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INVESTIGATION OF MOLECULAR BEAM EPITAXIAL GROWTH OF COMPOUND SE--ETC(U)
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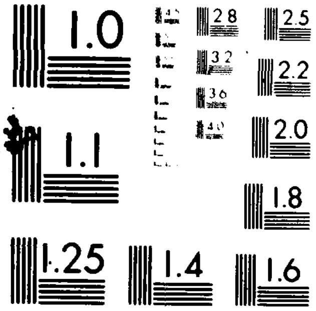

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MBE growth of non-alloyed ohmic contacts using a 250 Å layer of N^+ germanium between the N type GaAs and the metal has yielded specific contact resistances well below $1 \times 10^{-7} \Omega\text{-cm}^2$. Various N type dopants in GaAs were investigated; Si proved to be the best for making ultra thin doped or undoped donor regions, with Ge being nearly as good, except for a small amount of surface segregation. Beryllium proved to be the best for making ultra thin acceptor regions, and it was used to make the first planar doped barriers, constructed at Ft. Monmouth. The physical electronics of Ga,InAs/InP, with Al,InAs electron-

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confining layers, show promise for high frequency transistors.

FINAL REPORT

Contract # DAAG29-80-C-0069

INVESTIGATION OF MOLECULAR BEAM EPITAXIAL GROWTH OF COMPOUND SEMICONDUCTORS AND CONTACTS FOR MICROWAVE DEVICES

In the three years of this contract many advances have been made in the understanding of epitaxial growth of III-V compounds and alloys for use in microwave FET devices. This report is an attempt to summarize those areas where specific advances have been made on this program in both the physical and chemical understanding and the technology development. It includes non-alloyed ohmic contacts using a thin layer of N^+ germanium as well as limits of doping with a few donor species and the concept of doping in planes of lamellae. Finally it includes the initial phases of work on GaInAs/InP heterojunction transistors, using Al,InAs confining layers, following earlier fundamental work supported by ONR on the alloy and heterojunction growth and assessment.

HETEROJUNCTION NON-ALLOYED OHMIC CONTACTS

As devices get smaller, the contact areas have to be reduced in size proportionately with device active areas. This causes a rapid increase in parasitic series resistances associated with metal semiconductor interfaces. This in turn increases the overall time-constant of devices and therefore decreases the maximum operating frequency which one can expect. In addition, there are much higher current densities, due to both faster electrons and higher density of electrons, compounding contact problems. One of the facets of this study was to model ohmic contacts as Schottky barriers and to try and reduce barrier heights by splitting the problem into two parts. One is the Schottky barrier height and the other the doping just under the barrier. An intermediate layer of N+ germanium was chosen on this program for contact optimization.(1) It happens that metals form much lower Schottky barrier heights to germanium than to GaAs. It is also a happy coincidence that germanium has a very close lattice-match to GaAs. It also has a very close thermal expansion coefficient which menas that even after growth in a lattice-match condition it can be cooled down to normal temperatures without any substantial strain. The only unknown parameter before this study was embarked upon, was the conduction band discontinuity between germanium and GaAs. Literature values however indicated that this discontinuity was less than about .2 eV. Subsequently, studies under this contract and a related navy contract found the discontinuity (ΔE_c) to be ~ < .1 eV, thereby not noticably increasing resistance to electron-transport from metal through germanium and across the germanium/gallium arsenide interface. The other important-related problem that needed to be solved was to control the doping level in the germanium to a sufficiently high level that the tunneling probability from metal into the germanium was high.

