AD-A189 763 GAS SOURCE MBE (MOLECULAR BEAM EPITAXY)(U) COLORADO 1/1
STATE UNIV FORT COLLINS DEPT OF ELECTRICAL ENGINEERING
G Y ROBINSON NOV 87 AFOSR-TR-87-1742 AFOSR-87-0028

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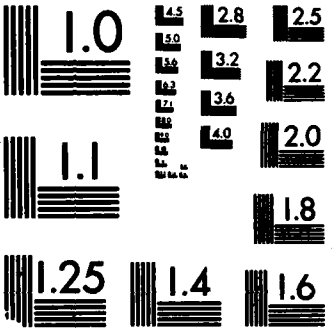

MICROCOPY RESOLUTION TEST CHART
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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 87-1742
6a. NAME OF PERFORMING ORGANIZATION Colorado State University 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AFOSR/NE
6c. ADDRESS (City, State and ZIP Code) Colorado State University Department of Electrical Engineering Fort Collins, Colorado 80523	7b. ADDRESS (City, State and ZIP Code) Bldg 410 Bolling AFB, Washington DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Same as 7a 8b. OFFICE SYMBOL (If applicable) NE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-87-0028
8c. ADDRESS (City, State and ZIP Code) Same as 7b	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2917; TASK NO. A3; WORK UNIT NO.
11. TITLE (Include Security Classification) Gas Source MBE	
12. PERSONAL AUTHOR(S) Professor Gary Robinson	
13a. TYPE OF REPORT Final 13b. TIME COVERED FROM 10-1-86 TO 09-10-87	14. DATE OF REPORT (Yr., Mo., Day) Nov 87 15. PAGE COUNT 10
16. SUPPLEMENTARY NOTATION	
17. COSATI CODES FIELD / GROUP / SUB. GR.	18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) molecular beam epitaxy

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report describes the equipment acquired and the research performed under the DoD University Research Instrumentation Program grant for "Gas Source MBE" at Colorado State University. The objective of the research supported by the grant is to grow epitaxial III-V semiconductor films using gaseous source materials for molecular beam epitaxy (MBE). The grant provided the critical equipment items needed to customize the existing commercial MBE system and allow growth of heteroepitaxial structures that can not be fabricated by other techniques. The resulting gas source MBE materials could provide the optoelectronic device technology required for the high data rate signal processing of the vast quantities of input data expected in future DoD space and ground-based sensing systems.

(Keywords:)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL CAPT KEVIN J. MALLOY	22b. TELEPHONE NUMBER (Include Area Code) (202) 767-4931 22c. OFFICE SYMBOL NE

AFOSR-TR- 87-1742

Final Report

to the

Air Force Office of Scientific Research

for

University Research Instrumentation Program
Grant No. AFOSR-87-0028
(1 Oct. 1986 to 30 Sept. 1987)
$194,000

entitled

"Gas Source MBE"

at

Colorado State University

Fort Collins, CO 80523

PI: Gary Y. Robinson

Department of Electrical Engineering

(303) 491-6575

November 1987

Final Report

AFOSR Grant #AFOSR-870-0028

I. Summary

This report describes the equipment acquired and the research performed under the DoD University Research Instrumentation Program grant for "Gas Source MBE" at Colorado State University. The grant began on October 1, 1986, was of 12-months duration, and provided $194,000 in funding.

The objective of the research supported by the grant is to grow epitaxial III-V semiconductor films using gaseous source materials for molecular beam epitaxy (MBE). The grant provided the critical equipment items needed to customize an existing commercial MBE system and allow growth of heteroepitaxial structures that can not be fabricated by other techniques. The resulting gas source MBE materials could provide the optoelectronic device technology required for the high data rate signal processing of the vast quantities of input data expected in future DoD space- and ground-based sensing systems.

II. List of Equipment

The following items of equipment have been purchased with funds provided by this URIP grant. All items have been received and are currently in use; the items are numbered as in the original proposal.

