDES ON SIC BY REMOTE PECVD

A. Gölz, R. Janssen, S. Groß, E. Stein von Kamienski, and H. Kurz
Institut für Halbleitertechnik, Lehrstuhl II, RWTH Aachen, Sommerfeldstr. 24, D-52074 Aachen

Thermally grown SiO_2 on silicon carbide is currently used as gate insulator in SiC based MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistor). An alternative method for oxide fabricaton is plasma enhanced chemical vapor deposition with much higher growth rates. These are of interest for the fabrication of thick field oxides, too. A plasma chamber similar to that described in ref. [1] was built up, where the SiH_4 is not subjected to direct plasma excitation; to prevent surface damage the specimen are located outside of the plasma generation region in the so-called after-glow area.

Commercially available (CREE Research, Inc.) Si-faced n- and p-type 6H-SiC epilayers (doping $\approx 1 \times 10^{16}\,\mathrm{cm}^{-3}$) on 6H-SiC substrates are used. After cleaning in acetone and by a standard RCA-clean the samples are dipped for 10 s in buffered HF solution and rinsed in DI-water. After that they are placed in the chamber where base pressure is 2×10^{-6} Pa. At first, a plasma-assisted precleaning in hydrogen or oxygen takes place determining the surface. After that an oxide layer of $\approx$ 25–30 nm is deposited. Both processes take place at 200 °C and at a pressure of 33 Pa. The gas flows are 100 sccm Ar, 10 sccm O_2 or H_2, 10 sccm 1% SiH_4 in Ar. Some samples are annealed in a quarz tube in different gas ambients. Finally, they are metallized with aluminum and patterned into MOS-capacitors with 0.4 mm diameter.

High-frequency capacitance-voltage (HFCV) measurements at room temperature are used to characterize the MOS-capacitors. Results are shown in figure 1. Concerning n-type 6H-SiC, after the deposition the CV-curve shows a shift towards positive voltages indicating a considerable density of oxide charges (interface states and fixed oxide charges). The quite large hysteresis indicates a high number of slow interface traps. However, after annealing in inert gas (Ar or N_2, 1150 °C) the CV-curve is shifted towards zero and becomes steeper. This reveals a decrease in oxide defects. From the flat band voltage an oxide charge density $N = -3.87 \times 10^{11}\,\mathrm{cm}^{-2}$ is obtained. By the Terman method we calculate the interface trap density $D_{it} = 2.3 \times 10^{11}\,\mathrm{eV}^{-1}\mathrm{cm}^{-2}$ (300 meV below the conduction band edge). The use of hydrogen instead of oxygen during the preclean slightly enhances N and D_{it}.

On p-type 6H-SiC the same process results in oxide layers which show high leakage currents, so that no CV-data can be obtained. In contrast a plasma-assisted preclean in hydrogen before the deposition reduces the leakage currents. But this is a chemically unstable state which can be destroyed by an inert gas anneal. If a forming gas (hydrogen in argon) anneal is carried out instead, CV-data as shown in figure 1 are obtained. In contrast to n-type material a large shift towards negative voltages occurs indicating an oxide charge density $N = 5.17 \times 10^{12}\,\mathrm{cm}^{-2}$. The calculated interface trap density is $D_{it} = 8.0 \times 10^{11}\,\mathrm{eV}^{-1}\mathrm{cm}^{-2}$.

The plasma-assisted two-step process (preoxidation and deposition) in a remote plasma has quite promising potentials for high quality oxides on SiC. Our results show that it is possible to fabricate oxides by RPECVD showing defect densities as low as thermal grown ones, but at much higher growth rates.

[1] G. Lucovsky Y. Ma, T. Yasuda, C. Silvestre, J. R. Hauser, Jpn. J. Appl. Phys. **31**, 4387 (1992)

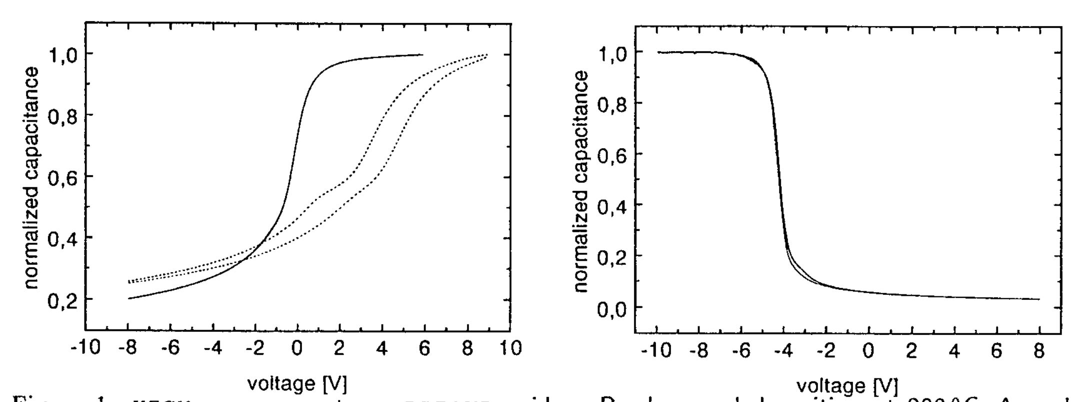


Figure 1: HFCV measurements on RPECVD oxides. Preclean and deposition at 200 °C. Annealing: 1150 °C, 50 min. Left: n-type, preclean in oxygen, dashed line: as-grown, solid line: annealing in inert gas. Right: p-type, preclean in hydrogen, annealing in forming gas.

Tuesday, October 8, 1996 15:00-16:45

POSTER SESSION (P2) : SiC-BASED DEVICE FABRICATION & CHARACTERIZATION.
SiC-RELATED MATERIALS

AN INTERFACE STUDY OF VAPOR-DEPOSITED RHENIUM WITH THE (0001) AND (000$\bar{1}$) FACES OF SINGLE CRYSTAL 6H- SiC

S. Kennou* , A. Siokou, I. Dontas and S. Ladas , Department of Chemical Engineering,
University of Patras , and FORTH- ICE/HT, P.O.B. 1414, GR-26500 ,Rion, Patras, Greece.
Phone: 061-997631 and 061-997856 FAX: 061-993255

Single-crystal silicon carbide surfaces are potential candidates for high-temperature device applications. In particular, metal/SiC contacts and the resulting Schottky barriers are important for such SiC-based devices. Although a number of studies appeared in the last years concerning the Schottky contact formation of many metals with SiC at room temperature, only very few have studied the effect of annealing at higher temperatures on the stability of the metal contact on SiC. Rhenium is a good candidate for such stability at high temperature because it does not react with SiC up to 1100°C as shown by recent studies of Re films, up to 300nm thick, on n-type β-SiC(001) [1] . On the basis of this thermodynamic inertness one would expect that the electrical behaviour of the Re contact on SiC would be stable with heat treatment, however changes are observed above 500°C which are attributed to minute changes at the interface [1] . In this work , we studied the early stages of the Re/SiC interface formation and its thermal stability on the two polar faces of single crystal n-type 6H-SiC, the (0001) (Si-rich) and the (000$\bar{1}$) (C-rich), using X-ray photoelectron spectroscopy (XPS), work function (WF) measurements and low energy electron diffraction (LEED). Rhenium was evaporated in ultra-high-vacuum (UHV) near room temperature onto the specimens ,which were mounted together on the sample holder, at gradually increasing coverages up to a thickness of about 2nm and then the specimens were annealed at gradually increasing temperature up to about 800°C. After each deposition or annealing interval XPS, WF and LEED measurements were carried out. Both clean substrates exhibited a 1x1 hexagonal LEED pattern which was more intense for the C-face . The latter exhibited a Si2p/C1s XPS intensity ratio of 0.8 compared with 1.1 for the Si-face. Both faces exhibited a small O1s peak in the XP spectrum and the Si2p photopeak exhibited only traces of an oxidized component . The deposition of Re caused a WF increase up to the point where the film became metallic, whereas the LEED pattern became weaker with increasing coverage, especially for the Si-face, without the appearance of any new spots. The Si2p and C1s substrate peaks were attenuated by Re deposition and exhibited only a minute shift of about 0.15eV towards smaller binding energies, from which we estimated a Schottky barrier height below 1 eV for both faces. The Re4f7/2 peak binding energy decreased during Re deposition from about 41.1eV below monolayer coverage, to 40.6eV for a 2nm film, indicating an island growth of the film. Annealing of the deposited films up to 800°C did not cause any shift in the Si2p and C1s substrate peaks indicating that the Schottky barrier height remained constant ,therefore no pronounced reaction between SiC and Re occurred at the interface. However , the Si2p peak at the highest annealing temperature exhibited traces of a lower binding energy component which could have resulted either from elemental Si or $ReSi_2$. The effect was more pronounced on the Si-face which also exhibited a new C1s component at higher binding energy corresponding to free carbon. In both faces annealing caused a significant increase in the intensity of the substrate peaks, whereas the WF decreased by a small amount. These results can be interpreted as due to the coalescence of the film into larger particles leading to partial exposure of the substrate. The latter is supported by LEED which after annealing exhibits again a 1x1 pattern. In conclusion, although annealing of the Re films up to 800°C on both faces leads to Re particle coalescence without affecting the low Schottky barrier at the interface , there are indications of chemical changes on the Si-face which could affect the electrical characteristics of the contact.

[1] J.S.Chen, A.Bächli,M.-A.Nicolet, L.Baud, C.Jaussaud and R.Madar, Materials Science and Engineering B29 (1995) 185

---

* Permanent address: Physics Department, University of Ioanninna, P.O.B. 1186, GR-451 10
Ioannina, Greece

TEM STUDY OF Ni AND Ni_2Si OHMIC CONTACTS TO SiC

B. Pécz, G. Radnóczi, G. Vincze, S. Cassette*, C. Brylinski* and C. Arnodo*

Research Institute for Technical Physics PO Box 76, H-1325 Budapest, Hungary, phone: 36-1-1698-961, fax: 36-1-1698-037, E-Mail: pecz@mufi.hu
* THOMSON-CSF/Laboratoire Central de Recherches, Domaine de Corbeville 91404 Orsay Cedex France

Ni layer with a thickness of 150 nm was deposited onto 4H-SiC substrate by high vacuum electron beam evaporation. As-deposited and annealed samples have been studied by cross-sectional TEM (Transmission Electron Microscopy).

The as-deposited Ni layer is homogeneous in thickness and it exhibits a smooth surface. The Ni layer is of polycrystalline structure showing a (111) type texture.

The contact layer of the sample annealed at 950 °C exhibits a large number of voids (Kirkendall voids) and is substantially increased in thickness. A large number of voids are shown to be present at the original interface. When the layer was EDS analyzed quantitative measurements showed a 2:1 Ni:Si proportion which indicates that the Ni layer reacted with SiC during the annealing and this resulted in a polycrystalline nickel silicide layer. Although the contact is ohmic with a specific contact resistivity of $3x10^{-6}$ Ωcm^2 the creation of large number of voids during the ohmic contact formation should be avoided.

Due to the solid phase reaction during annealing SiC decomposed at the top region of the substrate. The excess carbon can be traced everywhere within the reacted layer by Auger depth profiling, while some carbon atoms were segregated to the specimen surface from the top region. The presence of large number of voids within the layer suggests that carbon is segregated to the surface of the voids. This excess carbon content of the contact layer is also a potential factor of instability.

Ni and Si layers with the nominal composition of 2Ni: 1Si have been deposited onto SiC. The idea was to prepare Ni_2Si contacts without a strong reaction between the substrate and the contact layer. After annealing the contact layer is free from voids, however, there are a few voids at the contact/substrate interface. The contact layer transformed to δ-Ni_2Si orthorhombic phase as it was identified by several electron diffraction patterns. The specific contact resistance of the Ni_2Si layer is higher with one order of magnitude than in the case of pure Ni contacts. From this point of view further optimization is necessary.

This work was supported by the COPERNICUS project No. CP940603.

DETERMINATION OF OHMIC CONTACTS TO N-TYPE 6H- AND POLYCRISTALLINE SiC USING CIRCULAR TRANSMISSION LINE STRUCTURES

J. Kriz, K. Gottfried, Ch. Kaufmann, T. Geßner
Zentrum für Mikrotechnologien, Technische Universität Chemnitz - Zwickau, 09107 Chemnitz, Germany;
Tel.: +49 371 531 3656; Fax.: +49 371 531 3130; email: kriz@infotech.tu-chemnitz.de

Ohmic contacts to both polycristalline 3C and single crystalline 6H - SiC have been studied using two different circular transmission line models. The CTLM is an often used method because of its simple technology. With respect to a possible high temperature application tungsten and titanium-tungsten (10/90 vol%) were investigated. These materials were chosen because of their high melting points and their thermal stability [1]. This work has two aims: In the first part the two different CTLM's will be presented and compared and in the second part both will be applied to measure the specific contact resistance between SiC and both tungsten and titanium-tungsten. Investigation of contacts to tungsten disilicide are currently under progress and will be presented.

The two different models are the one by Reeves [2] and the one by Marlow and Das [3]. They are varying in their arrangements of the contact pads (see figure 1). In the model of Reeves several rings with the same centre point are used. This causes an outmost contact with a very large circumference. It allows a contact end resistance measurement which was proposed by Reeves to distinguish the sheet resistance within and without the contact area. On the other hand in the model of Marlow and Das several pairs of contacts are lined up. These pairs of contacts differ in the spacing from each other. The inner contact stays equal in each measurement and therefore contact resistance increases with the spacing.

In the second part of the presentation the results of both methods will be presented. Because of the lower bandgap both contact materials show ohmic behaviour after deposition on the polycristalline SiC. The specific contact resistivity is in the range of 1...2 x10^{-4} Ωcm^{-2} for both materials. After annealing this value improves further. In case of the 6H-SiC the contacts show also ohmic behaviour after annealing.

Literature

[1] J. Kriz, K. Gottfried, T. Scholz, C. Kaufmann, T. Geßner to be presented at the EMRS Spring Meeting, Symposium A, Strasbourg, June 1996
[2] G.K. Reeves, Solid State Electronics, Vol. 23, No. 2, pp. 487-490, 1980
[3] G.S. Marlow and M.B. Das, Solid State Electronics, Vol. 25, No. 2, pp. 91-94, 1982

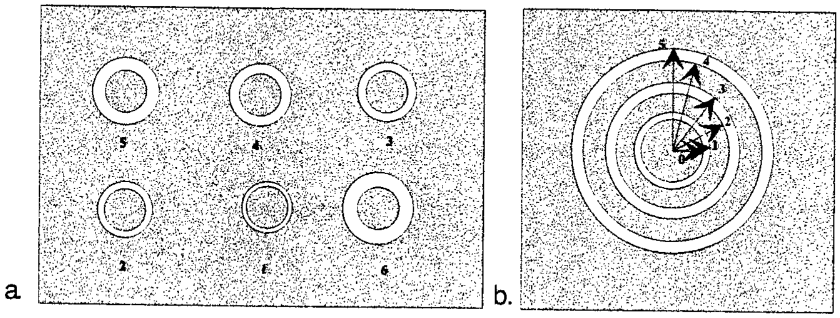


Figure 1: **a. CTLM by Marlow & Das d = 5... 30µm**
b. CTLM by Reeves r_0 ....r_5 = 80 ....400µm

ION BEAM ASSISTED DEPOSITION OF A TUNGSTEN COMPOUND LAYER ON 6H-SILICON CARBIDE

H. Weishart, W. Matz and W. Skorupa
(Forschungszentrum Rossendorf e.V., Institut für Ionenstrahlphysik und Materialforschung, Postfach 510119, D-01314 Dresden, Germany, Tel +49 351 260 3345, Fax +49 351 260 3411)

Silicon carbide is presently one of the most promising materials for high-temperature semiconductor devices because of its superior properties such as high thermal conductivity, high electron mobility and wide bandgap [1 , 2]. High temperature devices, however, are in need of a reliable metallization for their working temperature of up to 700°C. A proper ohmic contact should have a low resistivity, good adhesion to the underlying SiC, as well as a high stability at elevated temperatures for more than 1000 hours. Contacts that meet all of these requirements are either layered structures consisting of a reactive metal to ensure adhesion, a diffusion barrier and a low resistivity metal, or highly temperature stable low resistivity materials. A promising material of the latter class is tungsten carbide. We synthesize a W-based compound layer on 6H-SiC by tungsten deposition and high dose ion implantation of C^+. We study in detail the influence of dose and annealing on composition and structure of the synthesized layer.

Deposition of W and implantation of 30 keV C^+ were performed at room temperature. The mean projected range for this energy according to TRIM is 51 nm. Wafers of single crystal n-type 6H-SiC from Cree Research, Inc. served as substrates. We chose two different doses for the first experiments, namely 2.5×10^{17}cm^{-2} and 5.0×10^{17}cm^{-2}. Subsequently, the samples were given an anneal at 950°C and 1100°C for 30 min. Investigation of the W profile and stoichiometry of the synthesized layers was made by Rutherford Backscattering Spectrometry (RBS) of 1.2 MeV He^+. In addition, Auger electron spectroscopy (AES) in combination with sputter depth profiling during sample rotation was performed using a 3 keV Ar^+ beam at an incidence angle of 54° to the surface normal. The AES spectra of crystalline Si, 6H-SiC, WSi_2 and WC were taken as references to characterize chemical states of the elements. X-ray diffraction (XRD) with gracing incidence was employed to determine the crystalline phases.