First of all, to determine the growth parameter dependence of the electrical properties of MBE germanium, layers of germanium were grown on semi-insulating GaAs at various substrate temperatures and ambient arsenic pressures. The results indicated that growing much above 450°C significant diffusion of germanium into GaAs and vice versa led to p-type germanium. This is explained by virtue of the very rapid diffusion coefficient of arsenic compared to that of gallium in germanium. The interface would then be very heavily doped with gallium. The remaining arsenic which diffuses rapidly to the surface, leaves by evaporation. Below ~ 450°C, especially with increasing arsenic background pressures, donor levels in the germanium increased monotonically up to a value of ~ $2\times10^{20}cm^{-3}$ at ~ 280°C with P_{As_4} ~ ; x $;-^{-9}$Torr). This doping level is more than an order of magnitude higher than that in GaAs, substantially benefitting low contact resistance. At temperatures below ~ 220°C, and especially at higher arsenic fluxes, the electron density rapidly decreased owing, as we believe, to the formation of polycrystalline germanium as a direct result of the decrease in surface kinetics of the growth processes associated with reducing temperature and supersaturating with As_4. Optical microscopy and real-time reflection-electron-difraction confirm that ~ 280-300°C was the best physical and structural temperature to grow these very heavily arsenic doped germanium layers.

These very heavily doped germanium layers were then grown on n-type MBE GaAs films to an eventual thickness ~ 250°A° without exposure to air between the growth. Subsequent gold evaporations in the form of resistance test strips were then used to determine the contact resistance as functions of both germanium epitaxial layer thickness and doping level and also as a function of the doping-level and thickness of the underlying GaAs. Plotting resistance as a function of pad to pad separation, and extrapolating down to zero separation, gave values of contact resistance in terms of transfer length. Simple calculations then showed that this value was well below any previously reported value. In fact, a finite-elements solution had to be employed as transmission-line model assumptions are no longer valid when the contact resistance is so low. To this day, it has not been possible to measure accurately these very low values of contact resistance, but all indications are that the best values are approximately 3×10^{-8} Ω-cm^2 on N+ GaAs, and are 5×10^{-8} Ω-cm^2 for thicker N+ germanium (> 1000 Å) on 1×10^{17}/cm^3 GaAs.

LIMITS AND CONTROL OF DOPING

In N-type semiconductors grown by MBE, early work(2) showed that Sn segregates on the surface. This yielded slow build-up of donor density with time and distance and slow reduction. Predeposition of a layer of Sn led to a natural exponential reduction.

In the past three years, the study of N-type doping S, Se, and Te was made at various laboratories following initial work(3) on this program showing that PbSe (or PbS, PbTe) could be used as an MBE source. Although the volatility and diffusion of the elements reduces in the progressing of the ordered sequence S, Se, Te, both of these properties are unwanted, due to contamination of the MBE machine and due to degradation of device profiles. Thus the search proceeded.

Germanium proved to be quite valuable as an N-type dopant, with a small amount of surface segregation, compared with tin. Ge had now volatility or diffusion problem. It was also finally found, in agreement with other, that Si was even better than Ge, having no apparent surface segregation. The use of thin planes of dopant, termed lamellae(4) was introduced using Ge. The limits of doping with Ge in the bulk,(5) and at a single atomic plane were found, beyond which the formation of deep levels occurred. It was found that the impurities could be put into thin layers a few 10's of angstroms thick, to avoid this problem. As well as single doping planes, complex donor density profiles were synthesized using properly spaced lamellae and proper Debye length considerations.(6) Both doping in very thin layers and preventing doping in very thin layers were developed on this program.

An interesting application, initiated on the ONR program at Cornell, of the thin undoped layers, was that of a 60 Å undoped Al,GaAs next to the GaAs heterojunction in modulation doped structures. This allowed a high mobility(7) of 80,000 cm^2/v-s at 77° K for the first time, compared with only 30,000 cm^2/v-s obtained at Bell Laboratories earlier without the thin undoped region. This thin undoped region is now universally used.

As part of the ARO program, application of thin doped regions was made in controlling the properties of potential barriers. A Cornell student, Roger Malik, was sent to Ft. Monmouth on educational leave to pursue his Ph.D. on the new MBE machine there. His study was under the thesis direction of the principal investigators of this contract. He returned to Cornell for one year to complete his studies, and is now back at Ft. Monmouth. Using thin layers of beryllium acceptors in undoped layers sandwiched between N^+ regions, he was the first to develop the planar-doped barriers with triangular potential profiles.(8) The beryllium was well behaved, with no surface segregation and negligable diffusion. These planar doped barriers were intended at first to simply be completely controlled majority carrier non-linear elements to replace Schottky diodes. Because of other OSR-supported work on ballistic electrons initiated at Cornell by one of the principal investigators, Lester Eastman, he in turn saw that planar doped barriers could be designed to be excellent launchers of ballistic electrons. High frequency transistors using planar doped barriers in GaAs and InGaAs are now being pursued on various contracts at Cornell.