Item #1
Gas storage cabinets with automatic shut off; gas delivery system with leak valves and provision for computer control; custom designed for CSU
Precision Flow Devices; MKS Instruments; Bush Electronics. $39,544

Leak-free fittings and gas lines for connecting gas delivery system to existing MBE equipment	
MDC Components; Omega; Denver Valve and Fitting	3,546
High temperature heater and molybdenum blocks for sample mounting and cleaning during testing of gas flow system	
Perkin-Elmer Corporation	5,147
Optical pyrometer for temperature measurement during gas flow experiments	
Williamson 3100	1,459
Glove/dry box for sample introduction without escape of hazardous gas; custom designed for CSU	
Southwest Plastics	924
TOTAL	$50,620

Item #2	
Primary toxic gas sensor with high sensitivity and automatic logging of gas levels in laboratory	
MDA Scientific 7100	$ 8,005
Secondary toxic gas sensor with low maintenance for monitoring exhaust effluent	
International Sensor Technology Model AG3100	1,299
Self contained breathing apparatus for use in toxic atmospheres	
Scott Air Pack 2.2	1,658
Uninterruptible power source for above toxic gas sensors	
BFA Corporation	1,070
Portable hazardous gas leak detector to be used during changing of gas tanks	
Matheson 8057	988
HEPA vacuum cleaner for removal of hazardous materials	
Lab Safety D1950	677
TOTAL	$13,697

Item #3	
Cryopump with closed-cycle He refrigerator and special vent valve and UHV gate valve for pumping H_2 gas load	
CTI-Cryogenics CT-8 and VAT10146	14,205

Mechanical vacuum pump with non-reactive pump fluid and demountable filter system Alcatel 2012/93169	5,262
Heat exchanger for cooling MBE system during H_2 pumping Neslab HX-150	4,951
Vacuum components and hardware for interconnecting cryopump and mechanical pump MDC Vacuum Components and Granville-Phillips	3,278
Storage tank for liquid N_2 for cooling sublimation pumps to reduce H_2 gas load Minnesota Valley Engineering	1,800
TOTAL	$29,496

Item #4

Residual gas analyzer with quadrupole mass spectrometer Baltzers 120/420 (additional funding from other sources for total of $30,175)	10,055
Vacuum pump, capacitance manometer, flow controller for residual gas analysis Baltzers PMS01702;MKS Instruments 222/1259	9,465
Data acquisition system for residual gas analysis with switch control unit and plotter compatible with existing computer Hewlett-Packard 3488/7440	3,011
Camera for data recording Tektronic C-53P	1,325
TOTAL	$23,856

Item #5

New X-ray diffractometer with computer-controlled double crystal X-ray spectrometer, X-ray generator, scintillation counter and electronics, and refurbished ϑ-2ϑ diffractometer Northeast Analytical Corp; Bede Model 6; Hiltonbrooks; General Electric (additional funding from other sources for total of $65,600)	52,200
Computer system for X-ray diffractometer IBM AT; Epson 100; Hewlett Packard 7440	6,746
TOTAL	$58,946

Item #6
Surface profiler for film thickness measurement with automatic leveling and X-Y stage and strip chart recorder
Tencor 100 $17,785

GRAND TOTAL----------	$194,400
University Cost Share	-400
DoD URIP Grant	$194,000

All of the above six items were requested in the original proposal and the available funds met the intended need. The final costs for Items 1 and 3 were higher than the estimates in the proposal; however it was not necessary to request additional funds since the costs of Items 2,4,5, and 6 charged to this grant were substantially less than originally estimated. The purchase of Items 4 and 5 were cost shared with funds from other sources, and Items 2 and 6 were purchased at lower cost than anticipated.

