AD-A281 406

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
		Final 1 Sep 92-2Mar94

4. TITLE AND SUBTITLE

Investigation of Novel Electrical Transport Phenomena in Semimetal-Semiconductor Heterostructures

5. FUNDING NUMBERS

DAAL03-92-G-0385

6. AUTHOR(S)

Terry Golding
John Miller

DTIC
ELECTE
JUL 13 1994
S F D

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Houston
Houston, TX 77006

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARO 30772.7-MS

11. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Sb/GaSb system has been proposed as a unique new material which has significant potential for quantum transport studies, electronic devices, incorporating semimetal/semiconductor heterostructures, and for infrared optical and nonlinear optical applications requiring an indirect narrow band-gap material. Researchers have demonstrated the growth of both single Sb/GaSb heteroepitaxial layers and elementary GaSb/Sb/GaSb multilayer structures using MBE and MEE on GaSb [111] substrates. Magnetotransport measurements have yielded electron and hole mobilities in excess of 3×10^4 $cm^2/V \cdot s$, which correspond to mean free paths of >2 mum for both carrier types. Further studies are currently underway to characterize the transport and optical properties of Sb/GaSb multilayer structures.

DTIC QUALITY INSPECTED 5

94-21457

14. SUBJECT TERMS	15. NUMBER OF PAGES
Electrical Transport Phenomena, Heterostructures, Semimetals Semimetal-Semiconductor Heterostructures, Devices, Antimonide Semiconductors	
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

94 7 12 181

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std. Z39-18
298-102

30772.7-MS

INVESTIGATION OF NOVEL ELECTRICAL TRANSPORT PHENOMENA IN SEMIMETAL-SEMICONDUCTOR HETEROSTRUCTURES

Final Report

Terry D. Golding, Ph.D

John H. Miller, Ph.D

5/2/94

U.S. ARMY RESEARCH OFFICE

DAAL03-92-G-0385

University of Houston

INVESTIGATION OF NOVEL ELECTRICAL TRANSPORT PHENOMENA IN IN SEMIMETAL-SEMICONDUCTOR HETEROSTRUCTURES

Terry D. Golding and John H. Miller, Jr.
Department of Physics
University of Houston

A. STATEMENT OF PROBLEM

The project involved an experimental investigation of the electrical transport properties of semimetal-semiconductor based heterostructures and devices. The structures consisted of elemental (Sb) semimetals in combination with antimonide based III-V semiconductors (GaSb). The investigation of these novel semimetal-semiconductor heterostructures was motivated by their unique electronic properties and potential device applications, including high conductivity interconnects, double-barrier semimetal-base resonant tunneling transistors, and nanostructures operating in the mesoscopic regime. The structures were synthesized using molecular beam epitaxy, and their structural and electrical transport properties were investigated.

B. SUMMARY OF IMPORTANT RESULTS

We investigated Sb/GaSb heterojunctions and multilayers, and demonstrated, for the first time, the ability to synthesize such structures epitaxially. All structures were grown by molecular beam epitaxy and migration enhanced epitaxy in a commercial (Riber 32) growth chamber, employing a standard Sb effusion cell and standard liquid-metal Ga source. The substrates were nominally undoped (*p*-type) GaSb(100), (111)A and (111)B indium bonded to molybdenum blocks.

Growth of Sb on GaSb for (100), (111)A, and (111)B orientations was investigated. Prior to Sb deposition, a GaSb homoepitaxial buffer was grown. Epitaxial growth of Sb on both GaSb(111)A and (111)B was successful, and was achieved by increasing the Sb residence lifetime on the GaSb surface by lowering the temperature below a nucleation temperature, $T_n(J_{Sb})$ (where J_{Sb} is the Sb flux) which we found to be independent of growth orientation. For J_{Sb} employed in our study, T_n=260°C. Below this temperature, diffraction rings indicative of polycrystalline growth were observed.

Our studies found that a slow initial growth rate, for which accomodation and desorption are only slightly unbalanced, is a highly critical condition for epitaxy. For example, if the surface concentration of Sb was increased rapidly, by cooling quickly through T_n, then multiply oriented, three-dimensional growth occurred. However, a significant finding was that Sb could be successfully nucleated below T_n if the GaSb surface was not exposed to an Sb flux for a period of several seconds. Such results suggest that the successful nucleation of Sb is quite dependent on the degree of Sb surface coverage on the GaSb surface.

Having nucleated and grown epitaxial Sb at a fixed temperature, we found that GaSb could be grown on the Sb epilayers at a temperature compatible with the Sb growth using MEE. Upon initiating growth of GaSb, the streaked (1X1)Sb RHEED pattern evolved into a pattern of 1X1 wide streaks, with broad spots, indicative of a surface which is rough on the order of a few monolayers. This pattern persisted throughout growth of GaSb layers up to 0.3 µm thickness. A possible explanation of this roughness is the presence of antiphase domains. Further studies are now underway to investigate the necessary growth parameters for optimal stuctural properties.