The RBS spectra of the as-implanted samples indicate that sputtering of the surface during implantation becomes significant for doses in excess of 2.5×10^{17} C^+cm^{-2}. The lower dose of 2.5×10^{17}cm^{-2} produces an 80 nm thick tungsten rich layer. The W peak for a dose of 5.0×10^{17} cm^{-2} is strongly reduced indicating only a thin tungsten rich layer. Thus, in the end the amount of retained tungsten is reduced. The depth profiles of the elements affirm a stronger intermixing after high dose implantation. X-ray diffraction shows that crystalline phases are formed after annealing. Auger depth profiling of unannealed and annealed samples reveals the formation of tungsten carbide and tungsten silicide. The comparison of the C KVV and the Si KLL line shapes with reference spectra of 6H-SiC, WSi_2 and WC demonstrates clearly the depth dependent chemical states of Si, W and C. According to the work of Geib et al. [3] the abundance of defects present after implantation is responsible for an enhanced spontaneous formation of tungsten silicide and carbide even without annealing.

Resistivity measurements using the four point probe technique are underway.

---

1 . W.E. Nelson, F.A. Halden and A. Rosengreen, J. Appl. Phys. **37**, 333 (1966).

2 . G. Pensl and R. Helbig, Festkörperprobleme/Advances in Solid State Physics **30**, 133 (1990).

3 K.M.Geib, C. Wilson, R.G. Long, and C.W. Wilmsen, J. Appl. Phys. **68,** 2796 (1990).

HAFNIUM , CADMIUM AND INDIUM IMPURITIES IN 4H-SIC OBSERVED BY PERTURBED ANGULAR CORRELATION SPECTROSCOPY

T. LICHT, N. ACHTZIGER, D. FORKEL-WIRTH*, J. GRILLENBERGER,
K. FREITAG**, M. KALTENHÄUSER, U. REISLÖHNER, M. RÜB,
M. UHRMACHER***, W. WITTHUHN and ISOLDE COLLABORATION*

Institut für Festkörperphysik der Friedrich-Schiller-Universität Jena, D-07743 Jena, Germany
* CERN/PPE, CH-1211 Geneva 23, Switzerland
** Institut für Strahlen- und Kernphysik der Universität Bonn, D- 53115 Bonn, Germany
*** 2. Physikalisches Institut der Universität Göttingen, D-37073 Göttingen, Germany

Address:

Thomas Licht
Friedrich-Schiller-Universität Jena
Institut für Festkörperphysik
Max-Wien-Platz 1
D- 07743 Jena
Germany

Telephone: ++ 49 3641 / 63 58 21
Fax: ++ 49 3641 / 63 58 54
e-mail: licht@pinet.uni-jena.de

Abstract:

The annealing behaviour of hafnium impurities in silicon carbide after ion implantation and the formation and stability of complexes of hafnium in 4H-SiC have been studied by Perturbed Angular Correlation Spectroscopy (PAC) for the first time. This nuclear technique is based on the time differential detection of an anisotropic radiation pattern of a γ-γ cascade and enables the observation of the impurity interaction on a microscopic scale. The PAC spectra reveal the electric filed gradient (EFG) acting on the probe nucleus. Each EFG is a characteristic fingerprint of a specific lattice environment of the probe atom or a trapped defect.

Samples of 4H- silicon carbide single crystals were doped with radioactive ^{181}Hf ($t_{1/2}$ = 42.5d) by ion implantation with an implantation energy of 160 keV at the ion separator of the university of Bonn. The samples were annealed at temperatures between 800K and 1800K. After each annealing step a PAC measurement was taken at room temperature. Already after the first annealing step at 800K an axially symmetric EFG oriented along the c-axis of the crystal with a quadrupole coupling constant ν_Q = 610 (3) MHz was observed. The fraction of probe atoms exposed to this EFG increases with the annealing temperature. At 1700K almost 30% of the probe atoms observe this EFG. The coupling constant of this EFG changes with the measuring temperature (from 620 MHz at 77K to 550 MHz at 1200K), while the orientation and asymmetry parameter are constant.

These results are compared to PAC measurements performed at the $5/2^+$ level of ^{111}Cd, which is populated either by electron capture of ^{111}In or by the isomeric transition of ^{111m}Cd. Up to three EFGs showing c-axis orientation are observed in 4H-silicon carbide after ^{111}In implantation, only one of them occurs at the low annealing temperature of 800K. The annealing behaviour and the temperature dependance of this EFG are comparable to the behaviour of the EFG measured after hafnium implantation.

NUCLEAR TRANSMUTATION DOPING OF 6H - SIC WITH PHOSPHOROUS

Hans Heissenstein, Christian Peppermüller and Reinhard Helbig
Institute of Applied Physics, University Erlangen-Nürnberg
Staudtstr. 7, A3, D-91058 Erlangen, Germany
Phone +49 9131 85 8428, fax +49 9131 85 84 23

ABSTRACT

Semiconductor materials for power electronic devices must be doped homogeneous.
Almost homogeneous doping by ion - implantation implies sophisticated multiple steps using different energies. Whereby the depth of doping is restricted to surface near layers.
In silicon technology the nuclear transmutation doping is a standard process for getting homogeneous n- type material.

We irradiated p - type 6H - SiC consisting of a p^- - epilayer ($N_A - N_D \approx 5.2 * 10^{15}$ cm^{-3}) on a p^+ - bulk ($N_A - N_D \approx 10^{18}$ cm^{-3}) with neutrons of a moderated reactor spectrum. The total neutron flux was between $9 * 10^{19}$ cm^{-2} and $6* 10^{20}$ cm^{-2} to get a concentration of $10^{16}cm^{-3}$ to $10^{17}cm^{-3}$ of the phosphorous isotop of mass 31. By measuring the β^- - decay the concentration of the transmuted silicon nuclei was controlled (uncertainty factor ≈ 2).

Since phosphorous is a donor in SiC the basic idea is to create a p-n junction. Based on an electrical activity of the phosphorous of 100 percent the epilayers of our samples are doped with $N_D - N_A \approx 10^{16}$ cm^{-3}, $5* 10^{16}cm^{-3}$ and $10^{17}cm^{-3}$.

The high purity of our samples is manifested by an unexpected low radioactive radiation after neutron irradiation.
We have further investigated the decrease of the radiation defects with rising annealing temperature by various methods. Thus phosphorous-correlated effects and radiation defects can be distinguished.
The irradiated 6H - SiC is black coloured and begins to recover visible transmission at annealing temperatures above 1000°C depending on the total neutron flux.

FTIR- Spectroscopy shows the reststrahlen - peak recovering with annealing temperatures less than 1400°C. The IR - transmission recovers in the same scale apart from the energy - range higher than 300meV.

Low - Temperature - Photoluminescence spectra show the radiation induced D_1 - complex with intensity ratios of the L_1, L_2 and L_3 lines differing from the ion - implanted case.
The electrical properties of the samples are evaluated by CV - and Hall - effect measurements.

INVESTIGATION OF THE EFFECTS OF HIGH TEMPERATURE IMPLANTATION AND POST IMPLANTATION ANNEALING ON THE ELECTRICAL BEHAVIOR OF NITROGEN IMPLANTED β-SIC FILMS

W. Reichert, R. Lossy, M. González Sirgo, E. Obermeier, and W. Skorupa*

Technical University of Berlin, Department of Electrical Engineering,
Microsensor and Actuator Technology Center, Sekr. TIB 3.1,
Gustav-Meyer-Allee 25, D-13355 Berlin, Germany
Tel.: +49 - 30 - 314 72 539, Fax: +49 - 30 -314 72 603

*FZ Rossendorf, POB 510119, 01314 Dresden, Germany
Tel.: +49 - 351 - 591 36 12, Fax: +49 - 351 - 591 32 85

Ion implantation is a very accurate way to intentionally introduce dopants into a semiconducting material. In the case of SiC the implantation process must occur at elevated temperatures or post implantation annealing needs to be done to obtain the necessary electrical activation. The effects of both ways of thermal treatment on the electrical behavior of nitrogen implanted β-SiC films were investigated during this work. Therefore the implantations were performed at different temperatures and one set of the samples was electrically characterized without having had a post implantation thermal treatment while the other set was annealed at T = 1200°C before the electrical measurements were done.

The implantation of nitrogen into p-type β-SiC was performed in a wide temperature range between room temperature and T = 1200°C. The implantation dose and implantation energy were $5 \cdot 10^{14}$ cm^{-2} and 50 keV, respectively.

Secondary Ion Mass Spectroscopy (SIMS) was used to characterize the implantation profiles. The results show little influence of the implantation temperature on the doping profiles of the implanted samples.

However, the electrical behavior of the as-implanted β-SiC films (no post implantation annealing took place) strongly depends on the implantation temperature. Temperature dependent resistivity and Hall measurements using van der Pauw structures (5x5 mm^2) were made and the resistivity, mobility, and free carrier concentrations in the temperature range between T = -190°C and T = 450°C were determined. The results show an increasing electrical activation with increasing implantation temperature.

To investigate the effect of thermal post implantation treatment on the electrical behavior a second part of the whole set of samples was annealed at the highest implantation temperature of T = 1200°C for 1 hour. Resistivity and Hall measurements were done on the annealed samples. The results show an increase in the electrical activation and the mobilitity values of the implanted films after the thermal treatment.

Since the same series of implanted samples was characterized with and without post implantation thermal treatment, direct comparison of the effects of high temperature implantation and post implantation annealing on the electrical behavior of nitrogen implanted β-SiC was possible. The results show that even if the implantation process took place at high temperatures a post implantation annealing step is favorable since higher electrical activation and higher electron mobilities are obtained.

β-SIC FILMS ON SOI SUBSTRATES FOR HIGH TEMPERATURE APPLICATIONS

W. Reichert, E. Obermeier, and J. Stoemenos*

Technical University of Berlin, Department of Electrical Engineering,
Microsensor and Actuator Technology Center, Sekr. TIB 3.1,
Gustav-Meyer-Allee 25, D-13355 Berlin, Germany
Tel.: +49 - 30 - 314 72 539, Fax: +49 - 30 -314 72 603

*Aristotle University of Thessaloniki, Physics Department,
54006 Thessaloniki, Greece
Tel.: +30 - 31 - 998 191, Fax: +30 - 31 - 214 276

For the development of micromechanical devices single crystal β-SiC films deposited on Si substrates offer the advantages of the high bandgap material SiC and the advanced micromachining technology of Si. However, since the SiC/Si-heterojunction starts leaking at temperatures around 150°C, which results in a current flow through the Si substrate, the high temperature potential of SiC cannot be fully exploited. By deposition of β-SiC on SOI (Silicon On Insulator) substrates both advantages can be utilized allowing the fabrication of micromechanical devices for high temperature applications.

First experiments with such a SiC On INsulator (SiCOIN) technology were very promising. The SOI substrate used for β-SiC deposition was a SIMOX (Separation by IMplantation of OXygen) wafer. The SIMOX wafer consisted of a 200 nm thick Si overlayer which was separated from the bulk Si by a 370 nm thick, implanted, buried oxide layer. Therefore the growth of the SiC layer started on Si as is the case with regular SiC deposition on Si substrates. This resulted in a crystal quality of the SiC layer comparable with the single crystal quality obtained with SiC films deposited on Si substrates. The SiC/SIMOX system offered a maximal operating temperature of approximately 150°C higher than the SiC/Si system. The maximal operating temperature of this material system was limited by the insulating capability of the buried oxide. The SiO_2 layer was damaged during β-SiC deposition and cavities extending from the Si overlayer to the buried oxide were visible under the TEM.

To further increase the maximal operating temperature of SiC/SOI based test structures SOI substrates with a 200 nm thick Si overlayer and a 400 nm thick, bonded oxide layer have been used for β-SiC deposition. 2 μm thick, n-type β-SiC layers have been deposited by CREE Inc., USA on the (100)-oriented UNIBOND wafers obtained from SOITEC, France. The β-SiC deposition took place under standard conditions and at deposition temperatures of 25°C and 50°C below standard deposition conditions to investigate the influence of the deposition temperature on the damage of the buried oxide layer and therefore the insulating properties of that layer.

Transmission electron microscopy (TEM) was used for structural analysis of the deposited β-SiC films and resistivity and Hall measurements with 5x5 mm^2 van der Pauw samples have been performed in the temperature range between T = -190°C and T = 450°C to electrically characterize the SiC/SOI system. Ohmic contacts were made by sputtering Al to the SiC layer and annealing of the contacts at 450°C in a nitrogen atmosphere for 30 minutes. The room temperature values for the resistivity, free carrier concentration, and mobility were $\rho = 2.2 \cdot 10^{-2}\ \Omega cm$, $N_D = 2.9 \cdot 10^{18}\ cm^{-3}$, and $\mu = 99\ cm^2/Vs$, respectively. The temperature dependent characterization shows SiC-like behavior (no effect of current flow through the Si substrate) in the full temperature range up to 450°C.

The presented SiCOIN material system offers the possibility to utilize the high temperature capability of SiC and to make use of the well-developed Si micromachining technology. The current upper limit for the operating temperature (T = 450°C) was set by the limit of the test equipment and not by the quality of the samples.

SURFACE CHEMISTRY OF 6H-SiC AFTER REACTIVE ION ETCHING

N. Sieber, M. Hollering, A. Ziegler, R. Graupner, L. Ley
(Universität Erlangen, Institut für Technische Physik II, Erwin-Rommel-Str.
1, 91058 Erlangen, Tel. +49 9131/85-7080, Fax: +49 9131/85-7889)

We report phototemission measurements on plasma treated C-terminated 6H-SiC surfaces with the intention to elucidate some of the surface chemistry responsible for the etching process.

A parallel plate type reactor with capacitive coupling of the rf-power (13.56 Mhz) was used in conjunction with CHF_3+O_2 as the etch gas. The highest etch rate of 100 nm/min was obtained with the sample placed on the cathode and a CHF_3:O_2 ratio of 4:1, a flow rate of 10 sccm and pressure and rf-power of 50 Pa and 100 W, respectively. Under these conditions the sample attained a self bias of about -700V. The etch rate drops to 3 to 4 nm/min under the same conditions if pure CHF_3 is used.

X-Ray (Al-K_α 1486.6 eV) induced core level photoemission spectra of etched in pure CHF_3 surfaces are indicative of a surface rich in hydrogenated and fluorinated carbon with only a few percent of silicon and oxygen. Heating the samples in ultra high vacuum up to about 1000°C removes virtually all of the surface fluorine and hydrogen, leaving a carbon rich surface.
The addition of oxygen leads in all cases (as prepared and after heating) to a substantial (about 10at%) oxygen contamination.

The best results are obtained if the CHF_3:O_2 etch is followed by a CHF_3 etch and subsequently a plasma treatment in pure H_2. This yields after heating at 950°C a stoichiometric SiC surface with only minimal oxygen contamination. The surface so prepared is partially ordered as witnessed by a (1x1) LEED pattern that can be observed down to at least 40 eV electron energy.

PREFERENTIAL ETCHING OF SiC CRYSTALS

R. Yakimova[1,2], A.-L. Hylén[1], M.Tuominen[1], M. Syväjärvi[1], and E. Janzén[1]

[1] Dept. Physics and Measurement Technology, Linköping University, S-581 83 Linköping, Sweden
[2] Outokumpo Semitronic AB, S-161 11 Bromma, Sweden

Linköping University, Dept. Physics and Measurement Technology, S-58183 Linköping, Sweden
Phone: +46 13 28 25 28; Fax: +46 13 14 23 37; e-mail: roy@ifm.liu.se

Silicon carbide (SiC) is a very attractive material for semiconductor devices working at extreme conditions. High inter atomic bonding energy makes it temperature stable and chemically inert. However difficulties arise when processing SiC because of its outstanding stability. For instance, SiC can not be etched in chemical solutions that are commonly used to attack preferentially the conventional semiconductors, e.g. Si, GaAs, etc. This is especially important for revealing structural imperfections in SiC crystal obtained via sublimation growth method which is known to result in rather high density of structural defects.

Molten KOH (T>450°C) is most frequently applied to achieve preferential etching of SiC crystals. However very little has been reported about the etching process and the effect of the etching conditions on the etch patterns produced. In this work an investigation of the etch rate and etch pit appearance of SiC treated by molten KOH has been carried out at different temperatures. Sublimation grown SiC crystals have been examined and the results have been analysed with respect to the growth conditions.

It has been observed that molten KOH attacks both Si- and C-terminated faces but the etch pits appearance is different. In particular, the micropipe related hexagonal openings are larger on the Si face. The etching time dependence of the micropipe size is linear for the Si-face and sublinear for the C-face which suggests different etching mechanism. On the Si-face hexagonal patterns are found on threading micropipes, deep (40μm) and shallow (10μm) microcavities. Some micropipes are observed to follow grain boundaries whereas some split, presumably into partial dislocations, and thus changing their directions. The total etch rate (both sides etched) is determined to be ~2.6 μm/min at about 500°C and it is exponentially dependent on the temperature. The weight loss and its temperature dependence is determined as well. The apparent activation energies of the etching process derived from the Arrhenius plots are quite similar, being about 50 kJ/mole. This value is much above the energy cited for a diffusion limited etching of the conventional semiconductors.
X-ray photoelectron spectroscopy analysis of SiC etched surfaces has been performed and the chemistry of the etching has been discussed.

