

**INTEGRATED TRANSMITTERS AND LONG-WAVELENGTH  
VCSELs**

**ONR Grant No. N00014-96-1-0024**

Annual Progress Report  
For the period:

October 1, 1999 – September 30, 2000

Submitted to

Dr. Yoon Soo Park  
Office of Naval Research  
Program Director  
Optoelectronics  
800 N. Quincy St.  
Arlington, VA 22217-5660

By

Pallab Bhattacharya

Solid State Electronics Laboratory  
Department of Electrical and Computer Engineering  
The University of Michigan  
Ann Arbor, MI 48109-2122  
Telephone: 734-763-6678

**DTIC QUALITY INSPECTED &**

**20001115 026**

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB NO. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comment regarding this burden estimates or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 11/2/2000	3. REPORT TYPE AND DATES COVERED Progress Report 10/1/99-9/30/00	
4. TITLE AND SUBTITLE "InP-Based Monolithically Integrated Transmitters Integrated Transmitters & Long-Wavelength VCSELs			5. FUNDING NUMBERS	
6. AUTHOR(S) Pallab Bhattacharya				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The University of Michigan Dept. of Electrical Engineering & Computer Science 1301 Beal Ave. Ann Arbor, MI 48109-2122			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAMES(S) AND ADDRESS(ES) Office of Naval Research 800 North Quincy Street Arlington, VA 22217-5660			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
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) <p>The objective of this program is to develop InP-based monolithically integrated transmitters, including internal (current) and external modulation. The basic issues involved in such integration and operation of the individual devices will be explored both theoretically and experimentally. Thus, intrinsic and extrinsic factors that limit internal and external modulation, propagation and scattering of light in guided structures and through mirrors, and circuits, materials and lithography issues to develop high-frequency (&gt;30 GHz) transmitters will be explored. Integrated chips with driver circuits and guided wave elements will be developed and tested.</p> <p>At the same time we are also developing novel top- and edge-emitting microcavity laser structures in which zero or very low threshold currents are expected due to phonon confinement. Preliminary results, both theoretical and experimental, are very encouraging, and we envisage that these low threshold, high frequency devices will be extremely useful for chip-to-chip and array-based optical interconnects.</p>				
14. SUBJECT TERMS			15. NUMBER OF PAGES	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OR REPORT <b>UNCLASSIFIED</b>	18. SECURITY CLASSIFICATION OF THIS PAGE <b>UNCLASSIFIED</b>	19. SECURITY CLASSIFICATION OF ABSTRACT <b>UNCLASSIFIED</b>	20. LIMITATION OF ABSTRACT <b>UL</b>	

## Objective

To design, fabricate and characterize microcavity lasers and LEDs and 1.55 $\mu$ m monolithically integrated transmitters.

## Progress

### 1. 1.55 $\mu$ m oxide-confined VCSELs

We have successfully demonstrated low threshold (5mA) oxide confined InP-based VCSELs with quasi-CW operation at room temperature and high  $T_0$ . This unique device, called the patterned VCSEL, has a GaAs-based *defect-free* DBR, made by patterned regrowth. The output has stable polarization and a small beam divergence of only 15°. Our technique for making large-scale VCSEL arrays.

Work is in progress to lower the threshold current to ~1mA, to achieve CW operation at room temperature, and to fabricate and characterize arrays.

### 2. Electrically Injected Single Defect Photonic Bandgap Surface-Emitting Laser at Room Temperature

A single defect in a two- or three-dimensional photonic bandgap (PBG) crystal forms a true microcavity and it is possible to achieve a single-mode LED, or a zero-threshold laser, with such microcavity, *without the use of mirrors*. We have recently demonstrated, for the first time, an electrically injected (previous work was only with optically excited PBG microcavity) defect-mode PBG microcavity surface emitting laser at room temperature. 931 nm lasing was observed with  $I_{th}=300\mu$ A. Near- and far-infrared model characteristics confirm lasing from the defect-related microcavity in the photonic bandgap crystal. *It may be noted that the laser has no mirrors.*

Work is in progress to demonstrate a zero threshold PBG-Defect laser at 1.55 $\mu$ m and arrays of these devices.

