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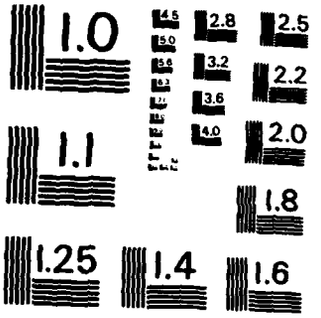

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The purpose of this three-year research program was to study electron transport in III-V semiconductors, starting with an investigation of ballistic transport in GaAs. Also for experimental studies of electron transport in the III-V semiconductors, test devices were to be constructed from submicron layers grown by molecular beam epitaxy. For ballistic electron transport in submicron GaAs devices, the influence of the boundary conditions were explained, a theory for low-field diode conductance was developed, the high-field diode impedance was

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ABSTRACT (cont).

calculated, and experimental data was compared to theoretical predictions. This work led to an investigation, both experimental and theoretical, of electron transport in the two-dimensional electron gas (TEG) of a modulation-doped heterostructure. The theoretical studies produced a model of electron transport in GaAs/AlGaAs modulation-doped structures and prediction of the electron mobility in TEG layers. The experimental work led to a new method of III-V heterojunction characterization and to an explanation of the temperature-dependent behavior of a modulation-doped transistor.

Final Report

ELECTRON BALLISTIC EFFECTS IN III-V SEMICONDUCTORS

Principal Investigators:

Gary Y. Robinson
Michael Shur

9/25/80 to 9/24/83

U. S. Army Research Office
Contract DAAG29-80-K-0087
Proposal DRXRO-17683-EL

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Statement of Problem Studied

The purpose of this three-year research program was to study electron transport in III-V semiconductors, starting with an investigation of ballistic (collision-less) transport in GaAs. Also for experimental studies of electron transport in the III-V semiconductors, test devices were to be constructed from submicron layers grown by molecular beam epitaxy (MBE).

For ballistic electron transport in submicron GaAs devices, the influence of the boundary conditions were explained, a theory for low-field diode conductance was developed, the high-field diode impedance was calculated, and experimental data was compared to theoretical predictions.

This work led to an investigation, both experimental and theoretical, of electron transport in the two-dimensional electron gas (TEG) of a modulation-doped heterostructure. The theoretical studies produced a model of electron transport in GaAs/AlGaAs modulation-doped structures and prediction of the electron mobility in TEG layers. The experimental work led to a new method of III-V heterojunction characterization and to an explanation of the temperature-dependent behavior of a modulation-doped transistor.

The research program was successful in explaining transport in certain, commercially important, III-V device structures and provided a new method of semiconductor materials qualification.

Summary of Results

The major accomplishments of the research program sponsored by ARO are as follows:

- Developed a theory of low-field conductance and high-field impedance in submicron structures [1,7].

- Developed a new analytical model for short-channel GaAs FETs [7].

- Performed experimental study and provided theoretical explanation of temperature dependence of threshold voltage in modulation-doped FETs [8].

- Developed a modified DLTS technique for study of traps in modulation-doped structures [10].

- Developed a theory for modulation doped structures which included the calculation of the maximum concentration n_{so} of the electrons in the two-dimensional electron gas (TEG) [4], the establishment of the relationship between the maximum transconductance and n_{so} [3], a computer and analytical calculation of the channel conductance as a function of the gate voltage [5], computer and analytical calculations of the I-V characteristics [6], an approximate calculation of the C-V characteristics [8], a detailed analysis of the undoped spacer layer [30], a calculation of the low field mobility of the TEG and an analysis of the maximum current swing [5,13,14].

- Joint research with Professor Hadis Morkoc (University of Illinois) led to joint publication of highest FET transconductance yet reported (565 mS/mm at 77K) [2].

- 18 papers published or submitted for publication; 13 conference presentations.

- Nine graduate students supported with two PhD degrees and three MS degrees awarded.

Publications

1. M. Shur and D. Long, "Performance Prediction for GaAs Submicron SDFL Logic," IEEE Elect. Device Letts., EDL-3, No. 5, pp. 124-127, 1982.

2. T. J. Drummond, S. L. Su, W. G. Lyons, R. Fischer, W. Koop and H. Morkoc, K. Lee and M. S. Shur, "Enhancement of Electron Velocity in Modulation Doped (Al,Ga)As/Ga FETs at Cryogenic Temperatures," Electronics Letters, 18, pp. 1057-1058 (Nov. 1982).

3. K. Lee, M. S. Shur, T. J. Drummond, S. L. Su, W. G. Lyons, R. Fisher and H. Morkoc, "Design and Analysis of Modulation Doped (Al,Ga)As/GaAs FETs (MODFETs)," J. Vacuum Science and Technol., B1(2), April-June, pp. 186-189, 1983.

4. K. Lee, M. S. Shur, T. J. Drummond and H. Morkoc, "Electron Density of the Two-Dimensional Electron Gas in Modulation Doped Layers," J. Appl. Phys., 54(4), pp. 2093-2096, April 1983.

5. T. J. Drummond, H. Morkoc, K. Lee and M. Shur, "Model for Modulation Doped $Al_xGa_{1-x}As/GaAs$ Field Effect Transistors," IEEE Electron Dev. Lett., EDL-3, No. 11, pp. 338-341 (1982).

6. K. Lee, M. S. Shur, T. J. Drummond and H. Morkoc, "Current-Voltage and Capacitance-Voltage Characteristics of Modulation Doped Field Effect Transistors," IEEE Trans. on Electron. Dev., ED-30 (March 1983).

7. M. S. Shur, "Low Field Mobility, Effective Saturation Velocity and Peformance of Submicron GaAs MESFET's," Electronics Letters, 18, No. 21 (1982).