SCHOTTKY BARRIER CONTACTS ON REACTIVE ION ETCHED 6H-SiC

G. Constantinidis[1] K. Tsagaraki[1], M. Androulidaki[1] and J. Kuzmik[2]

[1] Foundation for Research and Technology-Hellas, Institute of Electronic Structure and Laser,
P.O. Box 1527, 711 10 Heraklion, Crete, Greece, Tel.: +30-81-239779, Fax: +30-81-239735

[2] Institute of Electrical Engineering, Slovak Academy of Sciences, Dubravska cesta 9, 842 39
Bratislava, Slovakia

Dry etching remains the main practical technique for SiC removal for device fabrication using conventional photoresist techniques. Reactive Ion Etching (RIE) of SiC is performed with either fluorine-based gases such as CF_4/O_2, SF_6, CHF_3/O_2, $CBrF_3$ and CCl_2F_2 or chlorine-based gases such as CCl_4/O_2.

In this work Schottky contacts on RIE etched α-SiC were compared to reference Schottky contacts on non etched α-SiC. SiC RIE etching was performed on monocrystalline 6H α-SiC samples with CF_4/H_2-based gas mixtures to a depth of 150nm.

Scanning Electron Microscopy (SEM) was employed to investigate the morphology of the etched surfaces. Fourier Transform-Infra Red Spectroscopy was conducted for further examination of the smoothness of the etched surfaces. Auger-electron spectroscopy was used to analyze the etched surfaces.

Cr/Au ohmic and Pt/Au Schottky contacts were fabricated. C-V and I-V measurements were used for Schottky diode characterization. From C-V measurements a donor concentration of 7×10^{17} cm^{-3} and comparable capacitances were obtained for contacts on etched and non-etched surfaces. Thus, no RIE-related free carrier compensation or passivation effects were observed.

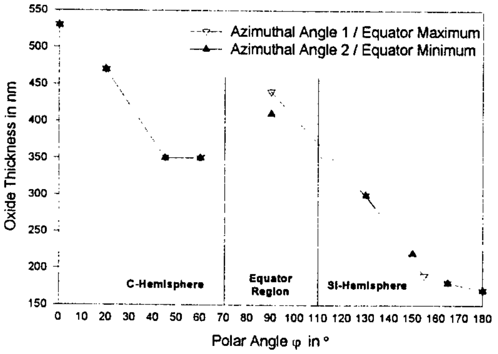
Subsequent rapid thermal annealing treatments drastically affected the diode characteristics. The optimum value for the ideality factor (n=1.3) and barrier height (Φ_B=1.0eV) were obtained for both etched and non-etched surfaces for annealing at 400°C. Further annealing up to 1000°C degraded the diode characteristics. This degradation was more evident for the contacts on etched surfaces. The presence of RIE-originated fluorine species on the etched SiC surface that may enhance the formation of a metal/semiconductor interfacial layer can account for it.

ANISOTROPIC OXIDATION OF 6H-SILICON CARBIDE

Kai Christiansen and Reinhard Helbig
Institute of Applied Physics, University Erlangen-Nürnberg,
Staudtstraße 7, A3, D - 91058 Erlangen, Germany, Phone +49 9131 858434, fax +49 9131 858423

Silke Christiansen , Martin Albrecht and Horst P. Strunk
Institute of Microcharacterization, University Erlangen-Nürnberg,
Cauerstraße 6, D - 91058 Erlangen, Germany, Phone +49 9131 858613, fax +49 9131 858602

The progress in SiC research in the recent years makes it possible to realize power electronic devices on SiC. A typical class of these devices are V-groove Metal Oxide Semiconductor Structures. These structures require insulating oxides on faces with crystallographic orientations other than the well investigated (0001) Si- and $(000\bar{1})$ C-faces. Consequently, we have investigated the thermal oxidation in a whole range of crystallographic orientations by oxidizing a sphere made from a 6H-SiC bulk crystal.
The wet chemical oxidation at 1100°C for 12h results in different oxide thicknesses at the various crystallographic planes already visible by different interference colors at the surface. Regions with significantly different oxidation morphology can be distinguished at the Si-hemisphere, the C-hemisphere and at the equator. Remarkable is the starshaped coloration around the (0001) Si-pole. The equator area exhibits regularly alternating 6 maxima and 6 minima in the oxide thickness. Laue diffraction patterns show that the maxima and minima emanate from the (0001) pole in $\langle 1\bar{1}00 \rangle$ direction and $\langle 11\bar{2}0 \rangle$ direction respectively.
We use Rutherford Backscattering Spectrometry (RBS) at a 2MV He^+ Van De Graaff accelerator to determine the oxide thicknesses. This method permits thickness measurements also on curved surfaces with a negligible error as long as the He^+-beam diameter is small as compared to the diameter of the sphere. We measured the oxide thicknesses on several spots of the sphere as a function of the polar angle φ. The sphere shows decreasing oxide thickness from φ=0° ($(000\bar{1})$ C-pole) to φ=180° ((0001) Si-pole) with an intermediate maximum around φ=90°(c.f. fig.). Further a slight difference as dependent on the azimuthal angles is observed.



Oxide thickness vs. polar angle for two different azimuthal angles.
On the C-hemisphere (0-90°) the oxidation is independent of the azimuthal angle and in the equator region and on the Si-hemisphere (90-180°) the oxide thickness varies with azimuthal angle.

In addition, the interfacial structure (0001) SiC and $(000\bar{1})$ SiC to SiO_2 is investigated by Cross-sectional Transmission Electron Microscopy (XTEM) and by High Resolution Transmission Electron Microscopy (HRTEM). The C-face showed a rough (on the nm scale) interface with many ripples with an amplitude of about one unit cell of 6H-SiC (15Å) and a wave length of about 20-30Å. The interface of the Si-face is much smoother and the ripples have a wave length of some hundred Å for the the same amplitude (about 15Å). The main result of that microstructural characterization is, that in our case the continuous oxidation of bilayers on large scale is not observed.

"CARBON-CLUSTER MODEL" FOR ELECTRONIC STATES AT SiC/SiO$_2$ INTERFACES

M. Bassler, G. Pensl
Institut für Angewandte Physik, Universität Erlangen-Nürnberg, Staudtstrasse 7,
D-91058 Erlangen, Germany, Phone (+49) 9131 / 85 84 - 26, Fax - 23

V. Afanas'ev
KU Leuven, Lab. voor Halfgeleiderfysica, Celestijnenlaan 200D,
B-3001 Heverlee-Leuven, Belgium, Phone (+32) 16 / 327-167, Fax -987

The electronic properties of SiC/SiO$_2$ interfaces are of great interest for the operation of MOS devices. It turns out that the lowest density of states observed at 6H-SiC/SiO$_2$ interfaces is at least one order of magnitude larger than that one at Si/SiO$_2$ interfaces. We have strong indications that this enhanced density of states is caused by residual carbon (graphite, carbon clusters) bonded at the interface.

For our investigations, we prepared (40-60)nm thick thermal oxides (dry oxidation, 1120°C) on n- and p-type SiC epilayers of different polytypes. The interface states are investigated by the capacitance-voltage technique (C-V), admittance spectroscopy (AS), constant-capacitance DLTS (CC-DLTS) and internal photoemission (IPE). AS and CC-DLTS result in the determination of energetically resolved interface state densities over the whole band gap, while IPE leads to a corresponding integral quantity.

IPE investigations show that the upper edge of the valence band of the investigated polytypes 3C, 4H, 6H and 15R is energetically fixed at 6eV below the lower edge of the SiO$_2$ conduction band. We, therefore, refer all the energies of the SiC/SiO$_2$ band scheme to the upper edge of the SiC valence band.

For 6H-SiC, we obtained an U-shaped distribution of interface states with a minimum value of approx. 1×10^{11}cm^{-2}eV^{-1} at 2eV and a maximum value close to the conduction and the valence band edge, respectively, of about 1×10^{13}cm^{-2}eV^{-1}. A special feature is observed in the lower half of the 6H-SiC band gap. Beginning at 1.5eV (4.5eV below the conduction band of SiO$_2$) the interface state density increases strongly (approximately one order of magnitude) towards the valence band up to a peak height of 1×10^{12}cm^{-2}eV^{-1} at 1eV.

We assume that carbon at the interface is the prevailing contamination that is responsible for this special feature and the general enhancement of interface states. Two possible processes may act as a source for carbon: a) residual carbon at the SiC surface, which is already present prior to the thermal oxidation and b) carbon that is trapped at the interface by the overgrowth of the thermal oxide. While the carbon contamination at the surface can partially be removed by an ultraviolet-ozone cleaning, the carbon generated during the thermal oxidation is hard to avoid. Carbon may be present at the interface in the form of graphite-like clusters and sp^2-bonded rings.

We have tested the carbon hypothesis by depositing amorphous hydrogenated carbon (a:C-H) with differing band gaps (between 0.7eV and 3.0eV adjusted by the deposition conditions) on SiO$_2$ layers. We measured the IPE signal originating from the a:C-H and observed for a carbon layer with a band gap of 3eV a strong increase of the IPE signal located at the same energy position like the special feature in the 6H-SiC band gap. This result strongly supports our hypothesis that carbon is responsible for the enhancement of the density of states at the SiC/SiO$_2$ interface. We have, therefore, proposed a "Carbon-Cluster Model", which qualitatively describes all the interfacial properties of (3C, 4H, 6H)-SiC MOS structures we have experimentally determined.

INVESTIGATION OF WALK-OUT PHENOMENA IN SiC MESA DIODES WITH SiO_2/Si_3N_4 PASSIVATION

Zoran Ovuka and Mietek Bakowski

Industrial Microelectronic Center, P O Box 1084, S 164 21 Kista, Sweden
Tel. +46 8 752 10 00
Fax +46 8 750 54 30

The high critical electric field of SiC, one order of magnitude larger than for silicon, makes it an interesting material for high voltage devices. The realization of reliable junction termination becomes at the same time more difficult. The electric field at the surface has to be reduced to values comparable to those of silicon devices as long as the same passivation schemes are used. Unless the surface electric field is reduced far enough instabilities become more pronounced as they are most often exponentially dependent on the electric field magnitude.

Instabilities in SiC-devices are usually connected with interface and passivation material characteristics like interface states and bulk trapping properties. One of the instabilities that occur is breakdown voltage drift, which is caused by redistribution of surface charges. This phenomenon is called walk-out. It can be measured either by applying a reverse bias current and record the increase of the breakdown voltage as a function of time, or apply a constant voltage and measure the decrease in leakage current as a function of time.

In the present study the walk-out of the breakdown voltage in unterminated 6H SiC mesa diodes passivated by a double layer of 1000Å SiO_2 and 3000Å Si_3N_4 [1] was investigated. The walk-out was measured for different values of the leakage current as a function of time using the Keithley SMU high voltage unit. The breakdown voltage drift was recorded during measurement intervals up to ten hours for three groups of devices subjected to different surface and oxidation treatments. The three groups of devices did either have a wet oxide or a dry oxide with a prior plasma clean with and without additional high temperature (1000°C) hydrogen etching of the SiC surface prior to oxidation. The drift characteristics of these devices are presented and compared to each other. The breakdown voltage drift is most pronounced in the diodes having wet oxide passivation. A walk-out model involving electron trapping in deep interface states or oxide traps in the interfacial region is presented. The differences in walk-out characteristics are explained by the differences in the concentration of interface traps following different treatments.

ACKNOWLEDGMENTS
The members of the Silicon Carbide Electronics Group at IMC are acknowledged for providing the samples.

REFERENCES

[1] S.M.Savage, et al, Proceedings of ESSDERC'94, 1994, pp. 753-756.

ANALYSIS OF BLOCKING CAPABILITIES OF α-SiC PLANAR P-N JUNCTIONS FOR POWER DEVICES

E. STEFANOV, L. BAILON, and J. BARBOLLA
Department of Electricity and Electronics - Faculty of Sciences, University of Valladolid,
47071 Valladolid, Spain, Fax: (+34)-83-423217, Phone: (+34)-83-423220

Due to its unique electrical and thermal properties SiC focus attention as a promising material for high power devices. The design of high voltage devices rely considerably on the design of junctions that have the necessary high voltage handling capabilities. In the last years various Junction Termination Extension (JTE) techniques such as floating metal ring, resistive Schottky barrier field plate [1,2], and mesa edge termination, have been explored for SiC devices but only 50 % of the ideal plane breakdown voltage was observed. The recent technology developments to fabricate planar devices based on 6H-SiC are encouraging [3], and the opportunity to use some of JTE technics directly from the Si tecnology becomes more and more realistic. The lake of studies in this field for α-SiC [4], makes actual the interest for theoretical considerations and numerical analysis.

The paper reports a numerical study of the effect of the junction curvature on breakdown voltage V_{BR} for cylindrical p-n junctions in α-SiC. The effect of the junction radius (X_j =0.1-10 μm), n-epitaxy layer doping ($1.10^{15} - 1.10^{18} cm^{-3}$) and thickness, and fixed interface charge density (N_f=0 - 5.10$^{12}cm^{-2}$) on V_{BR} is analyzed for a junction with a gaussian profile. The results are compared with the plane parallel junctions and the abrupt one. When studying the JTE technics we concentrate our attention on junctions with X_j=1 μm, due to the technological problems to obtain deeper junctions. Two JTE concepts are studied: 1) Field Plates (FP), and 2) Field Guard Rings (FGR). In the first concept the effect of oxide thickness d_{ox}, FP length L_{FP}, and oxide charge are analyzed in order to obtain the optimal maximum of breakdown voltage. For a non reach-through junction with Xj=1 μm, epitaxy layer doping 1,5.10^{16} cm^{-3} the maximum V_{BR}=640 V is obtained by using oxide thickness d_{ox}=0.4 μm, and FP with L_{FP}=10 μm. This technique shows an increase of some 60 % for the breakdown compared to this one for unprotected cylindric junction, and ideality coefficient in respect of the plane parallel junction is K_{id}=0.65.

The multiple FGR concept was studied by using a new effective method [5] to optimize the basic parameters, exerting influence on the breakdown capabilities: ring-to-ring spacing d_r, ring width W_r, and number of rings. A brief description of this optimization procedure is given. In result a structure with 5 FGR was optimized to give a breakdown at V_{BR}=863 V, showing an increase of 110 % of the breakdown compared to cylindric unprotected junction, and coefficient K_{id}=0.9. The widths of the rings are: 8, 4, 2, 2, and 2 μm, respectively. The lateral spread of the structure extends some 30 μm in respect of the main junction. The V_{BR} sensitivity of multiple FGR strucure is studied in respect of the fixed interface charge, and epitaxy layer thickness. The results presented in the report clearly demonstrate the superiority of the FGR concept, and also the possibility to achieve high coefficient K_{id} for shallow junctions.

The user-oriented program POWER2D [6,7] was used to analyse the breakdown behavior of the device. The simulation is based on the solution of Poisson's equation for an arbitrary 2D structure together with the calculation of the ionization integrals. The criterion for achieving breakdown voltage is when these integrals tend to unity. A special algorithm included in the program, ensures fast and automatic search of breakdown voltage. In order to model the case of multiple FGR device structure an efficient algorithm is developped. It allows to adjust automatically the quasi-Fermi potential for the floating rings using 3 updates per ring, when solving the Poisson's equation.

References

[1] M. Bhatnagar, H. Nakanishi, S. Bothra, P. McLarthy, and B. Baliga, Proc. of the 5th ISPSD, vol.5, p.89 (1993).
[2] Dev Alok and B. Baliga, Proc. of the 7th ISPSD, vol.7, 96-100, (1995).
[3] S. Sheppard, M. Melloch, and J. Cooper, IEEE Trans. on El. Devices, 41, 1257-1264 (1994).
[4] T. Wang, T. Chow, D. Brown, and M. Ghezzo, Proc. 4-th Int. Symp. ISPSD & Ics, Tokyo, p.303.
[5] E. Stefanov, L. Bailon, and J. Barbolla, submitted to Solid-State Electron. (1996).
[6] E. Stefanov and G. Charitat, POWER.2D - User's Guide, Rapport LAAS n°93306, Toulouse France, 1993.
[7] N.Nolhier, E.Stefanov, G. Charitat and P. Rossel, COMPEL, 13, (4), 771-783 (1994).