X-ray diffraction scans were performed along the <10.*L*> direction of the reciprocal lattice using a hexagonal coordinate system in which <00·1> is parallel to <111> of the cubic system. Figure 1 shows a scan obtained from a 2000 Å GaSb epilayer grown on a 2500 Å Sb epilayer. Reflection peaks at 10·7 *and* 10·8 for both Sb and GaSb are observed. Scans of homoepitaxial GaSb exhibited, as expected, no peaks at 10.8. The 10X8 peak for GaSb in this structure is therefore interpreted as originating from the terminal GaSb epilayer. An off-axis scan confirmed that the Sb epilayer has a rhombohedral structure and the in-plane lattice parameter for the Sb layer was found to match that of the GaSb in the (111) plane.

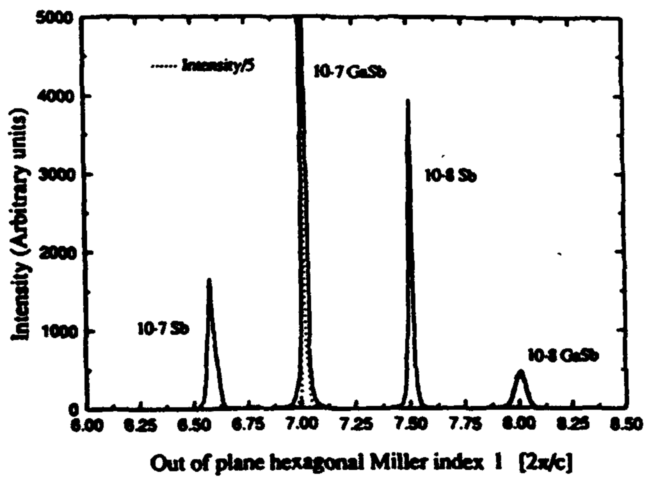

Fig. 1. X-ray scan along the (hexagonally indexed) <10·1> direction of a 2000 Å GaSb/1500 Å Sb/2500 Å GaSb/GaSb (111) structure. Abscissa is in units of $2\pi/c$, where c is the out of plane lattice parameter of the GaSb unit cell.

From magnetotransport measurements on a 1.9-μm-thick Sb film grown on a GaSb homoepitaxial layer, Figs. 2 and 3 show temperature-dependent electron and hole densities and mobilities obtained from a mixed conduction analysis of the field-dependent data. As expected for semimetallic Sb, the low-temperature *n* and *p* in Fig. 2 are equal and nearly independent of *T*. However, the densities obtained (~8x10^{19} cm^{-3}) are a factor of 2 larger than those appropriate for bulk Sb[1] (see the arrow in the figure). The apparent decreases (especially of *n*) at higher temperatures should be viewed as an artifact, possibly related to a thermal activation of the carriers into lower-mobility states which are less sensitively probed by $\rho_{xx}(B)$ and $\rho_{xy}(B)$ when $B \leq 7$ T.

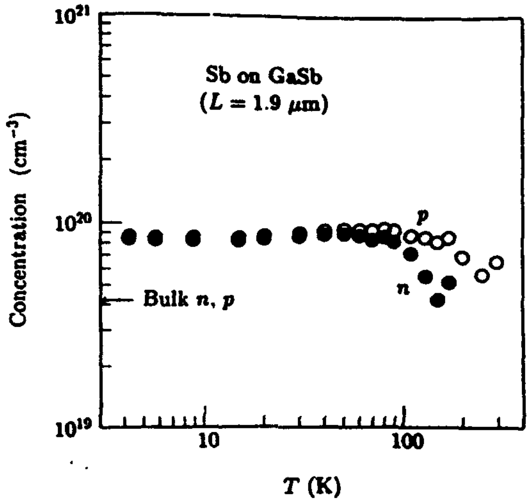

Fig. 2. Experimental electron and hole concentration vs. temperature, for a 1.9-μm-thick Sb film on a (111)GaSb substrate. Values for bulk Sb are indicated ($n=p$, nearly independent of T).

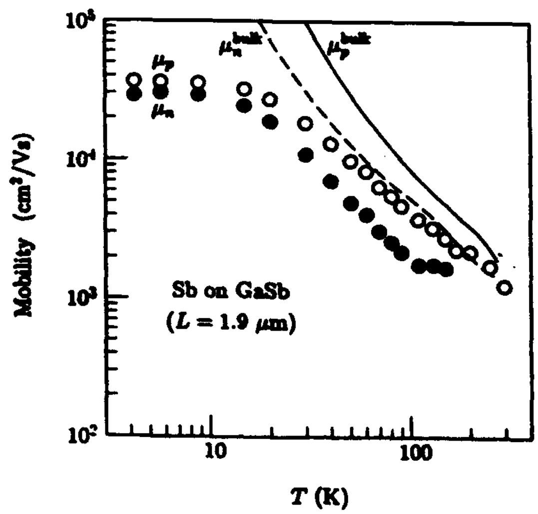

Fig. 3. Experimental electron and hole mobilities vs. temperature (points), for the same Sb film whose carrier concentrations are shown in Fig. 2. The dashed curves are mobilities for bulk Sb, which have been averaged over crystal orientations within the plane.