Double Heterostructure Alloy Field Effect Transistors

Early work on alloy growth and assessment alloys and their heterojunctions with each other and binary compounds, has been carried out at Cornell under ONR sponsorship. InGaAs, and InAlAs heterojunctions confining layers were studied on that program earlier.

The physical properties and the fundamental physical chemistry of growth of InGaAs and InAlAs grown on InP substrates has been, and will continue to be, a thrust on the ONR program at Cornell. The fundamental physical electronics, design and testing of novel electron devices using these materials have been initiated on this present ARO contract and will continue to be the major thrust in the ARO follow-on program.

On the ONR program it was found that there was approximately 50% higher mobility and saturation velocity in InGaAs lattice-matched to InP, making it an interesting alternative to GaAs as an active FET layer material.

The problem with this particular alloy is not one of high series-resistance ohmic contacts as in the case of GaAs but a very low Schottky barrier height (0.2 eV). This makes a conventional MESFET technology impossible without the use of p-n junction, or as was invented and exploited during this contract period, a thin lattice matched Schottky-assist film which has both a higher Schottky-barrier-height and a higher band-gap than the active layer. The first approach on that program was to grow GaInAs on InP substrates. Before this could be done however, it was necessary to develope a technique for heat-cleaning InP in a vacuum system above its congruent temperature sublimation. This was possible by a method developed with A. R. Calawa at Lincoln Labs using arsenic as a stabilizing flux to the surface, while heat-cleaning to approximately 510°C for a period of 30 seconds. Nominally undoped layers of GaInAs could then be nucleated without any problem on the surface so produced. They were subsequently grown at temperatures from 480-530°C and subjected to both electrical and optical assessment. Background doping levels in GaInAs layers were found ~ high $10^{15}cm^{-3}$ to low $10^{16}cm^{-3}$ n-type. The source of these donors is not yet fully understood, however it appears to be ubiquitous in any GaInAs or InP material grown epitaxially, especially by molecular beam epitaxy. This concentration however does not preclude the growth of $10^{17}cm^{-3}$ back doped GaInAs for use in FET active layers. Optical measurement showed very good crystal quality at elevated substrate temperatures. However, this is well above T_{cs} temperature of the alloy GaInAs which was found to be about 480°C. In order to stabilize this material during growth, it was necessary to have very high arsenic fluxes. Recent work at Varian has shown that optically very attractive GaInAs can be grown as low as 480°C which is close to the T_{cs} and therefore should allow more efficient use of arsenic in the molecular beam epitaxy system.

To overcome the low Schottky barrier height of metals to GaInAs, the use of AlInAs at approximately the same composition, latticed matched to both InP and GaInAs, was suggested by Ohno at Cornell and investigated onthe ONR program in the molecular beam epitaxy system.