LOW FREQUENCY NOISE IN SILICON CARBIDE SCHOTTKY DIODES

L.Anghel, T.Ouisse, T.Billon*, P.Lassagne* and C.Jaussaud*

Laboratoire de Physique des Composants à Semiconducteurs (LPCS) UMR-CNRS 5531, ENSERG,
23, rue des Martyrs, 38016, Grenoble, France (tel:33 76 85 60 50 fax: 33 76 85 60 70)
**LETI (CEA-Technologies Avancées), DMITEC-CEN/G, 85X F38041, Grenoble, France*

Fabrication of high quality Schottky barriers is a key aspect for developing various silicon carbide components. Devices such as SiC MESFET's and power Schottky diodes would represent serious competitors with respect to silicon and gallium arsenide, in the field of fast power switches and high frequency/high power transistors, respectively. Owing to the relatively recent development of material quality, a detailed investigation of their properties and performance is therefore required. Noise analysis can be useful not only for improving device performance but also for gaining substantial information on the physical properties of the SiC material. The aim of this paper is to present a systematic evaluation of the low frequency excess noise in SiC 6H Ti Schottky diodes fabricated at LETI, and then to give a quantitative interpretation of the obtained data.

Experimental results are summarized below: In all cases, the ideality factor was very close to unity, and the barrier height was found to be equal to 0.93eV from varying temperature measurements. In the 1/f part of the noise spectra, the noise power spectral density of the current fluctuations is experimentally found to be $S_I(f) \sim I_F^{\beta}/f^{\gamma}$, with β ranging from 1 to 1.4 and γ being very close to 1, in qualitative agreement with data previously found for other semiconductors [1]. It will be inferred from a detailed comparison between experiment and existing models that in state-of-the-art SiC Schottky barriers, noise is most probably due to mobility fluctuations manifesting themselves in the depletion region, where carrier drift and diffusion must be taken into acount for correcting the simplest form of Richardson's equation. Neither generation-recombination noise, nor trapping and multi-step tunneling or mobility noise in the neutral part of the semiconductor agree with the experimental data. The only model to agree with experiment is that of T.G.M.Kleinpenning [1], which gives as a result of the mobility fluctuations in the depletion region:

$$S_I = \frac{\alpha I}{16\pi f}\left[\frac{kT}{q(V_D - V_1)}\right]^{5/2}\left(\frac{q}{\mu m^*}\right)^2\left(\frac{m^*\varepsilon}{\pi N_D}\right)^{1/2}$$

where α is the Hooge factor and other symbols have their usual meaning. As can be seen in Fig.1, a Log-Log plot of S_I as a function of $I/(V_D-V_1)^{5/2}$ gives straight lines for all devices. Although a plot of S_I vs I gives a power law exponent which depends on the devices (between 1 and 1.4), in the somewhat more complicated plot of Fig.1 we found an exponent very close to unity for all samples. This greatly favours Kleinpenning's model. The experimental value of α is about 3×10^{-3}, a usual order of magnitude owing to the doping level (10^{17}cm^{-3}) and the impurity scattering. Hence, one can conclude that SiC Schottky diodes are probably very conventional devices from the point of view of defect density. GR noise is certainly drastically reduced, due to the wide band gap, as well as trap densities near the barrier. This contrasts with other interfaces which can be built on SiC, such as thermal or deposited oxides. In addition to the noise results, we will also report detailed data and interpretation of the reverse and forward current as a function of temperature.

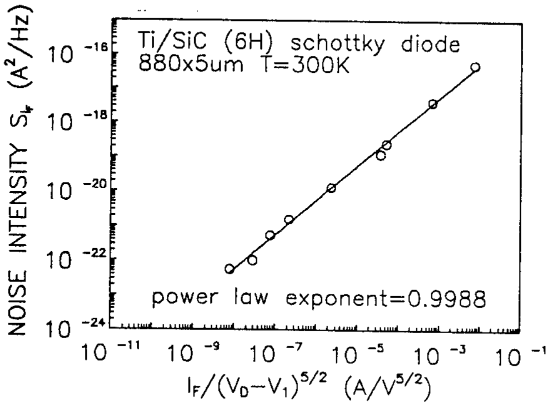


***Fig.1:** noise level at 1Hz vs $I/(V_D-V_1)^{5/2}$*

[1] T.G.M.Kleinpenning, *Solid-St. Electron.* **22**, pp.121-128 (1979)

FORMATION OF INVERSION LAYER IN 6H-SiC MOS STRUCTURES MADE FROM SSM AND CVD EPITAXIAL FILMS

P.A. Ivanov, K.I. Ignat'ev, T.P. Samsonova, V.N. Panteleev
Ioffe Physico-Technical Institute of Russian Academy of Sciences
26 Polytechnicheskaya, St-Petersburg, 194021 Russia
Tel: (812) 247-9988, Fax: (812) 247-1017

A.A. Maltsev, A.Yu. Maksimov, and N.K. Yushin
FTIKKS Enterprise
26 Polytechnicheskaya, St-Petersburg, 194021 Russia
Tel: (812) 515-1922, Fax: (812)-515-1922

Studies of kinetics of formation of layers with inverse conductivity in MIS structures are widely used for determination of certain parameters of semiconductor-insulator systems. These parameters which are important for different applications are the following ones: characteristics of generation-recombination processes in the semiconductor bulk, surface recombination rate, minority carrier leakage currents through the dielectric, etc. At the same time these investigations are helpful in optimizing the methods of fabrication of MOS structures themselves.

In this paper, we present study of the relaxation of the nonequilibrium high-frequency capacitance of MOS structures fabricated on 6H-SiC. We used the n-type 6H-SiC epitaxial films fabricated by both sublimation-sandwich method (SSM) and chemical vapor deposition (CVD).

Sublimation films with a concentration of noncompensated donors of about 10^{16} cm^{-3} were grown in an apparatus with inner accessories made of tantalum. Lely-crystals of the n-type were used as substrates. The oxide growth was carried out on the (0001)Si face of the crystals. CVD-films with a concentration of noncompensated donors of about 10^{16} cm^{-3} were grown on the Lely-substrates as well, but the substrate basal plane (0001)Si was disoriented by about 2° in the [1120] direction. The films grown were oxidized at 1100°C in a quartz reactor which could provide introduction of a deionized water vapor (for wet oxidation) as well as of a trichloroethylene vapor (for chlorine oxidation). Aluminum was used as the gate electrode. The back contact was made of tungsten.

We measured the relaxation of nonequilibrium high-frequency capacitance of MOS structures via computer control. The total recovery time varied from several hours to several tens of seconds at elevated temperatures. Relaxation curves were analyzed following the well known Zerbst technique. We varied the initial bias voltage in order to distinguish different mechanisms of minority carrier generation. A minority carrier generation process in the semiconductor space-charge region has been discriminated, with an activation energy to be closed to the half-width of the forbidden gap in 6H-SiC. The effective lifetime associated with this type of generation varied from tens of picoseconds to several nanoseconds for different samples. The rate of generation through the surface states under the gate electrode was found to have a lower activation energy, which is attributable to the presence of density-of-state maxima in the upper and lower parts of the forbidden gap of 6H-SiC. Some structures exhibited incomplete capacitance recovery which indicated minority-carrier leakage through the dielectric. The data on nonequilibrium capacitance relaxation were systematized for different samples.

We are grateful to Dr. E.Jansen and other members of the Linkoping University (Sweden) for growing CVD films which were used in this study. This work was supported in part by the US Department of Defense.

PASSIVATION OF INTERFACE TRAPS IN MOS-DEVICES ON N- AND P-TYPE 6H-SIC

E.G. Stein von Kamienski, C. Leonhard, S. Scharnholz, A. Gölz, and H. Kurz;
Inst. f. Halbleitertechnik II, RWTH Aachen, Sommerfeldstr. 24, D-52074 Aachen, Germany
Tel: +49 241 80 78 94; Fax: +49 241 8888 246; e-mail: stein@basl.rwth-aachen.de

MOSFET's (Metal Oxide Semiconductor Field Effect Transistor) on SiC are promising devices for high power applications. Their calculated superior device properites depend crucially on the qualities of the gate-oxide and the oxide-SiC interface. Oxide charges as well as interface states affect the threshold voltage and the conducting behavior of the device. This contribution focusses on the fabrication and electrical characterization of gate-oxides in MOS-(Metal Oxide Semiconductor)-capacitors as well as in n-channel MOSFET's on 6H-SiC.

The MOS-capacitors on n- and p-type 6H-SiC are characterized by CV-, photo- and Fowler Nordheim charge injection techniques to derive the densities of interface states and oxide traps, respectively. Furthermore, CV-measurements at elevated temperatures and after illumination are performed, in order to get information about interface traps which are located deep within the bandgap of SiC. These measurements reveal a still high density (> $10^{12}\,\mathrm{cm}^{-2}$) of donator- and a lower density ($10^{11}\,\mathrm{cm}^{-2}$) of acceptor type interface traps in dry or wet oxidized and in Ar annealed samples. The densities of oxide traps are in a relatively low range of $10^{11}\,\mathrm{cm}^{-2}$ for both, electron- and hole- traps, in these oxides. A large part of the donor type interface states can be passivated by annealing in hydrogen- or moistness atmosphere (Fig. 1). By these techniques interface state densities down to the $10^{11}\,\mathrm{cm}^{-2}$ range can be achieved in oxides on n- and p-type samples. However, these defect passivation is not stable at high temperatures. Furthermore, higher densities of oxide traps are detected, which are correlated to the water and/or hydrogen contents in the oxides.

The effects of a passivated and a non passivated gate-oxide on the properties of n-channel MOSFET's will be demonstrated. These devices are fabricated in an non self aligned process in planar technology. Because the passivation reduces mainly donor type interface states, the threshold voltages of both devices are equal at 3 V (Fig. 2). This result demonstrates that donor type interface states but not positive oxide charges dominate the CV-characteristics of our MOS-capacitors on p-type SiC. In the passivated transistor the effective interface state density is reduced by a factor of two. The channel mobility, however, does not increase.

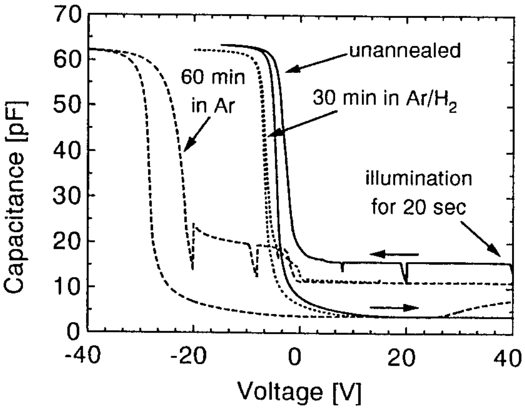


Fig. 1: CV-data of MOS-capacitors on p-type 6H-SiC; wet oxidation and annealing at 1150 °C in Ar or Ar/H_2 atmosphere.

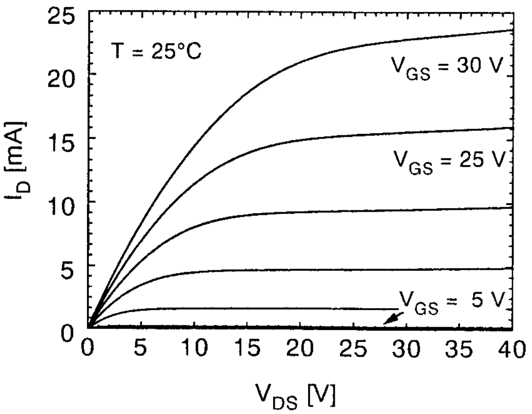


Fig. 2: I_D versus V_{DS} characteristic of 6H-SiC MOSFET, $W/L = 500/10\,\mu\mathrm{m}$, non passivated gate oxide.

THE POTENTIAL OF SiC AND GaN FOR APPLICATION IN HIGH SPEED DEVICES

Frank Schwierz
Technical University Ilmenau, Department of Solid-State Electronics
PF 0565, 98684 Ilmenau, Germany
Phone: +49/3677/693120, Fax: +49/3677/693132, email: schwierz@e-technik.tu-ilmenau.de

1. Motivation

During the past few years the wide bandgap semiconductors SiC and GaN attained increased interest because of their suitability for high-temperature / high-power and optoelectronic applications. Furthermore, there is considerable research under way to make use of SiC and GaN for high speed devices. Recently very promising results were reported, e.g. a SiC MESFET showing a maximum frequency of oscillation f_{max} of 25 GHz [1] and AlGaN/GaN MODFETs with measured values for cut off frequency f_T of 20 GHz and f_{max} of more than 70 GHz [2]. However, the frequency limits of SiC and GaN field effect transistors are not investigated in detail yet.

The aim of this work is to compare GaAs, Si, SiC (cubic), and GaN (both cubic and hexagonal) MESFETs in terms of transconductance and cut off frequency by means of device modeling taking into account the material properties most important for MESFET high speed behavior. Furthermore, the properties of AlGaN/GaN MODFETs will be estimated discussing two transport parameters of the two-dimensional electron gas at the AlGaN/GaN heterojunction.

2. Physical Model and Device Structure

MESFETs for high speed applications show gate lengths in the deep submicron range. Because in such short gate MESFETs nonstationary carrier transport plays an important role, first we investigated the effects of velocity overshoot in GaAs, Si, SiC and GaN (in the case of GaN to our best knowledge for the first time) by means of the relaxation time approximation (RTA) [3]. For transistor modeling the two region MESFET model of Statz et al. [4] has been used to calculate the transconductance and the cut off frequency of GaAs, Si, SiC, and GaN MESFETs with gate lengths varying from 1.5 µm down to 0.1 µm. Velocity overshoot has been taken into account.

To estimate the behavior of AlGaN/GaN MODFETs we calculated the carrier sheet density n_s at the AlGaN/GaN heterojunction and the products n_s × low field mobility and n_s × saturation velocity as parameters describing the high speed potential of MODFETs.

3. Results

It is shown that nonstationary carrier transport becomes an important mechanism in GaN MESFETs with gate lengths below 0.25 µm, whereas its role is negligible in SiC MESFETs even with gates as short as 0.1 µm. Simulated transconductances and cut off frequencies of MESFETs made from the four different materials mentioned above are presented as functions of gate lengths and drain source voltage. The results show that GaAs MESFETs by far have the best high speed behavior. GaN and SiC MESFETs show better performance than Si MESFETs for short gate lengths and can be operated at much higher drain source voltages as their GaAs and Si counterparts because of their much higher breakdown voltages. For low voltage operation and longer gate lengths the cut off frequency and transconductance of Si MESFETs is higher than in the case of SiC and GaN MESFETs.

The properties of the two-dimensional electron gas in AlGaN/GaN MODFET are discussed regarding the defined transport parameters.

4. Conclusions

SiC and GaN MESFETs show promising high speed properties. In conventional microwave electronics GaAs based devices will keep their dominating role but for applications where high breakdown voltage and / or high operating temperature have to be combined with high speed, SiC and GaN based FETs will outperform Si and GaAs FETs.

References

[1] S. Sriram et al., 52nd Annual IEEE Device Research Conf., Boulder, CO (1994)
[2] M. Asif Khan et al., Appl. Phys. Lett. 66, 1083 (1995)
[3] F. Schwierz et al., accepted for publication in Solid-State Electronics
[4] H. Statz et al., IEEE Trans. Electron Devices 21, 549 (1974)

DEPLETION-MODE SiC FETs FOR HIGH POWER, HIGH FREQUENCY APPLICATIONS (PHYSICAL OUTLOOK)

V.E. Chelnokov and P.A.Ivanov
Ioffe Physico-Technical Institute of Russian Academy of Sciences
26 Polytechnicheskaya, 194021 St-Petersburg, Russia
Tel: (812) 247-9125, Fax: (812) 247-1017

Silicon carbide is commonly considered to be a very promising material for high temperature, high power, and high frequency applications due to its large bandgap, high values of electric breakdown field, thermal conductivity, and saturated drift velocity of electrons. The present paper deals with analytical simulations of high power and high frequency 6H-SiC and 4H-SiC FETs (with n-channel doping of (2-4)$\cdot 10^{17}$ cm^{-3} being at present in practical use). Principles of design of depletion-mode FETs have been considered from the point of view of obtaining high carrier density in the channel and high drift velocity of carriers.

As to the carrier density in the channel (per unit area of the gate electrode), it is limited, for a depletion-type FET, by the surface density of dopants, Na, where N is the bulk concentration of dopants and a is the channel thickness. Under pinch-off conditions, the electric field, $E_p = qNa/\varepsilon$ is generated within the space-charge region. It is clear that this field cannot exceed the avalanche breakdown field, therefore the carrier density cannot exceed a value $(na)_{max} = \varepsilon E_b/q$. Note that for SiC FET, the carrier density, n can be made, in principle, more than 10^{13} cm^{-2} due to a very high magnitude of the avalanche breakdown field (E_b = 3-6 MV/cm). However, with moderate channel doping of N = (2-4) 10^{17} cm^{-3} high carrier density could be made at the expense of relatively high pinch-off voltage.