The large low-temperature mobilities in Fig. 3 (> 3×10^4 $cm^2/V\cdot s$ for both electrons and holes) confirm the high quality of the Sb epitaxy. While the mobilities at low T are probably limited by some form of surface roughness scattering, a decrease due to phonon scattering begins at $T\approx20$ K. In the phonon regime, the slopes of $\mu_n(T)$ are quite similar to the bulk dependences[2,3] indicated by the curves. However, the epilayer mobilities lie factors of 2-3 lower than the bulk values. The lower phonon-limited mobilities in Fig. 3 and the higher electron and hole concentrations in Fig. 2 imply that the band structure in our epitaxial layers has been altered slightly from its bulk form, possibly due to strain (which is expected to be small because of the close lattice match).

Summarizing, the Sb/GaSb system has been proposed as a unique new material which has significant potential for quantum transport studies, electronic devices, incorporating semimetal/semiconductor heterostructures, and for infrared optical and nonlinear optical applications requiring an indirect narrow band-gap material. We have demonstrated the growth of both single Sb/GaSb heteroepitaxial layers and elementary GaSb/Sb/GaSb mulilayer structures using MBE and MEE on GaSb [111] substrates. Magnetotransport measurements have yielded electron and hole mobilities in excess of 3×10^4 $cm^2/V\cdot s$, which correspond to mean free paths of >2 μm for both carrier types. Further studies are currently underway to characterize the transport and optical properties of Sb/GaSb multilayer structures.

C. LIST OF PUBLICATIONS AND TECHNICAL REPORTS

T. D. Golding, J. A. Dura, W. C. Wang, J. T. Zborowski, H. C. Chen, J. H. Miller, Jr., and J. R. Meyer, **"Sb/GaSb multilayer structures: potential applications as a narrow bandgap system,"** *Extended Abstracts of the 1992 International Conference on Solid State Devices and Materials* PC-10 (1992) 284.

T. D. Golding, J. A. Dura, W. C. Wang, J. T. Zborowski, H. C. Chen, J. H. Miller, Jr., and J. R. Meyer, **"Investigation of Sb/GaSb Multilayer Structures for Potential Application as an Indirect Narrow Bandgap Semiconductor,"** *Semicond. Sci. & Technol.* 8 (1993), pp. S117-S120.

W. C. Wang, J. A. Dura, J. T. Zborowski, and T. D. Golding, **"Preparation of Sb/GaSb (111)-oriented multilayer structures using molecular beam epitaxy and migration enhance epitaxy,"** *J. Vac. Sci Technol.* A11 (1993), 1001.

T. D. Golding, J. A. Dura, W. C. Wang, J. T. Zborowski, A. Vigliante, H. C. Chen, and J. R. Meyer, **"Sb/GaSb Heterostructures and Multilayers,"** *J. Cryst. Growth* 127 (1993), 777.

T. D. Golding, J. A. Dura, W. C. Wang, A. Vigliante, S. C. Moss, H. C. Chen, J. H. Miller, Jr., C. A. Hoffman, and J. R. Meyer, **"Sb/GaSb Heterostructures and Multilayers,"** *Appl. Phys. Lett.* 63 (1993), pp. 1098-1100.

D. LIST OF PARTICIPATING SCIENTIFIC PERSONNEL

Prof. T. D. Golding (principal investigator), Dept. of Physics, Univ. of Houston

Prof. J. H. Miller, Jr. (principal investigator), Dept. of Physics & TCSUH, U. Houston

Prof. S. C. Moss, Dept. of Physics, Univ. of Houston

Dr. J. A. Dura, Dept. of Physics, Univ. of Houston (presently at NIST)

W. C. Wang, Dept. of Physics, Univ. of Houston

J. T. Zborowski, Dept. of Physics, Univ. of Houston

H. C. Chen, Dept. of Physics, Univ. of Houston

Dr. A. Vigliante, Naval Research Lab

Dr. C. A. Hoffman, Naval Research Lab

Dr. J. R. Meyer, Naval Research Lab

INVENTIONS

"Semimetal-Semiconductor Heterostructures and Multilayers," *U.S.A., filed July 1992.*

"Optical Switches and Detectors Utilizing Indirect Narrow-Gap Superlattices as the Optical Materials," *U.S.A., filed July 1992.*

BIBLIOGRAPHY

1. J.-P. Issi, Aust. J. Phys. 32, 585 (1979).

2. M. S. Bresler and N. A. Red'ko, Zh. Eksp. Teor. Fiz. 61, 287 (1971). [Sov. Phys. JETP 34, 287 (1972)].

3. O. Oktu and G. A. Saunders, Proc. Phys. Soc. (London) 91, 156 (1967).