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PHOTONICS AT SANDIA NATIONAL LABORATORIES: FROM RESEARCH TO APPLICATIONS

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ABSTRACT

Photonics activities at Sandia National Laboratories (SNL) are founded on a strong materials research program. The advent of the Compound Semiconductor Research Laboratory (CSRL) in 1988, accelerated device and materials research and development. Recently, industrial competitiveness has been added as a major mission of the labs. Photonics projects have expanded towards applications-driven programs requiring device and subsystem prototype deliveries and demonstrations. This evolution has resulted in a full range of photonics programs from materials synthesis and device fabrication to subsystem packaging and test.

1.0 INTRODUCTION

Research in optoelectronics and photonics components and high-data rate communications systems at Sandia National Laboratories has been driven by defense, intelligence, and environmental program needs. Even while pioneering the use of lattice-mismatched (strained-layer) quantum well heterostructures for band structure engineering[1] in the early 1980s, Sandia had developed a comprehensive approach to in-house realization of radiation-hardened optoelectronics components and subsystems for special applications.

Currently, applications-driven programs are founded on an extensive in-house materials effort and an on-campus Compound Semiconductor Research Laboratory (CSRL) for device prototyping. Both Metal-Organic Chemical Vapor Deposition (MOCVD) and Molecular Beam Epitaxy (MBE) capabilities have grown with the program and are supported by a major effort in preprocess material characterization and real-time in-situ process monitoring. The CSRL is a 5000-square-foot class 100 clean room for device prototyping in the areas of electronic and microwave devices and circuits, photonic and optoelectronic devices, Optoelectronic Integrated Circuits (OEICs), and nanostructures. Subsystem packaging and a full complement of measurement capabilities enable application support.

This paper first describes some of the materials and device prototyping capabilities available at Sandia and then delineates selected applications. These applications focus on implementation of monolithic, heterojunction, multilayer semiconductor mirror-stacked devices, GaAs/AlGaAs waveguide structures and OEICs. Applications include photonic interconnects for stacked multi-chip modules, reflectance and transmission lightwave modulators, GaAs/AlGaAs-ribbed waveguides that implement direct microwave modulation of light for communications and steering of phased-array antennas, and Vertical Cavity Surface Emitting Lasers (VCSELs) in support of photonic interconnects. Although III-V electronic devices are not specifically part of this photonics review, they will be mentioned as an essential part of subsystem integration. For instance, high-frequency photonic devices require transmitter and receiver circuits. In addition, photonic interconnect applications are more successful when combined with high-speed low-power digital circuits, such as complementary heterostructure digital GaAs.

2.0 MATERIALS AND PROCESSING

MBE and MOCVD Materials

Sandia's materials program operates six MBE growth chambers and three MOCVD systems spanning a range of activity from novel devices and heterostructures, to fundamental growth science and technology, to development of novel materials. Reproducible epitaxial growth, in particular, has been a long-term activity and has led to the development of a number of new real-time monitoring technologies, including Reflection Mass Spectroscopy (REMS) for monitoring reflected fluxes during MBE as well as absorption spectroscopy and optical reflectance spectroscopy for on-line control of MOCVD and MBE growth. Some current projects involve AlGaInP, InGaAsSb and InGaAsP alloys in addition to the now-common strained-layer (In,Ga)As/(Al,Ga)As/GaAs and (In,Ga)As/Al,Ga)As/InP systems. An exploratory effort in the growth of CdTe and related II-VI compounds serves to balance the program. This diversity of material expertise enables Sandia to tailor optoelectronic devices for a wide range of applications.

Processing

Processing capabilities include electron beam lithography capable of sub-20 nm features, optical contact lithography, reactive ion beam etching (RIBE) of metals, dielectrics, and compound semiconductors, electron cyclotron resonance (ECR) ion etching, plasma enhanced chemical vapor deposition (PECVD), electron beam evaporation of metal films, sputter deposition of metal films and dielectrics, wet chemical etching, electroplating, ion implantation, and rapid thermal annealing. Figure #1 contains four scanning electron micrographs (SEMs). Figure #1a is the outer edge of a binary-optic lens. These lenses require submicron features and are employed for focusing beams for either free-space interconnects or more efficient fiber coupling. Figure #1b is a self-aligned tungsten-gate field effect transistor structure employed in a complementary digital GaAs program. Figure #1c is a Vertical Cavity Surface Emitting Laser (VCSEL) structure that has been etched by RIBE. Both visible and 980 nm VCSELs have been developed. Finally, Figure #1d is a AlGaAs/GaAs ribbed waveguide combiner OEIC. Structures such as high-frequency modulators and couplers have been developed.