As to the drift velocity of electrons in the channel, it was necessary to establish the ability for the average carrier velocity to be closed to saturated one. The matter is that the drift velocity is increased along the channel from source to drain due to increase of the lateral electric field $E(x)$. The electron velocity near the source is directly proportional to the electric field: $v = \mu E$, where μ is the low-field mobility of electrons. If the lateral field beyond the certain channel plane $x = x_s$ exceeds a field E_s, which is necessary for the velocity to saturate, then in a channel region, adjacent to drain, the drift velocity does not depend on the field and equals to the saturated velocity: $v = v_s$. For a depletion-type FET, the length of this region would depend on several factors such as: i) the voltages applied to the source and drain electrodes, ii) the channel length and thickness, iii) the value of saturated velocity, iv) the value of electron mobility. The value of practical interest is the carrier drift velocity averaged over the channel length which becomes higher while the bigger part of channel length is occupied by that with saturated velocity. It is a common knowledge that the low-field electron mobility in SiC is moderate and, in addition, decreases with increasing temperature. Fortunately, a high electric field can be created in SiC transistor (because of the high breakdown field of this material) thus accelerating carriers to a high velocity. We have shown by using a transistor model taking into account saturating drift velocity that the average value of electron velocity can be closed to the saturated one despite of the low value of electron mobility in SiC. However, with moderate channel doping by order of 10^{17} cm^{-3}, it can be achieved only at the expense of relatively high pinch-off voltage too. In particular, at pinch-off voltage of 30 V, the average velocity exceeds 10^7 cm/s with the channel length less than 5 µm, while at pinch-off voltage of 10 V, the same channel length must be less than 1.5 µm.

On the base of the above consideration we have simulated power and microwave transistors based on 6H-SiC and 4H-SiC. It has been shown that SiC materials would be superior to GaAs for high power and high frequency transistors when operating with higher values of pinch-off voltages.

This work was supported in part by the US Department of Defense.

TEMPERATURE DEPENDENCE OF ELECTRICAL PROPERTIES OF 6H-SIC BURIED JFET

C. Raynaud, C. Richier, G. Guillot, V. Séguier
Laboratoire Physique de la Matière - UMR 5511 - INSA, 20 av Albert Einstein 69100 Villeurbanne - France - tel. : (33) 72 43 87 32, Fax : (33) 72 43 85 31,

The electrical characteristics of buried gate n-channel junction field effect transistors (JFETs) fabricated in epitaxial layers grown on 6H-SiC wafers have been measured as a function of temperature from 250 to 500 K. Results of admittance and drain source current DLTS measurement show the level of Aluminium at Ev + 0.24 eV and a deep level situated at Ec - 0.95 eV localized closed to the SiO_2 passivated surface. This deep level could be due to the etching process of the active channel region or to the interface with the passivating SiO_2.

The electrical characterization of the JFETs follow quite well the classical model of standard abrupt-junction and the long channel JFET device. However we must take into account the two-level model of the nitrogen donor and their incomplete ionization in the channel due to their relatively high activation energies. By fitting the calculated saturated drain current to the measured value at 300 K, we can obtain the compensated acceptor concentration in the channel. We then determine a power law dependence of electron mobility on temperature as $T^{2.3}$ in very good agreement with Hall mobility results on epitaxial layers of comparable doping.

GROWTH OF $Al_xGa_{1-x}N$ FILMS ON 6H-SiC BY PLASMA ASSISTED MBE

D. Korakakis, D. Doppalapudi[a)] and T. D. Moustakas
Electrical and Computing Engineering Department and Center for Photonics Research, Boston University, Boston MA 02215, USA Tel:(617) 353 5803 Fax:(617) 353 6440
[a)]Department of Manufacturing Engineering and Center for Photonics Research, Boston University, Boston MA 02215, USA

6H-SiC is a promising substrate for Nitride growth due to the small lattice mismatch, ~3% for GaN and less for $Al_xGa_{1-x}N$ films. The electrical properties of SiC also permit the design and fabrication of vertical devices using the substrate as a contact. $Al_xGa_{1-x}N$ films, for $x \leq 0.50$, were grown directly on (0001) Si-terminated 6H-SiC, without the employment of a buffer. X-ray diffraction experiments show that the films have excellent crystal quality with rocking curves between 3 to 20 arcmin depending on Al content. Electron diffraction studies indicate excellent epitaxial relationship between film and substrate. There is no evidence of cubic domains and the stacking faults are confined to within 60 Å from the interface. The dislocation density is of the order of 10^{10} cm^{-2} at the interface and 10^9 cm^{-2} at a distance of 200 Å from it. The films were doped intentionally n-type with Si. Photoluminescence studies show that recombination occurs across the bandgap with FWHM at room temperature, for GaN films, of the order of 50 meV and at liquid nitrogen temperature the FWHM reduce to 27 meV and as the Al concentration increases the photoluminescence peaks broaden.

STRUCTURAL PROPERTIES OF GaN GROWN ON SiC SUBSTRATES BY HYDRIDE VAPOR PHASE EPITAXY

Yu.V. Melnik, I.P. Nikitina, A.E. Nikolaev, D.V. Tsvetkov, A.A. Sitnikova and V.A. Dmitriev

Cree Research EED and A.F. Ioffe Institute,
26 Polytechnicheskaya Street, St. Petersburg 194021, Russia.
FAX: +7 (812) 247-6425;
e-mail: YuVM@shuttle.ioffe.rssi.ru

GaN is one of the most promising materials for blue light emitting devices. However, there are difficulties in obtaining a vertical device configuration because of the dielectric nature of the materials usually used as substrates (Al_2O_3) or buffer layers (AlN) for GaN deposition. Recently, we reported on high-quality GaN grown on electrically conductive SiC substrates by hydride vapor phase epitaxy (HVPE) without any buffer layer [1]. This fact makes it possible to fabricate devices with the desired vertical structure.

In this study, we investigated the effect of SiC substrates (i.e. structural perfection, misorientation, micropipes) on properties of GaN layers.

GaN epitaxial layers were grown using the conventional HVPE system with a two-zone resistance furnace. In a horizontal open flow reactor, HCl reacted with liquid Ga to form GaCl gas which is transported to the growth zone and reacted with NH_3 resulting in GaN deposition on a SiC substrate. 6H-SiC and 4H-SiC (0001) wafers manufactured by Cree Research, Inc. were employed as substrates. Layers were deposited on the (0001)Si face of substrates. The growth temperature was usually kept between 950 and 1050 ^{o}C and the GaN growth rate was controlled in the range from 0.02 to 0.6 μm/min. Layer thicknesses ranged from 0.2 to 2 μm. Due to the good mixing of the reactant gases prior to deposition and high total flow rate, good growth uniformity was achieved. The layers have better than 5% thickness uniformity across a 30 mm-diameter wafer.

The layers were characterized by x-ray diffraction, low temperature photoluminescence and transmission electron microscopy (TEM).

The crystal quality of the GaN layers and SiC substrates was evaluated by x-ray double-crystal diffraction. Rocking curves (RC) were measured across 30 mm-diameter samples in 24 points. It was found that for layers grown under optimized growth conditions, the crystalline quality of GaN strongly depends on the crystalline quality of the substrate. As the full width at half maximum (FWHM) of RC(ω) for substrate changes from 17 to 30 arc sec, the FWHM of RC(ω) for the layer changes from 67 to 80 arc sec. These are the lowest value reported so far for GaN HVPE growth and for GaN layers deposited directly on SiC without a buffer layer. Properties of GaN grown on on-axis and off-axis SiC (0001) substrates will be compared.

The dislocation structure of the layers was investigated by TEM. Both cross section and plan view TEM images were studied. The layers have a density of dislocations in the range of 10^8 - 10^9 cm^{-2}.

[1] Yu.V. Melnik, I.P. Nikitina, A.S. Zubrilov, A.A. Sitnikova and V.A. Dmitriev. High-quality GaN Grown Directly on SiC by Halide Vapor Phase Epitaxy, Technical Digest of Int. Conf. on SiC and Related Materials, Kyoto, 1995, p. 198.

Structural and electrical properties of Schottky barriers on n-GaN

E.V. Kalinina, N.I. Kuznetsov, A.I. Babanin, Cree Research EED and Ioffe Institute, and
A.P. Kovarsky, A.V. Shchukarev, Mekhanobr Analyt Co.
Ioffe Institute, Dep. of Physics of Seiconductor Devices, 26 Politechnicheskaya str., 194021
St.Petersburg, Rusia.

Tel: +7(812) 247-6425
Fax: +7(812) 247-6425, E-mail: EED@cree.spb.su

Recently significant progress has been achieved on MOCVD growth of GaN layers on SiC substrates. Cr, Au and Ni Schottky barriers with reproducible and good mechanical haracteristics formed on n-GaN grown on SiC have been reported [1]. This report is devoted to the investigation of physico-chemical properties of such Schottky barriers.

Undoped and silicon doped GaN n-layers with Nd ranging from 10^{16} to 10^{18} cm^{-3} were grown on 6H-SiC substrates by MOCVD [2]. Cr, Au and Ni were deposited on the GaN layers by vacuum thermal evaporation to form Schottky barriers. Current-voltage and capacitance-voltage characteristics of the barriers were measured. Fundamental parameters: barrier height, elrctron affinity and effective Richardson coefficient were calculated. Interface chemistry of Cr, Au and Ni contacts on n-GaN was elucidated by using x-ray photoelectron spectroscopy, auger electron spectroscopy and secondary ion mass spectroscopy.

It was found, that interface Cr, Au and Ni Schottky barriers on n-GaN have abrupt character without metal diffusion into semiconductor. The correlations between evaporated metal, carbon and oxygen concentrations on interface were established for Cr, Au and Ni. Analysis of electrical characteristics and interface chemistry was carried out. Correlations between the chemical reactivity of the metals and electrical data is discussed.

[1] E.V.Kalinina et al.,accepted for publication in J.Electronic Mater.
[2] V.A.Dmitriev et al., in Proceedings of the 21st. Int. Symp. Compound Semiconductors, San Diego, CA, 1994, Inst. Phys. Conf. Ser. No 141, edited by H. Goronkin and U. Mishra (IOP. Bristol ,1995) pp. 497 -502.

LUMINESCENT PROPERTIES OF AlGaN SOLID SOLUTIONS GROWN ON 6H-SiC

A.S. Zubrilov[1] , *D.V. Tsvetkov*[1] , *V.I. Nikolaev*[1] , *I.P. Nikitina*[1] , *V.E. Bougrov*[1],
and V.A. Dmitriev[1,2]
1) CreeResearch EED & A. Ioffe Institute, 26 Polytechnicheskaya Street, St. Petersburg 194021, Russia.
2) Cree Research, Inc., Durham, NC 27713, USA.
e-mail: asz@shuttle.ioffe.rssi.ru
FAX: +7(812) 247-6425

AlGaN epitaxial layers with AlN mole fraction in the range from 0 up to 28 mol.% were grown by metal organic chemical vapor deposition (MOCVD) on Cree Research, Inc. 6H-SiC substrate [1]. Luminescent properties of these layers have been investigated at electron beam excitation in the range 4 - 15 keV, and structural properties was determined by X-ray diffraction. Fig. 1 shows the dependence of cathodoluminescnt (CL) edge peak position for $Al_xGa_{1-x}N$ ($0 \leq x \leq 0.3$) solid solutions at room temperature. It can be seen that the edge CL spectra had a character "blue" shift, and also increase of full width at half maximum (FWHM) and decrease of edge band intensity with increase of AlN mole fraction in AlGaN composition [2]. From the analysis of cathodoluminescence spectra, the dependence of the luminescence band position in the region of the edge absorption on composition of the $Al_xGa_{1-x}N$ solid solution was found to be expressed by $E(x)=3.39+2.19x+0.65x^2$ (eV) at T=300K and compared with linear band approximation $3.4+2.8x$ (eV) (Fig. 2). Alloy broadening of this band as a function on alloy composition has been studied. Experimental results were interpreted on the base of a model of the edge luminescence band broadening due to random fluctuation of alloy composition. This mechanism was shown to be much stronger than that for narrow-bandgap $A^{III}B^{V}$ solid solutions [3].

References.

[1] I. Akasaki, K. Hiramatsu and H. Amano, Memoirs of the Faculty of Engineering, Nagoya University, **43**, 147 (1991);

[2] I. Akasaki, H. Amano, Y. Koide, K. Hiramatsu and N. Sawaki, J. Crystal Growth, **98**, 209 (1989);

[3] L. Pavesi and M. Guzzi, J. Appl. Phys., **75**, 4779 (1994).

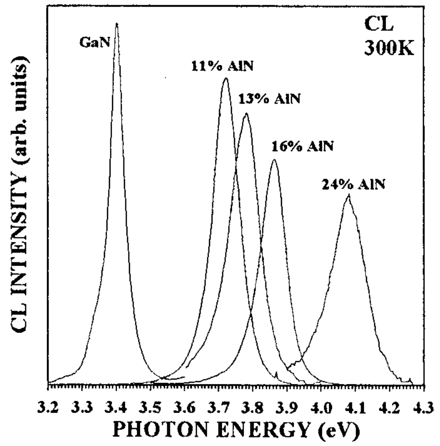


Fig. 1 CL spectra for AlGaN solid solutions for various AlN mole fractions.

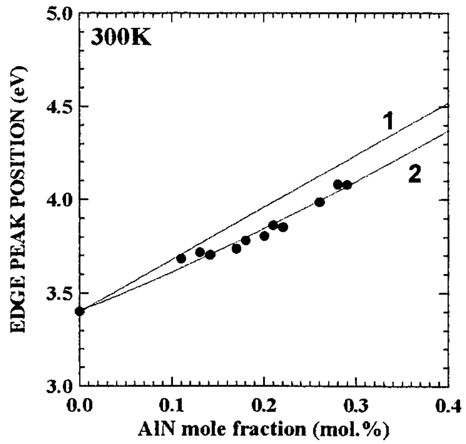


Fig. 2 Edge peak position vs AlN mole fraction,
curve 1 - linear approximation $E(x)=3.4+2.8x$
close circles - experiment
curve 2 - approximation $E(x)=3.39+2.19x+0.65x^2$

ANGLE RESOLVED NEXAFS SPECTRA OF HEXAGONAL AND CUBIC GaN.

M.Katsikini[a,b)], E.C.Paloura[a,*)], T. S. Cheng[c)], C. T. Foxon[c)]
a) Aristotle Univ. of Thessaloniki, Dept. of Physics, 54006 Thessaloniki, Greece.
b) Hahn-Meitner Institute (A.S.), Glienicker Str. 100, D-14109, Berlin, Germany.
c) Univ. of Nottingham, Dept. of Physics, NG7 2RD, England

GaN has been a subject of intensive study because it finds applications in visible-UV light emitters and detectors, as well as in high-frequency, -power and -temperature devices. A significant problem in GaN technology is related to the lack of a suitable substrate material, with comparable to GaN lattice constant and thermal expansion coefficient. Depending on the substrate type and orientation, epitaxially grown GaN can have either cubic or hexagonal symmetry while the co-existence of both phases is often observed [1].

Here we present a N-K-edge angle (θ) resolved near-edge X-ray absorption fine structure (NEXAFS) study of phase stabilized [2] cubic and hexagonal GaN grown by MBE. The NEXAFS spectra were recorded in the fluorescence detection mode, as a function of the angle of incidence. It is expected that the intensities of the individual resonances in the NEXAFS spectra are independent of ı if the material is cubic (allowed transitions $1a_1 \rightarrow t^*_2$), while they depend on $\cos^2\theta$ or $\sin^2\theta$ if the material has hexagonal symmetry (allowed transitions $1a_1 \rightarrow a^*_1$ and $1a_1 \rightarrow e^*_1$, strongest for grazing and normal incidence, respectively).

Indeed, it is demonstrated that the energy position and intensities of the characteristic NEXAFS resonances, measured as a function of ı, depend on the crystal symmetry and can be used as a fingerprint of the symmetry of the examined crystal. Deviations from the cubic or hexagonal symmetries are clearly detectable since they lead to a systematic shift in the resonances of the NEXAFS structure and a characteristic angular dependence. Based on the above results, a formalization for a quantitative accessment of the cubic and hexagonal contributions in a mixed-phase crystal is discussed.

---

[*] Address for correspondance : fax # : (30 31) 998036 or 998019, e-mail : paloura@olymp.ccf.auth.gr

[1] T. Lei, M. Fanciulli, R. J. Molnar, T. D. Moustakas, R. J. Graham and J. Scanlon, Appl. Phys. Lett. 59, 944 (1991).

[2] T. C. Cheng, L. C. Jenkins, S. E. Hooper, C. T. Foxon, J. W. Ortion and D. E. Lacklison, Appl. Phys. Lett. 66, 1509, (1995).

CONTACTLESS CHARACTERISATION OF 2D-ELECTRONS IN GaN/AlGaN HFETs

H. ALAUSE, C. SKIERBISZEWSKI, M. DYAKONOV, W. KNAP
Groupe d'Etudes des Semiconducteurs , Université Montpellier 2 - C.N.R.S. UMR357
Place E.Bataillon 34095 Montpellier, France, E-mail : Alause@ges.univ-montp2.fr

M.L. SADOWSKI[¤], S. HUANT
High Magnetic Field Laboratory, MPI-FKF and CNRS, BP 166, 38042 Grenoble, France
[¤] Institute of Experimental Physics, Warsaw University, Hoza 69, 0-681 Warsaw Poland

J. YOUNG , M. ASIF KHAN , Q. CHEN ,
A.P.A. Optics Inc., Blaine, Minnesota, USA

III-V nitride transistor technology is maturing fast. AlGaN/GaN heterostructures based FETs are focusing interest for their potential high temperature applications.