It was found easy to grow chemically, however electrically this material was poor when grown below 550°C. There is still very poor quality even at substrate temperature of 550°C and the 4K photoluminescence emision is ill-defined and weak. However, as a passive interfacial layer between GaInAs and the metal Schottky barrier, AlGaAs is acceptable and the current GaInAs quality is of adequate quality for active layers. The Schottky barrier height of AlInAs was not known at the start of this study but subsequently has been found to be between .5 and .6 eV (also receiving more study). That value of barrier height then enables a conventional MESFET technology. Subsequently, an FET with GaInAs active layer and AlInAs Schottky assist film with gold or Al Schottky barrier subsequently deposited was made. FET's fabricated from this sort of structure showed relatively high transconductance, however, they were almost impossible to pinch off. This was thought due to the interface properties between the InP and the GaInAs. In an analogous system, GaAs interfaces with GaAs substrates have been found much improved (here at Cornell) by the use of AlGaAs buffer layers. Such buffer layers not only act as electron confinement for channel electrons by virtue of the conduction band disconuity, but also have a very low free carrier mobility because of the indirect nature of the gap. AlInAs has a very large conduction band disconuity (~ .35 V) betwen itself and GaInAs. We therefore used thin layers (~ 300 Å) of AlInAs as buffer layers between the GaInAs/InP in the structures previously described. Devices were then very easy to pinch off and transconductance values of 165 mS/mm of gate width have been achieved, which is much superior to conventional GaAs devices. It was found that the mobility of electrons in GaInAs grown on InP was slightly higher than those grown on AlInAs buffers, which is another indication that the quality of the AlInAs is not yet what we would like. It is expected with the use of an arsenic dimer source that of both the electrical and optical quality AlInAs can be improved to allow it to be used itself as an active layer for heterojunction systems. One area, the difference in energy between the lower and upper valleys makes InGaAs (.58 V) potentially of increased interest over GaAs (.34 eV) for mm wave transistor applications, especially in the ballistic regime where we need to be able to excite the electrons up to as high an energy as possible without transfer to the upper valley.

In the latter part of the present ARO program, we have been concentrating almost entirely on GaInAs, currently looking at the use of the recently invented planar doped barrier as ballistic injection devices. We have also demonstrated the capability of the two dimensional electron gas system in the GaInAs, AlInAs modulation doped structures (as we previously predicted in the MBE Workshop of 1980). This structure will receive attention as FET device material processed into field effect transistors and dc and microwave measurements made.

It is hoped that on the next three year ARO follow-on contract, we will further understand the physical electronics of GaInAs and related confining layers in field effect transistors and other devices. Initial indications are that it does not behave well under high biased conditions. Some evidence for avalanching or real-space intervalley transfer between its own and AlInAs L-valleys has been observed. We therefore do not expect this material to be much use for power devices, however, for low-noise devices and for high speed digital applications, we feel that the work that we have carried out in the previous three years is very encouraging and lays the base for a very professional and optimistic study of this material in the near future. Work is also continuing on the electrical properties of the GaInAs/AlInAs interface by optical and electron transport techniques as functions of temperature. This work is ongoing on a related ONR contract. Work is also ongoing on Ge/AlGaAs heterojunctions structures in an attempt to utilize the very low Schottky barrier height of germanium to AlGaAs for uses in the two dimensional electron gas FET as an alternative to a graded AlGaAs/GaAs interface and also as a top layer for both graded and abrupt Ge/AlGaAs structures.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that non-alloyed ohmic contacts with superior properties are possible on GaAs using metallized, epitaxial MBE N^+ germanium. It is recommended for use where subsequent processing does not elevate the temperature above 450°C for extended times.

It is also concluded that abrupt dopant profiles have very important consequences and that silicon and beryllium can be used in MBE to make very thin donor and acceptor planes for use in novel electron devices. Germanium donors are nearly as good, but doe suffer from a small amount of surface segregation. Thin undoped layers, of benefit to modulation doped structures, are also very valuable. Planar doped barriers, first grown at Ft. Monmouth in conjunction with a Ph.D. thesis on this program, is the best example to date of such thin doping planes. It is recommended that such planar doped barriers and other applications of doping planes be exploited in novel devices. Finally, it is concluded that Ga,InAs/InP, with Al,InAs confining layers, could have high performance heterojunction FET's with doped channels and with modulation doped structures, as well as in planar doped barrier transistors. It is thus recommended that concentrated effort on high performance transistors be pursued in Ga,InAs/InP.