8. A. J. Valois, G. Y. Robinson, K. Lee and M. S. Shur, "Temperature Dependence of I-V Characteristics of Modulation Doped FET's," J. Vacuum Science and Technol., B1, 190 (1983).

9. G. Y. Robinson, "Schottky Diodes and Ohmic Contacts for the III-V Semiconductors," prepared for the Physics and Chemistry of III-V Semiconductors, C. W. Wilmsen, ed., Plenum Press (1983).

10. A. J. Valois and G. Y. Robinson, "Characterization of Deep Levels in Modulation-Doped AlGaAs/GaAs FET's," IEEE Elect. Device Letts., EDL-4, 360 (1983).

11. Kwyro Lee, M. Shur, A. J. Valois, G. Y. Robinson, Xichen Zhu, and A. van der Ziel, "Characterization of the End Resistance in Modulation-Doped FET's," to be submitted, IEEE Trans. on Electron. Devices.

12. K. Lee, M. S. Shur, T. J. Drummond, and Hadis Morkoc, "Low field mobility of 2-d electron gas in modulation doped $Al_xGa_{1-x}As/GaAs$ layers," J. Appl. Phys., accepted for publication.

13. K. Lee, M. S. Shur, T. J. Drummond, and Hadis Morkoc, "Parasitic MESFET in Modulation Doped FETs and MODFET Characterization," IEEE Trans. Electron Dev., accepted for publication.

14. K. Lee, M. S. Shur, T. J. Drummond, and Hadis Morkoc, "Room Temperature Mobility of the Two-dimensional Electron Gas in (Al,Ga)As-GaAs Modulation Doped Layers," Journ. Vac. Sc. Technol., pending.

15. J. Klem, W. T. Masselink, D. Arnold, R. Fisher, T. J. Drummond, H. Morkoc, K. Lee and M. S. Shur, "Persistent Photoconductivity in (Al,Ga)As/GaAs Modulation Doped Structures: Dependence on Structure and Growth Temperature," J. Appl. Phys., pending.

16. T. J. Drummond, W. G. Lyons, S. L. Su, W. Kopp, H. Morkoc, K. Lee and M. S. Shur, "Bias Dependence and Light Sensitivity of (Al,Ga)As-GaAs MODFETs at 77K," J. Appl. Phys., pending.

17. R. Fisher, T. J. Drummond, W. Kopp, H. Morkoc, K. Lee and M. S. Shur, "Instabilities in Modulation Doped Field Effect Transistors (MODFET's) at 77°K," Electronics Letters, 19, p. 789, Sept. 1983.

18. Kang Lee, M. S. Shur, Kwyro Lee, Tho T. Vu, P. C. T. Roberts and M. J. Helix, "Low Field Mobility in GaAs Ion-implanted FET's," IEEE Electron. Devices, pending.

Conference Presentations

1. M. S. Shur, R. Goyal and H. L. Grubin, "The Influence of Boundary Conditions on Transport in Two Terminal Submicron GaAs Elements," Workshop on Compound Semiconductors for Microwave Devices, February 1981.

2. M. S. Shur and A. Kastalskii, "Electron Transport in Short *n*-InSb, *n*-Ge and p-Ge Diodes," Workshop on Compound Semiconductors for Microwave Devices, February 1981.

3. M. Shur, "Ballistic Regime in Semiconductor Devices," (Invited Paper) American Physical Society Meeting, Nov. 1981.

4. A. A. Kastalsky and M. Shur, "Conductance of Small Semiconductor Devices," Conference on Microwave Semiconductor Devices and Circuits, Cornell Univ., August 1981.

5. Kwyro Lee and M. S. Shur, "Impedance of Thin Semiconductor Films in Low Electric Fields," Workshop on Compound Semiconductors (1982).

6. T. J. Drummond, S. L. Su, W. Kopp, R. Sischer, R. E. Thorne and H. Morkoc and K. Lee and M. S. Shur, "High Velocity N-ON and N-OFF Modulation Doped GaAs/$Al_xGa_{1-x}As$ FETs," IEDM Digest, San Francisco (1982).

7. M. S. Shur, "Low Field Mobility, Effective Saturation Velocity and Performance of Submicron GaAs MESFET's," in Proc. of Workshop on Physics of Semiconduc. Devices, presented June 1982.

8. A. J. Valois, G. Y. Robinson, K. Lee and M. S. Shur, "Temperature Dependence of I-V Characteristics of Modulation Doped FET's," Presented at Fourth MBE Workshop, Univ. of Illinois, (1982).

9. A. J. Valois and G. Y. Robinson, "Electron Traps in MBE AlGaAs/GaAs MODFETs," Presented at the Fifth MBE Workshop, Geo. Tech (1983).

10. K. Lee, M. S. Shur, T. J. Drummond, and Hadis Morkoc, "Low field mobility of 2-d electron gas in modulation doped $Al_xGa_{1-x}As$/GaAs layers," UGIM-83 Proceedings, pp. 173-177, Texas A&M University, 1983.

11. K. Lee, M. S. Shur, T. J. Drummond, W. J. Lyons and Hadis Morkoc, "Characterization of Modulation Doped FETs," presented at the Biannual IEEE High Speed Device Conference, August 1983.

12. T. H. Chen, M. S. Shur, B. Hoefflinger, Kang Lee, T. T. Vu, P. C. T. Roberts, and M. J. Helix, "DOMES - GaAs IC simulator," presented at the Biannual IEEE High Speed Device Conference, August 1983.

13. K. Lee, M. S. Shur, T. J. Drummond, S. L. Su, W. G. Lyons, R. Fisher, and H. Morkoc, "Design and Analysis of Modulation Doped (Al,Ga)As/GaAs FETs (MODFETs)," presented at the Fourth MBE Workshop, University of Illinois, (1982).

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