We report on properties of 2-D carriers in GaN/AlGaN heterojunction investigated by an optical method. This method consists of a Cyclotron Resonance (CR) experiment where optical absorption is measured under fixed magnetic fields up to 13T.

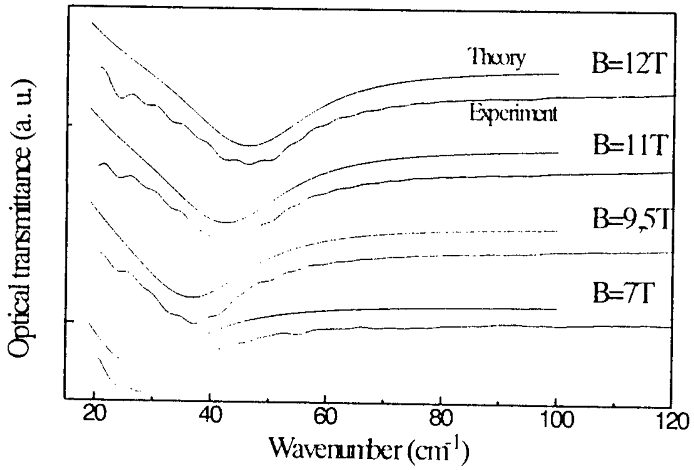


Figure : Optical transmittance measured and calculated at different magnetic fields. The theoritical curves yield values of carrier mobility $\mu = 3900\ \mathrm{cm^2/V.s}$ and concentration $N_s = 3.9.10^{12}\ \mathrm{cm^{-2}}$.

We introduce a theoritical approach that allows to interpret Cyclotron Resonance due to the thin 2D layer on the sapphire substrate. The absorption peaks at different magnetic fields show a non lorentzian behaviour that must be fitted by an accurate function. You can see on the figure both experimental and theoritical curves at different magnetic fields. Parameters of the fit are the carriers concentration N_S and mobility μ. Effective mass can be evaluated as well (see reference). We found that in the range up to 13T in studied HFETs, μ and N_S are constant with magnetic field, which allows a very accurate calculation of these parameters.

Reference : W. Knap, H. Alause, J.M. Bluet, J. Camassel, J. Young, M. Asif Khan, Q. Chen, S. Huant, M. Shur, *Sol. Sate Comm.* Vol. **99**, No. 3, pp. 195-199, (1996).

AMORPHOUS $GaAs_{1-x}N_x$ THIN FILMS ON CRYSTALLINE Si SUBSTRATES : GROWTH AND CHARACTERIZATIONS.

K. AGUIR, D. LOLLMAN, ,B. ROUMIGUIERES, & H. CARCHANO.
Laboratoire EPCM, Faculté des Sciences de St. Jérôme, Université d'Aix-Marseille III, 13397 MARSEILLE cedex 20, FRANCE.
TEL : 91 28 81 53 FAX : 91 28 94 03.

This work deals with the growth and study of a new nitride in thin films : $GaAs_{1-x}N_x$. The material is deposited in its amorphous form on crystalline Si substrates by means of RF sputtering of a GaAs target in an atmosphere of argon and a nitrogen carrier gas (NH_3). Raman spectroscopy used to study the physico-chemical properties of the film structure pointed out that $GaAs_{1-x}N_x$ is a wide gap material which is formed by the substitution of arsenic by nitrogen in the GaAs network [1].

In order to investigate the electrical properties of $GaAs_{1-x}N_x$ in view of potential applications in optoelectronic systems, C-V and J-V characteristics have been performed. The structures investigated were formed by a sandwich-like structure of a-$GaAs_{1-x}N_x$ thin films between the semiconductor substrate and a gold grid. An ohmic contact was formed on the back side of the substrate prior to film deposition.

J-V results show that the heterostructures exhibit a drastic falling off of forward and reverse currents with nitrogen incorporation. The conduction passes from a diode-type one for $x = 0$ [2] to an approximately symmetrical one with nitridation, i.e. for $x > 0$. The films present convenient high resistivity values and the structures present a manifest MIS-like behaviour with however some imperfections [3].

The C-V experimental characteristics of the heterostructures are compared to a theoretical model obtained by means of an exact calculation of an ideal MIS structure capacity. For $x = 0$, the comparaison reveals the existance of a flat-band voltage (V_{FB}) of about -2 V. With increasing x, a displacement of V_{FB} towards positive values of V is observed. This phenomenon is attributed to the accumulation of fixed positive charges in the "insulating" thin films. An increase in the barrier height between the metallic electrode (Au) and the c-Si(p) semiconductor might as well be responsible for these effects.

---

[1] K. Aguir, J. Bandet, D. Lollman, B. Roumiguières & H. Carchano : *IEEE-SIMC-9 Proceedings, May 1996.*

[2] K. Aguir, A. Fennouh, H. Carchano, J. L. Seguin, B. El Hadadi & F. Lalande : *Thin Solid Films, 257 (1995) 98.*

[3] K. Aguir, A. Fennouh, H. Carchano & D. Lollman : *J. Phys. III, 5 (1995) 1573.*

ELECTRICAL PROPERTIES OF PECVD AMORPHOUS SILICON-CARBON ALLOYS FROM AMORPHOUS-CRYSTALLINE HETEROJUNCTIONS

L. F. Marsal, J. Pallarès, X. Correig, M. Domínguez *, D. Bardés *, J. Calderer * and R. Alcubilla *

Departament d'Enginyeria Electrònica, Universitat Rovira i Virgili.
Autovia de Salou s/n, 43006, Tarragona, SPAIN.
* Departament d'Enginyeria Electrònica, Universitat Politècnica de Catalunya.
C/ Gran Capità s/n, Campus Nord C-4, 08071, Barcelona, SPAIN.
Phone: +34-77-559625
Fax: +34-77-559710
email: lmarsal@etse.urv.es

Hydrogenated amorphous silicon carbon (a-$Si_{1-x}C_x$: H) presents a great interest due to its wide optical band gap (1.7 to 3 eV) which can be controlled by varying the carbon composition and also because it can be deposited at low temperature. Particulary, a-$Si_{1-x}C_x$: H films are used in many different optoelectronic applications [1]. The knowledge of the density of states in the gap is of paramount importance in order to predict the optoelectronic properties of the resulting devices. A variety of optical and electrical measurement techniques have been developed to determine the gap states density: field effect, DLTS, photoacustic spectroscopy, ICTS, heterojunction-monitored capacitance, etc. The results seem to be dependent on deposition process (sputtering, glow discharge, etc.), deposition parameters (substrate temperature, doping, layer thickness, etc.), type of test structure (n-i-n, Schottky, p-i-n, n^+-n-n^+, MIS, etc.) and measurement technique (optical, electrical). Hence, the results obtained from different researchers are difficult to compare.

Within this context, amorphous $Si_{1-x}C_x$: H / crystalline Si heterojunction diodes have been fabricated and its electrical properties investigated by measuring current-voltage characteristics. The starting material is p-type CZ silicon, with <100> orientation and average resistivity value of 1 Ωcm. A back boron diffusion was carried out to improve the back contact. The amorphous material is deposited by plasma enhanced chemical vapor deposition (PECVD) form a mixture of CH_4 and 95% SiH_4 + 5% PH_3. A parallel-plate radio frequency reactor has been used with power density of 31 mW/cm^2 supplied at 13.56 MHz. The ohmic contacs are obtained by evaporation of pure aluminium. A 1:10 HF etching is carried out prior to metallizing.

The current-voltage characteristics show good rectifying properties (1000:1 at ± 0.5 V). The measured forward current shows two distinct regions. For low bias voltages (<0.4 V) the current increases exponentially with the applied voltage ($I \alpha \exp(qV/\eta kT)$), with an ideality factor η=1.5 while for at high bias voltages (>0.6 V) the current increases proportionally to the power of voltage ($I \alpha V^m$) with m=2.6. This power dependence is typical for space charge limited currents (SCLC) [2]. The reverse characteristic shows a leakage current and it increases exponentially. This leakage current, probabily could be explained by tunneling mechanisms due to the continuous distribution of states in the gap.

The existence of space charge limited currents in these heterojunctions, for applied voltages over 0.6 V allows to use such a device as a test structure for a first-order measurement of the density of states. The density of states profile for n-type a-$Si_{1-x}C_x$: H has been obtained from the differential method of Nespurek and Sworoski [3]. This method, although it is approximative and leads only to a quantitative estimation of g(E) above the Fermi level, needs the only knowledge of the current-voltage characteristic, a measurement that is routinely carried out in device characterization. The results show the increase of localised states when approaching the conduction band edge and that distribution can be aproximated by an exponential distribution in the range of the scanned energies.

The results are in reasonable agreement with some of the previously published results.

[1] J. Bullot and M.P. Schidt, Phys. Stat. Sol. (b) Vol. 143 pp. 345-418 (1987).
[2] Murray A. Lampert and Peter Mark, Current Injection In Solids, Academic Press, Inc. (1970).
[3] S. Nespurek and J. Swaroski, J. Appl. Phys. 51, 2098 (1980).

Effects of thermal and laser annealing on silicon carbide nanopowder produced by rf glow discharge.

G.Viera, S.N.Sharma, R.Q.Zhang, J.L.Andújar and E.Bertran.
LFCF, Departament de Física Aplicada i Electrònica, Universitat de Barcelona, Av. Diagonal 647, E08028 Barcelona, Spain.
Phone:343 402 11 44.
Fax: 343 402 11 38.

SiC nanoparticles (20-80nm) of high purity have been produced in radiofrequency glow discharges from silane and methane gas mixtures. In previous reports we have evidenced their nanometric size and their high hydrogen content. Spectroscopic studies showed: a)the hydrogen atoms are bonded to carbon atoms rather than to silicon ones, b)the optical gap decreases with the silicon content. Moreover, the high surface reactivity of the as-deposited particles can cause spontaneous oxidation when exposed to the atmosphere.

In order to chemically stabilize the SiC particles, we present a study of the structural, chemical and compositional modifications induced by thermal annealing, at different temperatures, and laser annealing. The post-treated powder was analyzed by HRTEM, elemental analysis (EA) and by RAMAN, FTIR and XPS spectroscopies. In addition, thermal desorption spectrometry (TDS) was used to monitor the thermal evolution of H_2, CH_4 and CO gases.

Effects of SiC powder treatments include: changes from yellow to dark brown color and H_2 desorption. We observed that the hydrogen desorption can be accompanied with important structural changes such as the formation of nanocrystallites of SiC and Si, depending on the temperature or the laser power density. Other effect is the drastic reduction of the surface reactivity, thus preventing the spontaneous oxidation of the SiC powder at room conditions.

The characteristics of the treated SiC powder, nanometric size and controllable structure, makes it a promising material for advanced engineering ceramic devices, nanoscale filters, or for supporting catalytic surfaces.

EMISSION AND EXCITATION SPECTRA OF SILICON-RELATED LUMINESCENT CENTERS IN CVD-GROWN DIAMOND FILMS

M. C. Rossi, S. Salvatori, F. Galluzzi, Third University of Rome, Dept. of Electronic Engineering, Via Vasca Navale 84, 00146 Rome, Italy, tel.: +39-6-55177091; fax: +39-6-5579078.

R. M. Montereali, ENEA, Dip. Innovazione, C. R. Frascati, P. O. Box 65, 00044 Frascati (RM), Italy.

F. Somma, Third University of Rome, Dept. of Physics, Via Vasca Navale 84, 00146 Rome, Italy.

The understanding of nucleation processes in CVD diamond films grown on silicon is a key factor for controlling material quality and its applications in high temperature electronic and optoelectronic devices. Actually, carbon/silicon interface region is strongly defected owing to both silicon surface pretreatments and interdiffusion processes. In order to understand the interactions between Si and C during the diamond growth we performed a photoluminescence (PL) excitation and emission study on diamond films deposited on Si by changing the exciting wavelength in the range 457-650 nm. The main feature of PL spectra is a strong zero phonon band at about 1.68 eV, whose lineshape and peak position depend on the excitation wavelength. The noticeable asymmetry of this band clearly suggests the presence of two lines. Indeed, from the analysis of the emission band two distinct components are found, peaked at 1.673 and 1.681 eV respectively, whose relative intensity changes with the excitation energy. These lines have been previously attributed to isolated carbon vacancies, usually observed in irradiated natural diamond (GR1 center), and to silicon-vacancy complexes formed in diamond during the growth, respectively. The former component has been also reported to shift at higher energy under internal stress. The 1.673 eV line appears to be preferentially excited at long excitation wavelengths, while the 1.681 eV component becomes predominant at shorter wavelengths. However, excitation profiles of these components exhibit similar narrow peaks in the range 1.95-1.97 eV, suggesting strong similarities between the low lying electronic levels of the two centers. A two-components scheme also allows to fit reasonably well the vibronic structure of the 1.68 eV emission band (in particular one- and two phonon replica) and to evaluate corresponding Huang-Rhys factors. Starting from these results, a simple model for the electronic configuration of the 1.673 and 1.681 eV centers is proposed, involving an electron trapped either at an isolated vacancy or at a vacancy close to a silicon atom impurity, and vibronically coupled to phonon vibrations of the diamond lattice and silicon-induced localized modes.

In addition to the 1.68 eV band, PL spectra excited at 457 nm also show a featureless broad emission located around 2 eV, which becomes structured by changing the excitation wavelength to 488 and 496 nm. This pink luminescence, usually observed in as-grown CVD diamond, could be attribuited both to defect centers involving nitrogen impurities and to amorphous carbon phases. It is shown that, also in this case, different contributions can be separeted by means of excitation spectra.

OBSERVATION OF WAVE–LENGTH TUNABLE LUMINESCENCE FROM THE VARIABLE THICKNESS a–C:H FILM ON THE FUSED SILICA SUBSTRATE

M.E.Kompan, V.A.Lukoshkin, I.I.Novak, O.I.Konkov, E.I.Terukov, I.N.Trapeznikova.
A. F. Ioffe Physico–Technical Institute RAS, 194021 Polytekhnicheskaya 26,
St.–Petersburg, Russia, FAX: 007–812–247–1017, Phone: 007–812–247–9125

The films of hydrogenated amorphous carbon with tetrahedral coordination (ta–C:H) are a new artificial material. They have a lot of promising applications in various fields of contemporary technology.

The high quantum yield of luminescence of this material (about 0,1) and a wide spectral interval of emitting radiation (almost over all visible region) make one to consider these materials as the new type of effective source of visible radiation.

The films were fabricated by RF–glow discharge method. The methane–argon mixture was used as the discharge media. The substrate temperature was varied from 300K to 600K.

The previous studies of the luminescence of ta–C:H films showed that the luminescence from those materials is due to radiative recombination of excitations in powerful density–of–state tails in energy quasi–gap of amorphous material. The specificity of ta–C:H is the cluster–type organization of material. This, as well as the high concentration of hydrogen in films provide the low level of radiation–less recombination and thus the high effectivity of luminescence. This work is the first, experimentally studied the abilities of ta–C:H as the new source of tunable–wavelength visible luminescence.

The in–plane luminescence of assembly of ta–C:H film on fused silica substrate was studied as the possible model of new type of optoelectronic device. It was observed, that the luminescence, propagated in the body of substrate, was essentially monochromated.

In the same time, normal to surface the typical ta–C:H emission, distributed over wide spectral region, was registrated. Up to eye, the later emission was almost white; the color of the former depends on the thickness of the film. The film with the variable thickness gave the ability to obtain the emission from green–blue to red ones.

The effect of wide–range monochromatization of light by orthogonal resonator is not trivial and was observed for the first time. The explanation of the effect was given on the basis of consideration of refraction and interference in three–interface assembly.

It is necessary to note, that some narrowing of the luminescence band was also observed while the intensity of excitation was increased, so the effects of superluminescence are to be take into account in more detail consideration.

This work was supported in part by grant of Arizona University, grant RFFI N 96–02–16851–a.

FORMATION OF SOLID SOLUTIONS IN SYSTEM WITH SILICON CARBIDE

Safaraliev G.K., Omarov O.A., Tairov Yu.M., Ofitcerova N.V., Nurmagomedov Sh.A,
Bilalov B.A.

367025, Russia, Daghestan, Makhahkala, Sovetskaya, 8, Daghestan State University
Tel: (872)(2)675817, 682326; Fax: (872)(2)682326; E-mail: root@daguniver.dagestan.su

Abstract

Analysis of solubility of elements in SiC, as well as results of researches on obtaining of epitaxial layers (EL) of solid solutions $(SiC)_{1-x}(AlN)_x$ and etching of them are given in the work. Compensation law was used [1] to evaluate diffusion parameters of elements on the basis of SiC. Objects of research was EL of solid solutions on the basis SiC, which was obtained by a sublimation from gas phase.

ROOM-TEMPERATURE PHOTOLUMINESCENCE OF AMORPHOUS HYDROGENATED SILICON CARBIDE DOPED WITH ERBIUM

E.I.Terukov, V.Kh.Kudoyarova, A.N.Kuznetsov, W.Fuhs*, Ioffe Physico-Technical Institute, 194021 St.Petersburg, Polytechnicheskay 26, Russia, Fax: (812) 247 10 17, *Hahn-Meitner Institut, Rudower Chausse 5, D-12489, Berlin, Germany

Recently the luminescent properties of erbium-doped crystalline silicon (c-Si:Er) have attracted much attention. The reason for this interest originates from the idea to fabricate LED`s which are integrable into silicon electronic devices and emit at a wavelength of 1.537 μm where the absorption of silica glass optical fibers is the lowest. The photoluminescence (PL) of c-Si:Er is strongly quenched with increasing temperature [1].