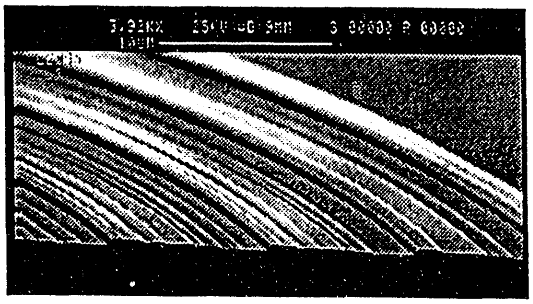

Figure #1a - Binary-Optic Lens

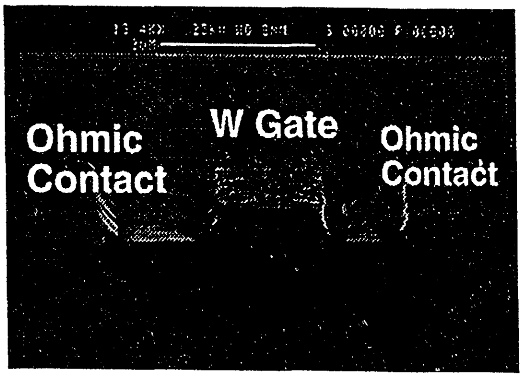

Figure #1b - Self-Aligned W-Gate FET

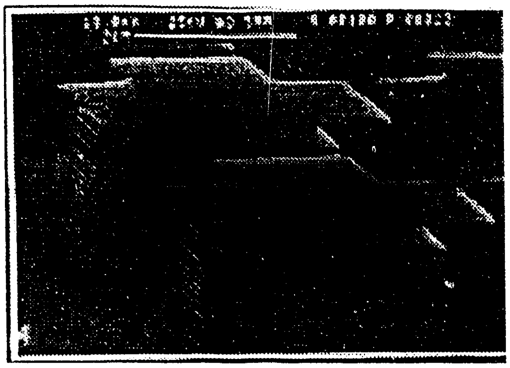

Figure #1c - RIBE etched vertical cavity surface emitting laser

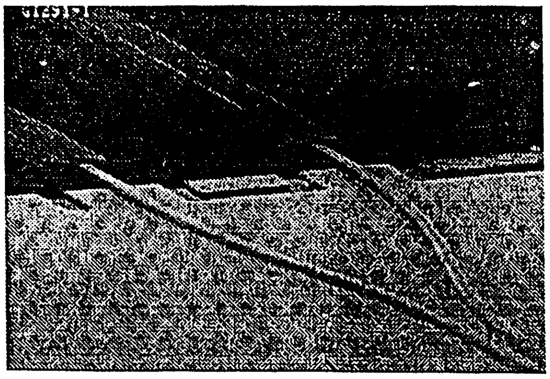

Figure #1d - AlGaAs/GaAs waveguide combiner

3.0 DEVICES AND APPLICATIONS

As the numbers of interconnects per multi-chip module (MCM) increases to approximately 2000 and the speed per interconnect approaches 100 MHz, conventional interconnect schemes begin to experience severe problems regarding interconnect density and resulting cross talk. One approach to the resolving these issues is the implementation of photonic interconnects. Applications needing small, real-time image processors require innovation in high-speed high-density interconnects. Photonic interconnect arrays can be employed throughout MCM layers to give a distributed interconnect matrix in which distances between digital chips can be minimized. Photonic data transmission between stacked multi-chip modules (MCM) becomes attractive with the advent of VCSEL technology due to the efficiency of directing light from one MCM layer to another. Since VCSEL beams are inherently more collimated than light emitting diodes, most of the light directed from one MCM layer to another can be collected by a single InP-based heterojunction bipolar transistor photoreceiver. Thus, transmitter power requirements are minimized. In contrast, employing a light-emitting diode array for free-space data transmission would require exotic beam capturing and focusing schemes to minimize diode power consumption. Additionally, Sandia is investigating use of VCSELs for board-to-board data communications via fiber optics. Sandia's red VCSELs are attractive for inexpensive plastic fiber-optic communications. Sandia 980 nm VCSELs are attractive for MCM-to-MCM data communications because device substrates allow light to pass in both up and down directions, thereby avoiding the necessity of using flip-chip technology in an MCM format.