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REFERENCES

1. "Ultra Low Resistance Ohmic Contacts to n-G As", R. Stall, C.E.C. Wood, K. Board and L.F. Eastman, Elec. Lett., 15 (24) 800 (1979).
2. "Tin Doping Effects in GaAs Films Grown by M.B.E.", C.E.C. Wood and B.A. Joyce, J. Appl. Phys., 49, 4854 (1978).
3. "'Surface Exchange' Doping of M.B.E. GaAs From S and Se 'Captive Sources'", C.E.C. Wood, Appl. Phys. Lett., 33, 770 (1978).
4. "Lamella Doping", invited paper at Univ. of Illinois MBE Workshop, C.E.C. Wood, R. Stall, G. Metze, D. DeSimone and L.F. Eastman (1979).
5. "Dependence of the Electrical Characteristics of Heavily Ge Doped GaAs on Molecular Beam Epitaxial Growth Parameters", G.M. Metze, R.A. Stall, C.E.C. Wood and L.F. Eastman, Appl. Phys. Lett., 37 (2) 165 (1980).

6. "A Photoconductive Detector for High Speed Fiber Communication", J.C. Gammel, G.M. Metze and J.M. Ballantyne, IEEE Trans. on Elec. Devices (1981).
7. "Extremely High Electron Mobilities in Modulation-Doped GaAs-$Al_xGa_{1-x}As$ Heterojunction Superlattices", W.I. Wang, C.E.C. Wood and L.F. Eastman, Elec. Lett., 17 (1) 36 (1981).
8. "Planar-Doped Barriers in GaAs by Molecular Beam Epitaxy", R.J. Malik, K. board, C.E.C. Wood, L.F. Eastman, T.R. AuCoin and R.L. Ross, Elec. Lett., 16 (22) 436 (1980).

RELATED THESES COMPLETED

R. Stall, Ph.D., at Bell Labs

R. Malik, Ph.D., at Ft. Monmouth

G. Metze, Ph.D., (only small part on this program), at Lincoln Labs

LIST OF PUBLICATIONS

1. "Hyper-Thin Channel M.B.E. GaAs Power F.E.T.s by Single Atomic Doping", C.E.C. Wood, S. Judaprawira and L.F. Eastman, Proc. Int. Electron Device Meet., Washington, DC, 338 (1979).
2. "Recent Developments in the Smallest Dimension - The Atomic Plane", C.E.C. Wood, U.S./France Workshop on Microstructures, Paris, France (1979).
3. "Ultra Low Resistance Ohmic Contacts to n-GaAs", R. Stall, C.E.C. Wood, K. Board and L.F. Eastman, Elec. Lett., 15 (24) 800 (1979).
4. "Non-Alloyed Heterojunction Ohmic Contacts to Semiconductors", R. Stall, C.E.C. Wood and L.F. Eastman, Patent Disclosure (1979).
5. "Surface and Interface Depletion Corrections to Free Carrier-Density Determinations by Hall Measurements", A. Chandra, C.E.C. Wood, D.W. Woodard and L.F. Eastman, Solid State Electronics, 22, 645 (1979).
6. "Complex Free Carrier Profile Synthesis by 'Atomic-Plane' Doping of MBE GaAs", C.E.C. Wood, G. Metze, J. Berry and L.F. Eastman, J. Appl. Phys., 51 (1) 383 (1980).
7. "Dependence of the Electrical Characteristics of Heavily Ge-Doped GaAs on Molecular Beam Epitaxy Growth Parameters", G.M. Metze, R.A. Stall, C.E.C. Wood and L.F. Eastman, Appl. Phys. Lett., 37 (2) 165 (1980).
8. "Planar-Doped Barriers in GaAs by Molecular Beam Epitaxy", R.J. Malik, T.R. AuCoin, R.L. Ross, K. Board, C.E.C. Wood and L.F. Eastman, Elec. Lett., 16 (22) 436 (1980).
9. "Growth-Parameter Dependence of Deep Levels in Molecular-Beam-Epitaxial GaAs", R.A. Stall, C.E.C. Wood, P.D. Kirchner and L.F. Eastman, Elec. Lett., 16 (5) 171 (1980).
10. "Improved Molecular Beam Epitaxial GaAs Power FET's", C.E.C. Wood, D. DeSimone and S. Judaprawira, J. Appl. Phys., 51 (4) 2074 (1980).
11. "A Molybdenium Source, Gate and Drain Metallization System for GaAs MESFET Layers Grown by Molecular Beam Epitaxy", W.J. Devlin, C.E.C. Wood, R. Stall and L.F. Eastman, Solid State Electronics, 23, 823 (1980).
12. "Double Heterostructure $Ga_{0.47}In_{0.53}As$ MESFETs with Submicron Gates", J. Barnard, H. Ohno, C.E.C. Wood and L.F. Eastman, IEEE Elec. Device Lett., EDL-1 (9) 174 (1980).
13. "Double Heterojunction GaInAs Devices by MBE", H. Ohno, J. Barnard, C.E.C. Wood and L.F. Eastman, Solid State Devices Section Proc. IEDM, Washington, DC, 434 (1980).