It has been shown that the intensity of the Er emission strongly depends on the band gap energy of the host semiconductor, mainly for the room temperature emission [2].

In this paper, the results obtained on erbium-doped amorphous hydrogenated silicon (a-Si:H:Er) [3] are extended to erbium-doped amorphous hydrogenated silicon carbide (a-$Si_{1-x}C_x$:H:Er) to increase the band gap energy limit.

It is shown that a-$Si_{1-x}C_x$:H:Er exhibit strong room-temperature PL at 1.54 μm, which is assigned to the internal 4f-shell transition in Er ions.

Films of a-$Si_{1-x}C_x$:H:Er have been prepared by cosputtering of graphite and Er targets applying the magnetron-assisted silane-decomposition (MASD) technique with mixtures of Ar and SiH_4 used as sputtering gas. The composition of films (x) and the presence of Er in the films have been monitored by Rutherford back scattering (RBS), (x) was varied in the range 0—0.29. The concentration of incorporated Er-ions was 6×10^{19} cm^{-3}. The content of hydrogen was estimated by IR-spectroscopy at 9–12 at %. The optical band gap was determined by CPM as an energy where the absorption coefficient is 10^3 cm^{-1} varied from 1.59 (x = 0) to 1.82 eV (x = 0.29).

A detailed comparison between the temperature dependences of PL in a-$Si_{1-x}C_x$:H:Er, a-Si:H:Er and Er-implanted c-Si:Er is presented. It was shown that the onset of temperature quenching of PL in the case of a-$Si_{1-x}C_x$:H:Er is observed at higher temperatures than for a-Si:H:Er and c-Si:Er and the quenching less pronounced. The weak temperature dependence of PL in a-$Si_{1-x}C_x$:H:Er is discussed in the terms of the model previously proposed by us for a-Si:H:Er [3]. In this model the mechanism of electronic excitation of Er ions is based on defect-related Auger excitation.

This work was supported in part by the Arizona University.

[1]. S.Coffa, G.Franzo, F.Priolo, A.Polman, R.Serna, *Phys. Rev.* **B49**, 16313 (1994).

[2]. P.N.Favennec, H.I.Haridon, M.Salvi, D.Moutonnet, Y.LE Guillou, *Electron. Lett.*, **25**, N 11, 718 (1989).

[3]. M.S.Bresler, O.I.Gusev, V.Kh.Kudoyarova, A.N.Kuznetsov, P.E.Pak, E.I.Terukov, I.N.Yassievich, B.P.Zakharchenya, W.Fuhs, A.Sturm, *Appl. Phys. Lett.* **67**, 24, 3599 (1995).

SOME TRIBOLOGICAL PROPERTIES OF REACTION-SINTERING SILICEN CARBIDE

A.P.Garshin,

St. Petersburg State Technical University,
Polytechnicheskaya, 29, St. Petersburg, 195251,
RUSSIA

Experimentally, it has been studied the dependences of the coefficient of friction (f) upon the unit pressure (p) and on the gliding speed (V_{sl}) for the couple of friction Silicon Carbide-Silicon Carbide (SiC-SiC) at different values of p and temperature (T). The wear intensity in the mass (I_g) have been studied also depending on the p for the couple friction SiC-SiC and SiC-Metal. It was stated that reaction-sintering silicon carbide has good antifriction material and it can be used in the couples of friction acting under the conditions of lubrication with water and chemically active compounds.(in different devices). But this material cannot function under the conditions of striking and vibrating loads.

1st European Conference on Silicon Carbide and Related Materials

Tuesday, October 8, 1996 17:00-19:10

SESSION 6: SiC-BASED DEVICES AND APPLICATIONS

Chairman: A. Christou

RECENT PROGRESS ON SiC-BASED DEVICES

D. Stephani,
Siemens AG, Corporate Research and Development, Dept. ZFE T EP 6,
Paul-Gossen-Str. 100, D 91052 Erlangen, Germany,
Tel. +49 9131 731718, Fax +49 9131 723046.

Silicon Carbide has become commercially available some years ago in the modifications 6H and 4H and since then SiC has been attracting more and more scientists because of its very promising semiconductor properties. We are interested in electronic devices exhibiting blocking voltages of more than 300 V, and it is the much higher electron mobility parallel to the c axis in 4H-SiC with respect to 6H-SiC why we have focused our activities to 4H-SiC. Epitaxial layers of high quality are inevitable in order to perform device related research and we make use of our own technology to reliably produce epilayers intentionally doped down to N_D-$N_A \geq 2{\cdot}10^{15}$ cm^{-3}. Unintentional background doping of less than 10^{14} cm^{-3} is routinely achieved in the central region of 35 mm 4H-SiC wafers.

In order to exhaust the capabilities of SiC with respect to blocking voltage an efficient edge termination has to be applied to cope with electric fields of the order of 2 MV/cm at the device periphery. We have developed a special extended bipolar junction termination to satisfy these demands.

We have fabricated Schottky diodes with nominal forward current of up to 4A (250 A/cm^2) and blocking voltage of 1200 V to serve as an example for the advantage of SiC devices. Static losses of these diodes compete favorably with silicon pn diodes, and switching losses are negligible in contrast to ultra fast silicon pn diodes.

Another type of devices we are interested in are n-channel enhancement SiC MOSFETs. Oxides grown on 4H-SiC and on 6H-SiC exhibit an electric field strength of more than 10 MV/cm and the total charge density at the interface between oxide and p-doped SiC can now be reduced by proper processing to about $2{\cdot}10^{11}$ cm^{-2}. We have developed a technology for fully implanted (p-base, n+ contact, channel stop, p+ contact) lateral MOSFETs and have fabricated them on 6H-SiC and on 4H-SiC.

On the basis of these investigations and exclusively using ion implantation into low n-doped epitaxial layers on high doped substrates, we have fabricated vertical TI^2MOSFETs (TI^2 = Triple Ion Implanted) with channel length of 1μm and gate periphery up to 1 cm.

OVERVIEW OF SILICON CARBIDE POWER ELECTRONICS

V.E.Chelnokov 1), A.L.Syrkin 2) and V.A.Dmitriev 1)

1 Ioffe Physical Technical Institute Russian Academy of Sciences, 26
Politechnicheskaya Street, 194021 St. Petersburg, Russia

2 Groupe d'Etude des Semiconducteurs Université Montpellier II "Sciences et
Techniques du Languedoc" cc 074, 34095 Montpellier Cedex 5, France

We will make an overview of four groups of problems actually limiting the progress of SiC based power electronics. The first group concerns structural quality of material which limits the working area of devices. It is common opinion that micropipes are the main defect limiting the size of high voltage SiC device. But weather it is the unique crucial type of defect?

The second group is important to resolve a problem of base modulation in SiC based high voltage power diodes. What are the main factors influencing diffusion length in SiC? How to improve it and weather it is possible?

The third one is strongly connected with the foregoing. It is the problem of main life time 'killers' in SiC, methods of investigation of such centers and methods of the control of life time.

And finally group of thermodynamic problems connected with the heat transport in power devices at high switching power density and appropriate design of SiC-based power elements.

The possible ways to resolve these problems will be also discussed.

2.5 KV ION-IMPLANTED p^+n DIODES IN 4H SiC

K. H. Rottner, A. Schöner, S.M. Savage and M. Frischholz
IMC, P.O. Box 1084, S-16421 Stockholm-Kista, Sweden, Tel.: +46 8 752 1047, Fax: +46 8 750 5430

Up to now high voltage diodes in SiC have been fabricated almost exclusively by epitaxial growth of a highly doped p layer on lowly doped n-layers using a dry etch process.

Ion implantation of dopants is a technique which allows doping with high throughput, excellent uniformity and reproducibility. An important application is the doping of selected areas of the semiconductor allows the realization of a large variety of different device structures e.g. fabrication of planar devices which avoids the drawbacks of mesa terminated diodes. These are e.g. different crystallographic orientations of the mesa surface causing problems for the oxidation process.

Using ion implantation to incorporate dopant atoms into SiC recently has become more and more an available technology. With the results achieved by high temperature implantation ($T_{impl} \geq 500$ °C) and subsequent annealing at temperatures well above 1500°C the activation of boron was demonstrated to be almost 100% [1].

Ion implanted pn junctions are reported [2,3] to have either high leakage current under reverse bias condition or high forward voltage drop or both. In order to evaluate the feasibility of using this technique for SiC rectifiers we have fabricated planar p^+n diodes in low doped 4H SiC using ion implantation. The device performance was compared to epitaxially grown mesa diodes with similar doping concentration and base layer thickness.

The breakdown voltage of the implanted diodes was found to be 2.5 kV - the highest reported value in literature. From the theoretical standpoint junction termination is needed in order to keep the surface electric fields low enough to avoid premature breakdown. However, our devices did not suffer from having no intentional junction termination. The experimental finding that diodes block higher voltages than 2D simulation predicts was already established in a previous study [4].

We conducted OBIC measurements (Optical Beam Induced Current) to study the electrical field distribution in these devices under reverse bias conditions. OBIC probes locally electric fields by generation of electron - hole pairs by UV photons. In depletion regions these carrier are separated and are detected as photocurrent.

In agreement with previous results the lateral depletion width of the diodes was found to be enlarged considerably. The depletion width was nearly independent of the applied bias voltage level. These experimental results indicate the presence of large negative surface charge. This charge provides a self-termination of the devices which lowers the surface electrical field. This can explain the finding that the diodes could withstand the high bias voltages than predicted by the device simulation.

The reverse leakage current levels were one to two orders of magnitude lower compared to a mesa diode with similar doping levels although the implanted diodes did not have any additional passivation layers on top of the SiC. No hard breakdown characteristic was observed but a steady increase in the reverse current. This might be due to the lack of a surface passivation/insulation. A pronounced walk-out phenomenon was observed in the implanted as well as the mesa diodes. The breakdown occurred by external flashover but did not irreversibly alter the device characteristics. This is in contrast to experimental findings on mesa diodes.

The forward current voltage curves of these diodes showed exponential behavior in a large current range with an ideality factor 1.05. However in the high current density region limitations by serial resistivities were observed which partly can be assigned to the external circuitry of the I-V measurement set-up.

[1] G. Pensl, Proc. 6th Int. Conf. on SiC and Related Material- 1995, Sept. 18-21, Kyoto
[2] M. Ghezzo et al. Appl. Phys. Letters **63** (1993), p. 1206
[3] D. Planson et al. Proc. 1st Int. Power Electronics and Motion Control Conf.94, Beijing
[4] K. Rottner et al. in Proc. 6th Int. Conf. on SiC and Related Material- 1995, Sept. 18-21, Kyoto

HIGH FIELD AND HIGH TEMPERATURE STRESS OF n-SiC MOS CAPACITORS

E.Bano, T.Ouisse, C. Leonhard*, A. Gölz* and E.G. Stein von Kamienski*
Laboratoire de Physique des Composants à Semiconducteurs (LPCS) UMR-CNRS 5531, ENSERG,
23, rue des Martyrs, 38016, Grenoble, France (tel:33 76 85 60 50 fax: 33 76 85 60 70)
**Institut für Halbleitertechnik, Lehrstuhl II, RWTH Aachen, Sommerfeldstr. 24, D-52074 Aachen,*
Germany

The development of reliable oxides built on SiC has become a very important issue with respect to either passivation processes or MOS applications. Up to now, oxides grown on n-type epilayers have been shown to be of higher quality than their p-type counterparts, and reliability aspects can therefore be investigated more systematically. The aim of this paper is to present a detailed investigation of Fowler-Nordheim injection in n-type SiC 6H MOS capacitors fabricated at RWTH, both as a function of the electric field magnitude and stress temperature. Systematic data have already been presented elsewhere for lower fields [1], and we focus here on the build-up of an anomalous positive charge at higher fields. Fowler-Nordheim injections were carried out with a constant injection current I_{inj} and at temperatures ranging from T=300 to 500K, with total injection doses up to 10^{19}charges/cm^2. I_{inj} was varied from 10^{-6} to 10^{-5} A/cm^2. The oxide thickness was 44nm and the net doping level was N_D-N_A=7×10^{15}cm^{-3}.

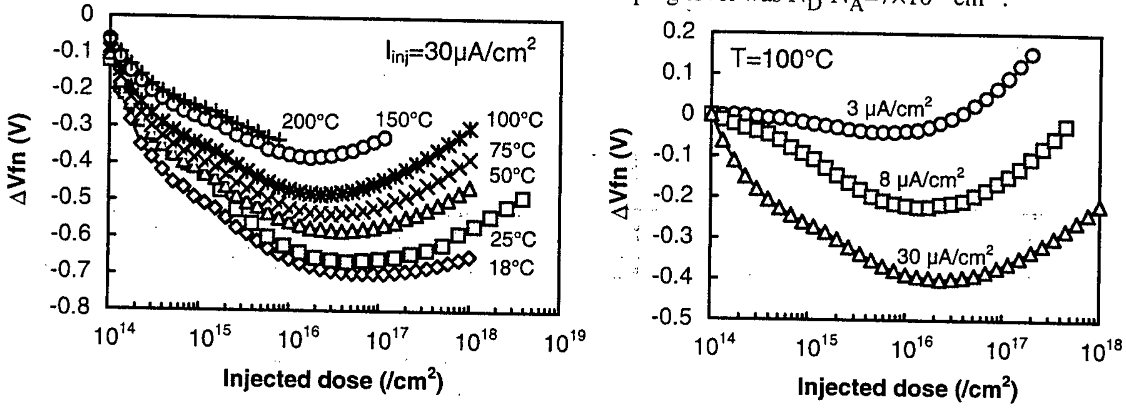


Fig.1: trapped charge vs injected dose for (a) various temperatures and (b) various injection currents.

Some observations resulting from a systematic variation of T and I_{inj} are summarized below:

- For large values of the average electric field during the stress, one always observes the building of a large positive trapped charge (Figs.1a and b). This positive charge can be dissociated into two different time processes, and increases continuously with the chosen value of I_{inj} (this contrasts with water-related traps). Besides, the positive charge build-up is strongly reduced by increasing the temperature (Fig.1a).
- Electron trapping mainly occurs via a single trapping process, and the order of magnitude of the trap density and capture cross section are 10^{11}cm^{-2} and 10^{-18}cm^2, respectively. The capture cross section is not appreciably modified by a change in temperature.
- Low frequency conductance data indicate a creation of interface states the density of which decreases with T and vanishes above T=150°C. These data also demonstrate that injection is homogeneous, since there does not seem to be any substantial change in the surface potential fluctuations.

We tentatively attribute the positive charge build-up to the trapping of holes generated by impact ionization in the oxide, and we will give a further detailed argumentation. In particular, this explanation is favoured by the electric field and temperature dependence, as well as the oxide thickness value. It has already been demonstrated that in SiO$_2$ on Si, and for E>7MV/cm and t_{ox}>20nm, the hot electron energy distribution tail was large enough so as to enable impact ionization and subsequent hole trapping [2]. From our results, it can be concluded that these phenomena remain essentially unchanged in the case of SiC.

[1] E.G.Stein von Kamienski, F.Pontheine, J.Stein, A.Gölz and H.Kurz, *J. Appl. Phys.* **79**, p.2529 (1996)
[2] D.J.DiMaria, D.Arnold and E.Cartier, *Appl. Phys. Lett.* **60**, p.2118 (1992)

PLATINUM METAL - INSULATOR - SILICON CARBIDE DEVICES OPERATING UP TO 1000°C

Peter Tobias, Amir Baranzahi, Anita Lloyd Spetz, Per Mårtensson, and Ingemar Lundström.
S-SENCE and Applied Physics, Linköping University, S-581 83 LINKÖPING, Sweden. Phone: +46 13 281000, Fax: +46 13 288969.

Platinum Metal - Insulator -Silicon Carbide (MISiC) devices are produced as both capacitors and Schottky diodes. Hydrogen containing molecules are dissociated on the surface of the catalytic metal. Hydrogen atoms formed rapidly diffuse through the metal. They are polarised at the metal insulator interface and influence charges at the silicon carbide surface. This lowers the flatband voltage of the capacitor and the threshold voltage of the Schottky diode. Both capacitors and diodes improved considerably from a buffer layer between the silicon dioxide and metal. Tantalum silicide and tantalum pentoxide have been demonstrated as buffer layers.

MISiC capacitors that show inversion capacitance at 1000°C have been fabricated. They were operated in an atmosphere of alternating 1 % oxygen/argon and 1 % propane in 1% oxygen/argon. The change in flatband voltage was monitored at a constant capacitance, and rapid changes in the gas atmosphere in the order of 1 second could be followed. Similarly, the threshold voltage of the Schottky diodes could be monitored to follow rapid changes in the gas atmospheres up to a temperature of 800°C. The MISiC sensors might be used in an application for rapid control of the fuel/air ratio of combustion engines [1].