III. DoD Research Projects Utilizing URIP Equipment

1. "Base Technology Support for InP/InGaAs Device and Circuit Development"

P.I.: D. L. Lile
Co-PIs: G. Y. Robinson and C. W. Wilmsen
Agency: Department of Air Force
Rome Air Development Center
Hanscom AFB, MA 01721
Contract #: SUB8218
Amount: $100,000
Duration: 7/85 - 6/86

This was a one-year contract to establish a new research program at Colorado State University in the device technology of InP and InGaAs insulated gate FETs for application in future mm-wave circuits. The III-V semiconductors InP and InGaAs exhibit high values of electron mobility and saturation velocity and thus are ideal candidates for high frequency and high speed FETs. The program included the CVD growth of dielectric layers for gate insulators using a custom-designed low temperature plasma-enhanced

reactor with in-situ monitoring of the dielectric-semiconductor interface, the analysis of the dielectric-InP interface by deep level transient spectroscopy (DLTS) using a computer controlled data acquisition and analysis system, and chemical assessment of the dielectric-semiconductor interface using XPS and SIMS as well as structural assessment using high resolution cross-sectional TEM. The MBE and DLTS portions of the program were under the direction of G. Y. Robinson while D. L. Lile was responsible for dielectric growth and C. W. Wilmsen supervised the chemical and structural characterizations.

The intent of the Air Force support was to help establish at CSU a viable III-V materials and devices activity for future research in monolithic mm-wave integrated circuits as well as optoelectronic devices. This required an inhouse epitaxial growth capability in order to achieve the performance predicted for optimumly designed InP and InGaAs MISFETs. The equipment Items 1,2,3, and 4 listed in this proposal were necessary for the InGaAs films already grown and the InP films to be grown and used for our MIS studies. Furthermore, the same equipment will be used for growth of heteroepitaxial structures of InP/InGaAs/InP. The double-crystal X-ray diffractometer in Item 5 is being used to determine the lattice mismatch of the InGaAs/InP interface and has greatly aided in establishing the growth conditions for device quality InGaAs. Beam fluxes and alloy composition x have been determined with Item 5 and film thickness with Item 6.

2. "Beam Assisted Fabrication of III-V/Si Monolithic Devices"

PI: G. Y. Robinson
Co-PIs: G. J. Collins and R. Solanki
Agency: Department of the Air Force
Air Force Office of Scientific Research
Contract #: F49620-86-K-0021
Amount: $343,989
Duration: 11 September 1986 to 10 September 1988

The objective of this research project is to explore two new methods for deposition of III-V semiconducting films on Si substrates. Using gas-source molecular beam epitaxy (MBE) and photon-beam and electron-beam assisted metal-organic chemical vapor deposition (MOCVD), GaAs and other III-V films with abrupt heterojunctions are being formed epitaxially on Si, and by means of optical and electrical characterization the suitability of the resulting III-V/Si structures are being examined for use in monolithic devices.

Gas-source MBE combines thermal cracking of the gaseous hydrides AsH_3 and PH_3 to produce beams of As_2 and P_2, respectively, with conventional MBE technology for Group-III molecular beam production from effusion cells. The availability of both As_2 and P_2 beams allows incorporation of buffer layers of wide composition range and lattice parameters and for exploration of III-V materials grown by MBE on Si other than GaAs. Item 1 is the gas delivery system which provides the precise control and rapid switching of the PH_3 and AsH_3 flow rates needed to grow superlattices and other heterostructures containing both As and P. Item 3 is the pumping system needed for accommodating the large H_2 load and for safe removal of the toxic hydrides. Item 2 is the safety equipment required for the hazardous materials involved. Item 4 has been used for analysis of the vacuum system and gas control system of Item 1. Items 5 and 6 have been extensively employed in characterizing the GaAs on Si and GaAs/InGaAs superlattices grown under this program.