14. "High Purity InP Grown by Liquid Phase Epitaxy", L.F. Eastman, Proc. 1980 NATO InP Workshop, Cape Cod (1980).

15. "Complex Free-Carrier Profile Synthesis by 'Atomic-Plane' Doping of MBE GaAs", C.E.C. Wood, G. Metze, J. Berry and L.F. Eastman, J. Appl. Phys., 51 (1) 383 (1980).

16. "Rectifying, Variable Planar-Doped-Barrier Structures in GaAs", R.J. Malik, K. Board, L.F. Eastman, C.E.C. Wood, T.R. AuCoin and R.L. Ross, Proc. 8th Int. Symp. on GaAs and Related Cpds., Vienna, Austria, Series 56, 465 (1980).

17. "Double Heterostructure Ga$_{0.47}$In$_{0.53}$As MESFETs by Molecular Beam Epitaxy", H. Ohno, J. Barnard, L. Rathbun, C.E.C. Wood and L.F. Eastman, Proc. 8th Int. Symp. on GaAs and Related Cpds., Vienna, Austria, Series 56, 151 (1980).

18. "Molecular Beam Epitaxy - A Review of Recent Progress", C.E.C. Wood, Proc. 8th Int. Vac. Conf., Cannes, France (1980).

19. "Schottky Barrier Heights of Molecular Beam Epitaxial Metal-AlGaAs Structures", K. Okamoto, C.E.C. Wood and L.F. Eastman, Appl. Phys. Lett., 38, 636 (1981).

20. "Integrated Double Heterostructure Ga$_{0.47}$In$_{0.53}$As Photoreceiver with Automatic Gain Control", J. Barnard, H. Ohno, C.E.C. Wood and L.F. Eastman, IEEE Elec. Dev. Lett., 2 (1) 7 (1981).

21. "Novel Device Structures by Molecular Beam Epitaxy", C.E.C. Wood, J. Vac. Sci. Tech., 18 (3) 772 (1981).

22. "Characterisation of Al/AlInAs/GaInAs Heterostructures", D.V. Morgan, H. Ohno, C.E.C. Wood, W.J. Schaff, K. Board and L.F. Eastman, IEEE Proc., 128, Pt. I (4) 141 (1981).

23. "Electron Transport Across the Abrupt Ge-GaAs n-n Heterojunction", J.M. Ballingall, R.A. Stall, C.E.C. Wood and L.F. Eastman, J. Appl. Phys., 52 (6) 4098 (1981).

24. "III-V Alloy Growth by M.B.E.", C.E.C. Wood, Chapter in Gallium-Indium-Arsenide Phosphide Alloy Semiconductors, John Wiley (1981).

25. "A Study of Ge/GaAs Interfaces Grown by Molecular Beam Epitaxy", R.A. Stall, C.E.C. Wood, K. Board, N. Dandekar, L.F. Eastman and J. Devlin, J. Appl. Phys., 52 (6) 4062 (1981).

26. "Resistivity Increase in MBE Ga$_{0.47}$In$_{0.53}$As Following Ion Bombardment", J. Barnard, C.E.C. Wood and L.F. Eastman, Electron Dev. Lett., EDL-2 (8) 193 (1981).

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