Photonic steering of phased-array antennas has begun to receive attention. Sandia has suggested that steering phased-array antennas can be accomplished by a single Coherent Optical Monolithic Phased-Array Steering System (COMPASS) chip [2-4]. Once developed, input to COMPASS chips will be laser light, radio frequency information, and beam steering data. Fiber output to each antenna element will contain both phase and radio frequency information. The OEIC chip that will perform the steering function is based on ribbed compound-semiconductor waveguide in the AlGaAs/GaAs materials system. Figure #1c illustrates a combining section of a waveguide structure that will be employed in a Mach-Zender modulator. Sandia has developed lightwave phase modulators that demonstrate the ability to modulate phase with direct millimeter-wave radio frequency energy to 30 GHz. The advantage of the AlGaAs/GaAs system is the high figure of merit (50-100 degrees per volt-mm) which will increase the functionality of the OEIC while reducing its size in comparison to lithium niobate waveguide structures. The technology that produces the COMPASS chip also shows promise for high-data-rate optical communications.

4.0 SUMMARY

Sandia's photonics program spans a broad range of topics from basic materials synthesis and theory to applications-based prototype subsystems. Development devices based on a broad-based material effort have enabled applications from VCSEL-based data communications over fiber links to free-space interconnects between stacked multi-chip modules. OEIC development produces a platform that can lead to photonic steering of phased-array antennas as well as high-data communications via direct microwave modulation of light in compound-semiconductor waveguides. *Work at Sandia National Laboratories is sponsored by the U. S. Department of Energy under contract DE-AC04-94AL85000.*

Speaker Biography

After completion of a Postdoctoral position at Sandia National Laboratories in Solid State Physics, Dr. Meyer worked for six years in Semiconductor devices and components. In 1980, he joined Power Hybrids Incorporated (PHI), Torrance, California, as Director of Research for semiconductor devices, which included a silicon research wafer fabrication facility. In 1981, PHI was purchased by M/A-COM, Inc. During the last four years of his tenure at PHI (1985 to 1989), he became Vice President of Research and Development and in the final two years, assumed the role of Production Wafer Fabrication Manager. From the period of 1989 to the present, Dr. Meyer has been a Manager at SNL with the responsibility for high-speed digital GaAs devices, high-frequency devices, and high-frequency subsystems. The speaker's address is: Sandia National Laboratories, Mail Stop 1060, P.O. Box 5800, Albuquerque, NM, 87185-1060, Phone:(505) 844-1867, Fax: (505) 844-7011.

6. REFERENCES

1. G. C. Osbourn, P. L. Gourley, I. J. Fritz, R. M. Biefeld, L. R. Dawson, and T. E. Zipperian, "Principles and Applications of Semiconductor Strained-layer Superlattices," Semiconductors and Semi-metals, R. Dingle Editor Vol. 24, Chapter 8, 1987

2. G. A. Vawter, J. F. Klem, G. R. Hadley, and S. H. Kravitz, "Highly Accurate Etching of Ridge-waveguide Directional Couplers Using *in situ* Reflectance Monitoring and Periodic Multilayers," Appl. Phys. Lett., 62 (1), pp. 1-3, Jan. 4, 1993

3. V. M. Hietala, G. A. Vawter, W. J. Meyer, and S. H. Kravitz, "Phased-array Antenna Control by a Monolithic Photonic Integrated Circuit," Proceedings of SPIE, Optical Technology for Microwave Applications V, Paper 1476-46, pp. 170-175, April 1991

4 G. A. Vawter, V. M. Hietala, S. H. Kravitz, and W. J. Meyer, "Direct Optical Phase Shifter for Phased-array Systems," Proceedings of SPIE, Optical Technology for Microwave Applications V, Paper 1476-14, pp. 102-106, April 1991

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