3. "Growth of Semiconductor Heterostructures by Gas-Source MBE"

PI: G. Y. Robinson
Agency: Naval Research Laboratory
Washington, DC 20375
Contract #: N00014-87-K-2044
Amount: $123,000
Duration: 30 July 1987-1 August 1989

Although MBE has become a mature epitaxial growth technology for fabrication of GaAs/AlGaAs structures, its application to other semiconductor materials has been hindered by the high vapor pressure of some elements when evaporated from the solid phase. These high pressures lead to practical difficulties when introducing these elements into an ultra-high vacuum system in a well controlled manner. The use of gaseous sources in MBE is in its early stages of development and appears to offer a practical means of handling relatively volatile elements. The resulting gas-source MBE technology combines the capability of producing thin film structures with interface abruptness on the atomic scale by using the line-of-sight molecular beams of MBE with the precise control of composition using the mass flow controllers of chemical vapor deposition. Thus gas-source MBE permits the growth of QW heterostructures with materials that have been previously impossible or very difficult to grow by conventional MBE or other epitaxial growth methods. The objectives of this research program are the following:

* To implement gas-source MBE technology and demonstrate the growth of high quality QW heterostructures using the InGaAs/InP system. Other materials systems will also be considered after qualification with InGaAs/InP.

* To transfer gas-source MBE technology to industry for increasing the output of commercial MBE production equipment.

* To explore in collaboration with researchers at NRL and other designated DoD laboratories, the application of gas-source MBE for the growth of non-conventional materials suitable for long wavelength detectors and sources.

All of the equipment purchased under the URIP grant is being used in this research project.

4. **"Semiconducting Transition Metal Silicides: New Materials for Optoelectronics on Silicon"**

PI: J. E. Mahan
Co-PI: G. Y. Robinson
Agency: National Science Foundation and Army Research Office
Contract #: ECS-85-1-4842
Amount: $69,995 (1st year)
Duration: 5/1/87 - 4/30/89

The principal thrust of this research is to experimentally characterize the optical, electronic transport, and photoelectronic properties of the narrow bandgap semiconducting silicides. The potential applications of the semiconducting silicides include (1) electro-optic interconnects for silicon microelectronics, (2) monolithic fiber optic sources, detectors, and signal processing electronics, and (3) improved silicon-based infrared detectors. The prospects for achieving epitaxial growth of several of these materials are good, and the primary objective of this work is to demonstrate how large area single crystal films can be formed. Items 5 and 6 **are being used extensively to characterize the films grown under this and related contracts.**

IV. Other Research of Interest to DoD

1. "Center for Optoelectronic Computing Systems"

PI: W. T. Cathey, University of Colorado - Boulder
Co-PIs: G. Y. Robinson and 4 faculty at Colorado State University; 16 faculty at University of Colorado-Boulder.
Agencies: National Science Foundation Engineering Research Center; Colorado Advanced Technology Institute; Industry.
Amount: NSF $14 million (5 years)
State $3.0 million (5 years)
Industry $0.5 million (first year).

The objective of this research program is to substantially advance the field of optical computing by developing three new proof-of-principle computing machines that take advantage of the speed, parallelism, and

connectivity of optical information transfer. The task of the investigators at Colorado State University is to provide III-V optoelectronic devices uniquely designed for the proof-of-principle machines. The initial research focuses on realization of a high speed two-dimensional electrically-addressable spatial light modulator (SLM) which will employ a metal-insulator-semiconductor charge coupled device (CCD). To maximize the modulation efficiency, the CCD array will be built on a multiple quantum well (MQW) heteroepitiaxial structure grown by gas-source MBE. We are currently growing MQWs of InGaAs/GaAs and will be growing MQWs of InGaAs/InP using the gas-source MBE equipment purchased under the URIP grant. The capability to abruptly change from an arsenide (InGaAs) to a phosphide (InP) in a distance of a few lattice constants or less, which is only possible with gas-source MBE, provides the means of engineering the III-V heterostructures for optimum optoelectronic properties. Device other than the CCD SLM that are currently under development are an optically addressed optical switch and a surface emitting laser array.

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