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13. ABSTRACT (Maximum 200 words) This project first demonstrated ultra-low threshold lasing with a lower n-type AlAs/GaAs DBR and an upper dielectric DBR. The threshold was reduced to -40uA for 3um laterally sized devices. This remains the lowest threshold that has been reproducibly achieved in the oxide-confined VCSELs to date. Oxide confinement is a key in achieving ultra low threshold. Studies have also shown that diffraction loss due to the optical penetration depth of the lasing mode into the lower AlAs/GaAs DBR is a real problem when the device size is made smaller than -3um diameter. The thickness of the oxide aperture layer is an important parameter in the mode confinement, and if the aperture is too thin higher efficiency is achieved at the expense of a large mode area (loss of optical confinement).			
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Final
AFOSR ~~PROGRESS~~ REPORT

**Project Title: Ultra-Low Threshold Index-Confined
Microcavity Lasers**

Grant No. F49620-96-1-0336

Period: July 1, 1996 - December 31, 1996

Dennis G. Deppe, Principal Investigator

**Microelectronics Research Center
The University of Texas at Austin
Austin, Texas 78712**

AFOSR Final Report July 1, 1996 - December 31, 1996

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Grant No.: F49620-96-1-0336

P.I.: D.G. Deppe, The University of Texas at Austin

1. Objective

The objective of this research is to develop the necessary semiconductor device technology to realize ultra low threshold microcavity lasers, and develop the understanding of the most important design issues involving both the dielectric cavity and gain coupling to the lasing mode. The effort includes materials work in molecular beam epitaxy and the application of selective oxidation to III-V semiconductors, and the exploration of the relevant laser physics.

2. Progress

We have achieved some excellent results in this project. We first demonstrated ultra-low threshold lasing with a lower n-type AlAs/GaAs DBR and an upper dielectric DBR. The threshold was reduced to $\sim 40\mu\text{A}$ for $3\mu\text{m}$ laterally sized devices [1]. This remains the lowest threshold that has been reproducibly achieved in the oxide-confined VCSELs to date, although USC has reported sub- $10\mu\text{A}$ also using the oxide confinement. The USC result continues to be questioned because it has not yet been reproduced. In any case it is clear that oxide confinement is a key in achieving ultra low threshold. Our studies have also shown that diffraction loss due to the optical penetration depth of the lasing mode into the lower AlAs/GaAs DBR is a real problem when the device size is made smaller than $\sim 3\mu\text{m}$ diameter [2]. We have also shown that the thickness of the oxide aperture layer is an important parameter in the mode confinement, and if the aperture is too thin higher efficiency is achieved at the expense of a larger mode area (loss of optical confinement.)

To address the limitation associated with penetration depth into the lower DBR we have designed a new type of VCSEL based on a lower $\text{Al}_x\text{O}_y/\text{GaAs}$ DBR [3]. This work has resulted in measurable reduction of diffraction loss for small size devices, but performance improvement is not as great as hoped. $50\mu\text{A}$ thresholds are achieved for small VCSELs of diameter of $\sim 2\mu\text{m}$. Because we are working in the high Q regime, slope efficiencies are somewhat low at $\sim 20\%$, but comparable to our larger area VCSELs that use lower n-type AlAs/GaAs DBRs. Strain in the lower $\text{Al}_x\text{O}_y/\text{GaAs}$ DBR is certainly a problem. It can be measured in the present devices through spectral splitting of otherwise degenerate polarizations of the lowest order lasing mode. The oxide termination buried within the crystal appears to be the major source of the strain.

We have also had some success in studying the exciton response from cavities fabricated with $\text{Al}_x\text{O}_y/\text{GaAs}$ DBRs [4]. The major result is that the mode coupling can be increased, and that allows the spectral splitting to be observed near room temperature. We have presented fairly complete characterization data showing the effect, and have accurately simulated the cavity response as well. These type of cavities will be important in raising the operating temperature of more practical light emitters that might be based on the quantum well polariton response.

3. New Findings

Within these studies we have characterized the smallest volume VCSELs yet realized to characterize the lasing mode. The results show that for very small apertures the optical mode depends critically on the aperture design, and diffraction loss is a concern. A

new type of $\text{Al}_x\text{O}_y/\text{GaAs}$ DBR has been demonstrated based on less than quarter-wave Al_xO_y layers that reduce the strain due to the mirror. We have also studied the exciton response in the high contrast microcavity to demonstrate near room temperature spectral splitting.

4. Personnel Supported

- 1.) D.G. Deppe, Associate Professor
- 2.) D.L. Huffaker, Post-Doctoral Research Associate
- 3.) T.-H. Oh, Graduate Research Assistant

5. Publications

- [1] D.L. Huffaker, L.A. Graham, H. Deng, and D.G. Deppe, "Sub-40 μA Continuous-Wave Lasing in an Oxidized Vertical-Cavity Surface-Emitting Laser with Dielectric Mirrors," *IEEE Phot. Tech. Lett.* **8**, 974 (1996).
- [2] T.-H. Oh, D.L. Huffaker, and D.G. Deppe, "Size Effects in Small Oxide Confined Vertical-Cavity Surface-Emitting Lasers," *Appl. Phys. Lett.* **69**, 3152 (1996).
- [3] D.L. Huffaker and D.G. Deppe, "Low Threshold Vertical-Cavity Surface-Emitting Lasers Based on High Contrast Distributed Bragg Reflectors," *Appl. Phys. Lett.* **70**, accepted for publication.
- [4] L.A. Graham, Q. Deng, D.G. Deppe, and D.L. Huffaker, "Exciton Spectral Splitting Near Room Temperature From High Contrast Semiconductor Microcavities," *Appl. Phys. Lett.* **70**, (17 February 1997).

6. Consultative and Advisory Functions

- 1.) Texas Instruments - Dr. G. Magel, and 11 others, submitted White Paper to BAA for DARPA OMNET - August 9, 1996
- 2.) Opti-Comp - Dr. Peter Guilfoyle, Texas Instruments - Dr. Lily Pang, serve as consultant on oxide VCSEL collaboration.

7. New Discoveries, inventions, patent disclosures - None.