At high enough temperatures, above 650°C, the inversion capacitance was found to be considerably lower in hydrogen compared to an argon or oxygen atmosphere, as also demonstrated earlier [2].

Some physical properties of capacitors were investigated for 4H and 6H SiC material from 700 to 800°C. The capacitance voltage curve showed a big hysterises in a constant gas ambient. This is discussed in terms of a charge injection into the oxide from the silicon carbide surface.

References:
[1] Fast responding high temperature sensors for combustion control, A. Baranzahi, A. Lloyd Spetz, M. Glavmo, J. Nytomt, and I. Lundström, Digest of Technical Papers, Transducers'95 & Eurosensors IX, vol.1, (1995) 741 - 744.
[2] Reversible hydrogen annealling of metal-oxide-silicon carbide devices at high temperatures, A. Baranzahi, A. Lloyd Spetz, and I. Lundström, Appl. Phys. Lett. 67, 21 (1995) 3203-3205.

1st European Conference on Silicon Carbide and Related Materials

Tuesday, October 8, 1996 19:15

ROUND TABLE DISCUSSION: SiC APPLICATIONS AND EUROPEAN INDUSTRY

Chairman: G. Pensl

Dr. C. Brylinski (Thomson-CSF), Dr. S. Lande (MAGUS Research), Dr. J. Lasseur (Schlumberger Ind.), Dr. E. Niemann (Daimler Benz), Dr. A. Sénes (Schneider Electric), Dr. D. Stephani (Siemens).

1st European Conference on Silicon Carbide and Related Materials

Wednesday, October 9, 1996   08:30-10:00

SESSION 7: NITRIDES GROWTH AND CHARACTERIZATION

Chairman: R. F. Davis

Growth of GaN single crystals and properties of homoepitaxial MOCVD and MBE layers

S. Porowski

High Pressure Research Center Polish Academy of Sciences
ul. Sokolowska 29/37, 01-142 Warsaw, Poland

Abstract

Thermodynamical properties of AlN, GaN and InN is reviewed. It is shown that significant differences in melting conditions, thermal stability and solubilities in liquid III group metals lead to different possibilities of growing crystals from high temperature solutions, at N_2 pressure up to 20 kbar.

It is shown, that the best conditions for crystal growth at available pressure and temperature conditions can be achieved for GaN. High quality 6-10 mm single crystals of GaN have been grown at high N_2 pressure in 60-150 hours processes. The mechanisms of nucleation and growth of GaN crystals are discussed on the basis of the experimental results

The crystallization of AlN is less efficient due to relatively low solubility of AlN in liquid Al. Possibility for the growth of InN crystals is strongly limited since this compound loses its stability at T>600^{o}C, even at 2 GPa N_2 pressure.

The crystals of GaN grown at high pressure are first crystals of this material used for homoepitaxial layer deposition. Both MOCVD and MBE methods have been successfully applied. Structural, electrical and optical properties of both GaN single crystals and homoepitaxial layers are reviewed.

GROWTH OF III-V NITRIDES BY MOLECULAR BEAM EPITAXY

T. D. Moustakas, Department of Electrical Engineering and Center for Photonics Research, Boston University, Boston MA 02215, tel.: (617) 353 5431,fax:(617) 353 6440

The heteroepitaxial growth and doping of III-V nitrides on (0001) sapphire by Molecular Beam Epitaxy was investigated. In this method the group III elements and the dopants (Si and Mg) are evaporated from regular effusion cells and active nitrogen is formed by passing molecular nitrogen through an Electron Cyclotron Resonance Source. Design criteria for the optimum operation of this source will be discussed.

The growth involves three steps. First the surface of the Al_2O_3 substrate is converted into AlN by plasma nitridation. The second step involves the deposition of a low temperature (about 500 °C) GaN buffer approximately 200-300 Å thick. The final growth takes place at 700-800 °C and involves the deposition of either a homogeneous III-V nitride film or InGaN/AlGaN heterostructures.

The role of the substrate nitridation and the low temperature buffer in the establishment of quasi-layer-by-layer growth with small two dimensional nucleation rate and high lateral growth rate will be discussed. The incorporation of misoriented domains or second phase (zincblende) during the growth of the low temperature buffer was found to have a significant effect in controlling the formation of inversion domains. The structure and microstructure of the films were investigated by XRD and TEM.

The same method was used for the growth of InGaN thick films and InGaN/GaN MQW structures. Phase separation of InN has been observed in thick InGaN alloys with In concentration in excess of 30%. This is thermodynamically expected since the critical temperature for miscibility of the GaN-InN pseudo-binary system was calculated to be almost 2500 K. Such phase separation is absent in single or MQW structures, which were found to have more intense and spectrally narrower luminescence than the bulk films.

The GaN films were doped both n and p-type with Si and Mg respectively to net carrier concentration of about 10^{19} cm^{-3}. The role of hydrogen in de-activating the Mg-dopants was investigated by post-growth hydrogenation.

This method for the growth of III-V nitrides has been successfully employed for the fabrication of LED's, detectors and transistors. A brief review of the properties of these devices will be presented.

RESIDUAL STRAINS IN GaN GROWN ON 6H-SiC

Nikitina I.P.*, Sheglov M.P.**, Melnik Yu.V.*, Irvine K.G.***, Babanin A.I.*,
and Dmitriev V.A.***

** - Cree Research EED and A.F. Ioffe Institute, 26 Politechnicheskaya Str., St Petersburg, Russia*
*** - A.F. Ioffe Institute, 26 Politechnicheskaya Str., St Petersburg, Russia*
**** - Cree Research, Inc., 2810 Meridian Parcway, Durham, NC, USA*
FAX: +7 (812) 247-6425;
e-mail: postmaster@shuttle.ioffe.rssi.ru

Epitaxial growth of GaN layers is a subject of great interest for fabrication of devices emitting light from the red to the ultraviolet region of the optical spectrum. Recently, high quality GaN epitaxial layers have been grown on SiC substrates. Nevertheless the C-lattice constant of these layers is less than that for bulk GaN crystals [1], indicating that residual strain is always present in the layers. Two main factors may cause strain in epitaxial layers: (1) the lattice mismatch and (2) the difference in the thermal expansion coefficients between the layer and the substrate. It was shown that the strains. caused by the GaN/SiC lattice mismatch relaxe due to the formation of a deformed initial GaN sublayer near the substrate independently of the growth technique and the buffer layer existence [2, 3]. It was suggested that the observed residual strains are a thermal in nature. The strains arise during cooling of samples after the growth. These residual thermal strains may cause a deterioration of electrical and optical properties of devices.

In this paper we report on the impact of the buffer layer existence and composition on residual strains in GaN epitaxial layers grown on SiC substrates. GaN layers were grown on 6H-SiC (0001) by HVPE without emploing any buffer layer [2] and by MOCVD [3] using AlN and AlGaN buffer layers. The thickness of the GaN layers ranged from 1 to 2 μm, the thickness of substrates was ~300 μm.

Table 1

Sample	buffer layer	$\varepsilon_{\perp}$ x10^3	$\varepsilon_{\parallel}$ x10^3
1	non	-1.14	+2.51
2	non	-1.02	+1.88
3	non	-1.37	+2.92
4	non	-1.35	+2.67
5	AlN	-0.77	+1.22
6	AlN	-0.58	+1.22
7	AlN	-0.54	+0.85
8	AlGaN	-0.35	+0.77
9	AlGaN	-0.31	+0.72
10	AlGaN	-0.28	+0.50
11	AlGaN	-0.08	+0.47
12	AlGaN	-0.31	+0.69

The measurements of GaN lattice constants were performed using X-ray Bond method for symmetrical (0004) and asymmetrical (11-24) CuKα reflections to estimate normal and tangent strains in the layers. The lattice constants were measured with an accuracy of 5×10^{-5} Å. Rocking curves in (ω) and (ω, 2θ) modes were measured using X-ray triple crystal spectrometer with 6H-SiC (0001) high quality single crystals as monochromator and analyser. Significant reduction in the residual strains occurs in GaN layers grown on SiC using AlGaN buffer layer comparing with GaN layers grown with or without AlN buffer layer. Results are shown in Table 1, where $\varepsilon_{\perp}$ is the strain parallel to [0001] direction and $\varepsilon_{\parallel}$ is the strain in the perpendicular direction.

Residual strains in GaN epitaxial layers will be analyzed together with results of AES and SIMS measurements. Some ways for futher decreasing of the strains in GaN grown on SiC, and in turn, its effect on improvement of devices performance will be discussed.

[1]. M. Leszcynski, T. Suski, H. Teisseyre, P. Perlin, I. Grzegory, J. Jun, and S. Porovski, Thermal expansion of gallium nitride, J. Appl. Phys.., 76 (8), pp.4909-4911, 1994

[2]. Yu. V. Melnik, I.P. Nikitina, A.S. Zubrilov, A.A. Sitnikova, V.A. Dmitriev, High quality GaN grown on SiC by halide vapour phase epitaxy, Technical Digest of International Conference on Silicon Carbide and Related Materials-1995, September 18-21,1995, Kyoto, pp. 198-199

[3]. I.P. Nikitina and V.A. Dmitriev, X-ray differential diffractometry applied to GaN grown on SiC, Inst. Phys. Conf. Ser. 141, ed. H. Goronkin and U. Mishra (IOP Publishing, Bristol, 1995), pp. 431-436

1st European Conference on Silicon Carbide and Related Materials

Wednesday, October 9, 1996 10:20-11:45

SESSION 8: AMORPHOUS SiC AND OTHER SiC-RELATED MATERIALS

Chairman: M.T. Mora-Clavaguera

Thin-Film-on-ASIC Applications of Hydrogenated Amorphous Silicon Carbide Alloys

Gerhard Müller
Daimler-Benz AG, Forschung und Technik,
Postfach 80 04 65, 81 663 München,
Fed. Rep. of Germany.

Abstract: Hydrogenated amorphous silicon carbide alloys (a-$Si_{1-x}C_x$:H; $0 < x < 1$) can be plasma-deposited at temperatures of the order of 200 to 400°C. The material properties of this alloy system can be tailored to application needs by varying the alloying parameter x and the deposition temperature T_d. Properties which make these materials interesting as add-ons to crystalline silicon wafer technologies are the following:

- the optical bandgap of the alloy films can be varied within the range 1.7 eV < hν < 3.5 eV depending on the alloy parameter x. This possibility is particularly interesting for realising optical and optoelectronic devices;

- alloys with $x < 0.4$ exhibit an extreme etch resistance with respect to KOH and HF based electrolytes. A-SiC:H layers therefore play an important role as passivation layers for the micromachining of silicon substrates. The HF resistance of a-SiC:H layers, in particular, allows novel micromachining concepts to be pursued which are based on porous silicon sacrificial layer technologies;

- etch-resistant a-SiC:H layers are characterised by a poor thermal conductivity. This latter property makes a-SiC:H an interesting membrane material. Using such membranes a range of micromachined sensor elements can be realised whose functioning is based on thermal effects.

In the present paper the preparation and properties of a-$Si_{1-x}C_x$:H alloys will be dealt with and a number of applications will be pointed out which had been demonstrated at the Daimler-Benz Research Laboratories. These examples include colour sensors as well as a range of micromachined membrane-type devices.

"SURFACE AND BULK EFFECTS IN *EX-SITU* HYDROGENATED a-SiC THIN FILMS"

J. Kalomiros[a)], E. C. Paloura[a,*)], C. Janowitz[b)], and A. Anagnostopoulos[a)].

[a)] Aristotle Univ. of Thessaloniki, Dept. of Physics, 54006 Thessaloniki, Greece.
[b)] Humboldt Univ. zu Berlin, Dept. of Physics, Invalidenstr. 110, 10115 Berlin, Germany.

Silicon carbide films (SiC) have been a subject of intensive study because they find a series of applications in microelectronic devices including photodiodes and phototransistors. Atomic hydrogen, introduced by low-temperature annealing in a glow-discharge atmosphere (*ex-situ* hydrogenation), has been used for the modification of electronic properties as well as surface cleaning and/or plasma etching of several material systems, including III-V compounds and Si. However, *ex-situ* hydrogenation of SiC has not been studied in detail yet. Here we present a study of surface and bulk modifications induced by exposure of a-SiC films to atomic hydrogen generated by an rf glow discharge (13.56MHz), at 230°C.

The near surface modifications were monitored with VUV spectroscopic ellipsometry while the co-current bulk changes were studied with dark dc conductivity and transmission measurements, in the region of the fundamental gap. Ellipsometry results show that, unlike in the case of *in-situ* hydrogenation[1], *ex-situ* hydrogenation promotes preferential Si etching from the surface and results in a drastic change in the dielectric function after the process. The treated samples show dielectric function and loss function peaks, characteristic of a carbon layer bonded by sp^2 and sp^3 hybridization[2,3]. The formation of the surface carbon layer, which is attributted to prefrential etching of Si from the surface of the SiC film, has been confirmed by XRD and XPS[4] measurements.

Dark conductivity measurements as a function of temperature show that the diffused atomic hydrogen passivates a number of states in the gap, resulting in a decrease of the DOS at the Fermi level. The activation energy for conduction is 0.2eV, a value that indicates conduction via hopping. Furthermore, hydrogenation results in an increase of the energy gap, calculated from Tauc plots, to an extent that depends on the hydrogenation conditions (pressure, rf power, time). By the above we have established that *ex-situ* hydrogenation changes drastically both the bulk electronic and surface properties of a-SiC.

Finally, the hydrogen-induced surface modifications could provide new insight in the problem of dry etching of SiC which is a critical step in device processing.

---

[*] Author for correspndence : fax # 30 31 998036, e-mail : paloura@olymp.ccf.auth.gr

[1] J. A. Kalomiros, A. Papadopoulos, S. Logothetidis, L. Magafas, N. Georgoulas and A. Thanailakis, *Phys. Rev. B* 49, 8191 (1994).

[2] J. A. Kalomiros, E. C. Paloura, A. Ginoudi, S. Kennou, S. Ladas, Ch. Lioutas, N. Vouroutzis, G. Voutsas, D. Girginoudi, N. Georgoulas, A. Thanailakis, *Solid State Commun.* 96, 735 (1995).

[3] C. Janowitz, J. Kalomiros, A. Ginoudi, E. C. Paloura and R. L. Johnson, *Solid State Commun.* (in press).

[4] S. Kennou, S. Ladas, E. C. paloura, J. A. Kalomiros, Appl. Surf. Science 90, 283 (1995).

OPTICAL STUDY OF BORON NITRIDE THIN FILMS PREPARED BY PLASMA-ENHANCED CHEMICAL VAPOUR DEPOSITION

M. C. Polo(1), M. Ben el Mekki(2), J. L. Andújar(1) and J. Pascual(2)

(1) Departament de Física Aplicada i Electrònica, Universitat de Barcelona, Diagonal 647, E-08028 Barcelona, Spain - Tel/Fax 34 (3) 402 11 38
(2) Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain -Tel/Fax 34 (3) 581 13 50

Transmission electron microscopy (TEM) has been widely used to study the microstructure of the BN films. But this is a destructive tecnique and requires a laborious sample preparation which becomes more difficult in the case of hard films. On the opposite, the Fourier-transform infrared (FT-IR) spectroscopy has been proved as a powerful non-destructive technique to identify the several phases of BN. In this work we present an FT-IR reflectance study to determine the structure of h-BN films.

Transparent and stochiometric BN films were prepared by radio frequency plasma enhanced CVD (RF-PECVD) from a gas mixture of NH3 and B2H6 (1% in H2). The films were deposited on silicon substrates heated at 300ºC. The FT-IR spectra of the films showed the B-N stretching (in-plane) vibration mode at around 1370 cm-1 (E1uLO) and the B-N-B bending (out-of-plane) vibration mode at about 780 cm-1 (A2uTO).

Because h-BN is anisotropic, different vibration modes can be excited depending on both, the orientation of the basal planes with respect to the surface substrate and the polarization of the ligth. For example, the 830 cm-1 (A2uLO) mode was not present in the spectra of some samples, even at high incidence angles. We have simulated the reflectance spectra for each possible configuration using the classical oscillator model and the Fresnel equations. We can conclude than these films have a highly oriented hexagonal structure with the c-axis parallel to the substrate surface in agreement with high resolution TEM cross sectional observations.

The stretching band shows a characteristic shoulder at around 1500 cm-1, which has been object of several interpretations in the literature. It has been ascribed to C-C, B-O and N-H2 bonds. On the other hand, it has been related to the films microstructure either by the presence of an amorphous BN phase or by surface low orbital phonons absorption. In addition, the shape of the bending band has been connected to the presence of different BN structure modifications. Therefore a better undestanding of the transmission spectra analysis is needed for tailoring the film properties to suit the requirement for a given application.

In this work we study absorption bands of good quality BN films. They always shows shoulder at energies around 1500 cm-1, in agreement with theoretical predicitons, the shape of this shoulder changes with the thickness of the film; so that, a careful interpretation of the transmission spectra is in order when growing BN films under different experimental conditions. In particular, the PECVD BN films does not show extrinsic effects in the absorption band at 1370 cm-1 and the quality of the film is stable with time. In addition, we show that the relative intensity of the in-plane and out-of-plane absorption is connected with the domaine structure of the film.