### 3. High-Power InP-Based 1.55 $\mu$ m Microcavity Light Emitting Diodes

For array applications, it would be technologically simpler to have surface-emitting light sources *without* DBR mirrors. To this end, we have investigated, designed, fabricated and characterized InP-based, oxide-confined microcavity LEDs for the first time. The smallest devices have a cavity radius of 0.5 $\mu$ m. The output power is ~30 $\mu$ W and due to microcavity effects, the output is very directional (angular width 20 degrees, compared to 50 degrees of conventional LEDs). We have measured the small signal bandwidths of these devices to be ~ 0.8 GHz. The devices are therefore comparable to VCSELs, but has much simpler fabrication technology, particularly for arrays.

### 4. Integrated 1.55 $\mu$ m VCSEL-Modulator

We are currently fabricating an integrated 1.55 $\mu$ m VCSEL-modulator, in which the modulating region forms an integral part of the top DBR. We have analyzed the performance characteristics of the device exhibits an intrinsic modulation bandwidth of ~50 GHz with very low chirp.

## Publications

Office of Naval Research  
N00014-96-1-0024

1. "Growth and Characterization of Defect-Free GaAs/AlAs Distributed Bragg Reflector Mirrors on Patterned InP-Based Heterostructures", H. Gebretsadik, K. Kamath, K.K. Linder, P. Bhattacharya, C. Caneau and R. Bhat, *J. Vac. Science and Technology*, **B-16**, (1998).
2. "InP-Based 1.5 $\mu$ m Vertical Cavity Surface Emitting Laser with Epitaxially Grown Defect-Free GaAs-Based Distributed Bragg Reflectors", H. Gebretsadik, P. Bhattacharya, K. Kamath, O. Qasaimeh, D. Klotzkin, C. Caneau and R. Bhat, *Electronics Letters*, **34**, 1316 (1998).
3. "Design and Realization of a 1.55 $\mu$ m Patterned VCSEL with Lattice-Mismatched Mirror Layers.", H. Gebretsadik, O. Qasaimeh, H. Jiang, P. Bhattacharya, C. Caneau, and R. Bhat, *IEEE Journal of Lightwave Technology*, (1999).
4. "Electrically injected single-defect photonic bandgap surface-emitting laser at room temperature", W.D. Zhou, J. Sabarinathan, B. Kochman, E. Berg, O. Qasaimeh, S. Pang and P. Bhattacharya, *Electronics Lett.*, **36**, no. 18, (2000).

## Conference Presentations

1. "1.55 $\mu$ m Patterned VCSELs with Mismatched Mirrors", (INVITED), P. Bhattacharya, *IEEE/LEOS Summer Topical Meetings* San Diego, CA, July, 1999.
2. "Processing and Characterization of a GaAs/Al<sub>x</sub>O<sub>y</sub> Quasi-Three Dimensional Photonic Bandgap Material", W.D. Zhou, P. Bhattacharya, J. Sabarinathan, D.H. Zhu, A.S. Helmy, and J.H. Marsh, *IEEE Lasers and Electro-Optics Society Annual Meeting*, San Francisco, CA, November, 1999.
3. "Patterned 1.54 $\mu$ m Vertically Cavity Laser with Mismatched Defect-Free Mirrors", O. Qasaimeh, H. Gebretsadik, P. Bhattacharya, C. Caneau, and R. Bhat, *IEEE International Electron Devices Meeting*, Washington, D.C., December, 1999.
4. "InP-Based Oxide-Confined 1.55-1.6 $\mu$ m Microcavity Light-Emitting Diodes", W. Zhou, O. Qasaimeh and P. Bhattacharya, *SPIE Photonics West*, San Jose, CA, January, 2000.