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13. ABSTRACT (*Maximum 200 words*)

We have investigated novel semiconductor growth, materials, processes and devices. Gaseous source development for metalorganic molecular beam epitaxy (MOMBE) and metalorganic chemical vapor deposition (MOCVD) has been studied (Stillman). Silicon concentrations greater than 1×10^{19} cm^{-3} have been demonstrated using $SiBr_4$ by MOMBE and semi-insulating InP layers with resistivities greater than 1×10^8 Ω-cm have been produced by using CCl_4 by MOCVD. High power and high performance semiconductor lasers and laser arrays have also been studied (Coleman). Several advanced processing techniques including reactive ion etching and e-beam lithography have been used to fabricate these lasers. In addition, the development of selective area epitaxy by MOCVD enables integration of lasers with electrical components for optoelectronic circuits on a single chip. Finally, use of impurity induced layer disordering (IILD) and native oxides on high Al content compound semiconductors have been used to develop novel semiconductor laser devices (Holonyak). Microdisk lasers have been demonstrated using the IILD process to define curved geometry lasers. The native oxide has been used in vertical cavity surface emitting lasers VCSELs to define the current flow and to fabricate high-contrast distributed Bragg reflectors (DBRs).

14. SUBJECT TERMS
Native oxide, impurity induced layer disordering, optoelectronic integrated circuit, SiBr4 doping, CCl_4 doping

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ABSTRACT

We have investigated novel semiconductor growth, materials, processes and devices. Gaseous source development for metalorganic molecular beam epitaxy (MOMBE) and metalorganic chemical vapor deposition (MOCVD) has been studied (Stillman). Silicon concentrations greater than 1 x 10^{19} cm^{-3} have been demonstrated using $SiBr_4$ by MOMBE and semi-insulating InP layers with resistivities greater than 1 x 10^8 Ω-cm have been produced by using CCl_4 by MOCVD. High power and high performance semiconductor lasers and laser arrays have also been studied (Coleman). Several advanced processing techniques including reactive ion etching and e-beam lithography, have been used to fabricate these lasers. In addition, the development of selective area epitaxy by MOCVD enables integration of lasers with electrical components for optoelectronic circuits on a single chip. Finally, use of impurity induced layer disordering (IILD) and native oxides on high Al content compound semiconductors have been used to develop novel semiconductor laser devices (Holonyak). Microdisk lasers have been demonstrated using the IILD process to define curved geometry lasers. The native oxide has been used in vertical cavity surface emitting lasers VCSELs to define the current flow and to fabricate high-contrast distributed Bragg reflectors (DBRs).

Studies at the University of Illinois under SDIO DAAL 03-92-G-0272 have focused on three areas of development related to the growth and characterization of optical semiconductor transmitters and detectors. These three thrust areas are described below and the significant work accomplished in each area is summarized.

Area 1 - Material Development

New materials critical for the development of optoelectronic devices and the techniques for producing these materials have been studied. These include InP and GaAs-based materials grown by both the chemical beam epitaxy (CBE) and the low-pressure metalorganic chemical vapor deposition technique (MOCVD). The use of CCl_4 as an extrinsic carbon doping source to produce p-type GaAs and InGaAs has been developed. In the CBE environment, CBr_4 has also been used to achieve carbon doped GaAs and InGaAs. Many devices including high speed HBTs and PIN photodetectors with a carbon doped base in both InP-based and GaAs-based materials have been demonstrated using this technology.

More recently, high resistivity InP epitaxial layers have been produced by flowing CCl_4 during growth at low temperature. These semi-insulating layers are easy to produce and do not have many of the harmful side effects of iron-doped semi-insulating layers. The potential applications for these layers includes use as a current blocking layer in semiconductor lasers, as a Shottky barrier enhancement layer in photodetectors and as buffer layers to isolate devices from the substrate or other devices. $SiBr_4$ has been developed as an alternative n-type dopant source of many III-V materials including GaAs, InGaP, InP and InGaAs. The doping efficiency of this source is much higher than that of other silicon sources used in CBE growth. For InP growth, carrier concentrations in excess of 1×10^{19} cm^{-3} have enabled the use of an InP contacting layers in an HBT rather than InGaAs contact layers. This simplifies the growth of InP-based HBTs and results in a transparent emitter structure allowing topside illumination.

Area 1 - Results

The most important results obtained in this objective were

1. Development of CCl_4 and CBr_4 doping of GaAs and InGaAs. These extrinsic doping sources give much better control and range in doping levels than previous methods used for carbon doping.

2. Development of InGaP/GaAs and InP/InGaAs HBTs with a carbon doped base. Carbon doped base HBTs have much better reliability than HBTs that use a Zn- or Be-doped base. In addition, extremely abrupt doping profiles and high doping levels are possible when using carbon as the base dopant.

3. Development of semi-insulating epitaxial InP using CCl_4 at low growth temperature. The simplicity of the growth of these layers and the lack of harmful side effects such as memory effects or migration during subsequent growths make these layers attractive in many applications where iron-doped InP is currently being used.

4. Development of $SiBr_4$ doping. The high incorporation efficiency of this is extremely useful in CBE growth. HBT using $SiBr_4$ for the n-type doping and CBr_4 for p-type doping have been demonstrated.

Area 2 - High Power Lasers and Laser Arrays

A large number of high power and high performance semiconductor lasers and laser arrays were studied as a part of this program. These included high power laser diode arrays, strained-layer distributed feedback ridge waveguide quantum well heterostructure lasers and arrays, strained-layer quantum well heterostructure circular ring lasers, reactive ion etched corner reflector strained-layer InGaAs-GaAs-AlGaAs quantum well lasers, and ridge waveguide distributed Bragg reflector InGaAs/GaAs quantum well lasers.

Area 2 - Results

The most important results obtained under this objective were

1. Nonplanar periodic laser arrays are suitable for very high power phase-locked operation and relatively simple to fabricate.
2. A form of a surface-processed ridge waveguide DFB laser can be made using direct write electron beam lithography and reactive ion etching. These lasers and similar arrays have very interesting characteristics but a better, simpler version involves using the same processes to form a deeply etched distributed Bragg reflector (DBR) laser structure.
3. Selective area metalorganic chemical vapor deposition (MOCVD) growth processes can be used to design the quantum well thickness and, hence, transition energy, anywhere on a wafer using simple low resolution oxide masking. These structures are suitable for low threshold buried heterostructure lasers and a variety of integrated photonic structures.

Area 3 - Impurity-Induced Layer Disordering and Native Oxide Formation of Al-bearing III-V Compounds

Impurity-induced layer disordering (IILD) and the selective oxidation of Al-bearing III-V materials are powerful processing technologies which were discovered at the Solid State Devices Laboratory. These technologies allow nearly planar, selective conversion of semiconductor material to material with distinctly different material properties, useful in defining device geometries. Using IILD to intermix heterolayers, the energy band gap, index of refraction and conductivity of a material can be selectively altered. Native oxidation of Al-bearing III-V's converts semiconductor material into an insulating material which has a low index of refraction and improved surface passivation properties. These layers are useful in many optical devices.

Area 3 - Results

The most important results obtained under this objective were

1. The IIID and native oxide technologies have been used to define curved geometry lasers. Micro disk (10 μm diameter and less than 1 μm thick) laser geometries have been fabricated and optically excited. Additionally, very low threshold ring laser diodes with small (200 μm) diameters have been demonstrated.
2. The native oxide has been used to define current flow in lasers with buried heterolayers and it has been used to fabricate high-contrast distributed Bragg reflecting mirrors used in VCSEL's and in thin cavity edge emitting laser diodes.
3. The native oxide has demonstrated a surface passivation effects that has led to enhanced device lifetimes in light emitters.
4. The native oxide technology has been used to demonstrate an enhancement mode MOSFET in the AlGaAs/GaAs material system.
5. IILD and native oxide technologies have been used to define the geometries of low-threshold, index and gain-guided stripe laser diodes. These technologies have also been used to fabricated coupled stripe laser diodes.

Personnel and Degrees Earned

Kevin Beernink	Ph.D.	1993
Eugen Chen	M.S.	1993
Timothy Cockerill	Ph.D.	1993
Carolyn Colomb	Ph.D.	1993
Tony Curtis		
Nada El-Zein	Ph.D.	1995
Micheal Fresina	M.S.	1993
David Forbes	Ph.D.	1995
Nathan Gardner	Ph.D.	1995
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Mike Krames	Ph.D.	1995
Robert Lammert	M.S.	1995
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Steve Maranowski	Ph.D.	1995
Mike Ries	M.S.	1993
Steven Stockman	Ph.D.	1993

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Area 3 - Publications

T. A. Richard, S. A. Maranowski, N. Holonyak, Jr., E. I. Chen, M. J. Ries, J. G. Neff, P. A. Grudowski, and R. D. Dupuis, "Enhanced Hot-Carrier Spontaneous and Stimulated Recombination in a Photopumped Vertical Cavity $Al_xGa_{1-x}As$-GaAs Quantum Well Heterostructure With Multiple Top and Bottom Native Oxide Mirrors," Appl. Phys. Lett. 66, 589-591 (30 Jan 1995).

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