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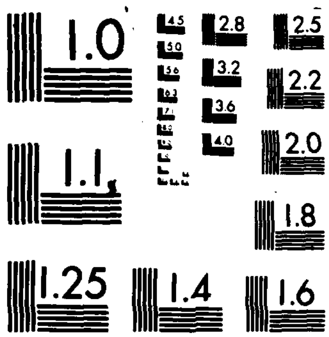

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Compound semiconductors of GaAs and (GaAl)As were studies for optical and microwave applications. Two growth processes were employed for device fabrication: (1) the liquid-phase epitaxy (LPE) and (2) the molecular beam epitaxy (MBE). The procedure for LPE growth was well established in the laboratory. On the other hand, the MBE growth process required a considerable amount of effort to establish the growth procedure and optimize the growth conditions.

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STUDIES OF III-V COMPOUND SEMICONDUCTORS
FOR OPTICAL AND MICROWAVE APPLICATIONS

Final Report

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STATEMENT OF THE PROBLEMS STUDIED:

Compound semiconductors of GaAs and (GaAl)As were studied for optical and microwave applications. Two growth processes were employed for device fabrication: (1) the liquid-phase epitaxy (LPE) and (2) the molecular beam epitaxy (MBE). The procedure for LPE growth is well established in our laboratory. On the other hand, the MBE growth process is new to us. Therefore, a considerable amount of effort was spent on establishing the growth procedure and optimizing the growth conditions.

In the device area, five major problems were studied: (1) stabilization of longitudinal modes, that is, elimination of mode hopping in semiconductor lasers over an extended operating temperature range, (2) continuous tunability and sudden wavelength switching of semiconductor lasers, the former for heterodyning and the latter for wavelength multiplexing, (3) control of the relative phase in coupled-waveguide lasers for the development of high power laser arrays, (4) optical pulse compression utilizing nonlinear optical effects in coupled waveguides, and (5) establishment of MBE growth capabilities. For items (1) and (2), excellent results have been achieved, demonstrating the effectiveness of the various interferometric lasers we developed. Experiments are in progress to demonstrate the high-speed modulation capabilities of these lasers in the GHz region. For items (3) and (4), exploratory studies have yielded very encouraging results. Experiments are in the planning stage to apply our coupled-waveguide approach to laser arrays and to demonstrate the pulse compression capability of coupled semiconductor waveguides. For item 5, both heterostructure and multiple quantum-well lasers with built-in two-dimensional waveguides have been successfully grown by MBE. Now that we have demonstrated our MBE growth capability, experiments to apply MBE technique to grow microwave FET structures are being planned.

SUMMARY OF THE MOST IMPORTANT RESULTS

The development of high-performance optical communication systems depends on our ability to control the longitudinal-mode or spectral behavior of semiconductor lasers. In our laboratory, we have initiated a research program on the use of interference effects to control the laser spectrum. Several interferometric laser structures using multiple cavities and coupled waveguides have been developed. These include the integrated-etalon-interference (IEI) laser (paper A9), the internal-reflection-interference (IRI) laser (paper A7), the open-ended Michelson interferometric (OEMI) laser (paper A8), the interferometric coupled-waveguide (ICW) laser (paper A17), and the twisted double heterostructure (TDH) laser (paper A14). One serious problem with simpled Fabry-Perot (FP) lasers is mode hopping which occurs for a temperature change as small as 1-1.5° C. Accompanying mode hopping is excessive amount of noise known as mode-partition noise. In interference lasers, lasing takes place at the wavelength of the coincidence resonance modes (CRM's) where the coupled cavities are at resonance simultaneously. Because the CRM's are far apart, the laser wavelength can be locked to a CRM for an extended temperature range without hopping to another CRM. A mode-stable temperature range ΔT as large as 23° C was achieved in the IEI laser (paper A9) and ΔT as large as 25° in the TDH laser (paper A19). Since mode hopping is eliminated within ΔT, the lasers are expected to show no partition noise in the mode-stable temperature range.

Besides temperature stability of interferometric lasers, another important achievement is the tunability of laser wavelength. This is accomplished by pumping separately the sections of a multiple-cavity interferometric laser (papers A15 and A17). Under separately pumping, the carrier concentrations in each segment of a multi-cavity laser are no longer held at fixed values even though the overall gain is still fixed by the laser threshold condition. Because the refractive index is a function of carrier concentration the interference condition and hence the lasing wavelength can be controlled by adjusting the relative magnitudes of the two currents used in separate pumping. Two distinct modes of tuning operation (papers C5 and C7) were observed: continuous tuning and sudden switching. A continuous tuning range as large as 3.5 Å was achieved, corresponding to bandwidth $\Delta f \approx 140$ GHz. On the other hand, for large changes in the relative magnitudes of the two currents, a sudden switching of wavelength as large as 90 Å was obtained. This demonstration of tunability should open up new applications for semiconductor lasers such as heterodyning and wavelength multiplexing.

Besides the laser work just described, we also initiated research on (1) coupled-waveguide semiconductor lasers and (2) nonlinear coupled waveguides for optical pulse compression. Even though both works are still in the exploratory stage, the results obtained thus far are very encouraging and may lead to potential important applications. Recently a great deal of interest has been given to laser arrays in which couplings between neighboring waveguides are introduced along the whole length of the waveguides. A major difficulty in laser arrays is that the lasers do not lase with all the lasers in phase. In our work, the coupling region is only few microns long as compared to a waveguide length of few hundred microns. The fields in the two coupled waveguides are thus forced to be in phase as in interferometric coupled-cavity lasers. The experiment on a semiconductor laser with two coupled waveguides (paper A18) has indeed borne out this prediction.

Pulse compression is an important technique to generate ultrashort optical pulses. Truly remarkable results have been achieved with the dye laser system using saturable absorbers. In our laboratory, we have studied an alternate way of shortening optical pulses. Recently, much attention has been paid to optical bistability phenomenon observed in semiconductors. Because of large nonlinear susceptibilities, nonlinear optical effects can be observed even at moderate power densities. The effect we examined is the nonlinear optical effect in coupled waveguides for the purpose of pulse compression. In linear coupled waveguides, all the power is transferred from one guide to the other at a distance L such that $\kappa L = \pi/2$ where κ is the coupling constant. In nonlinear coupled waveguides, κ is dependent on the incident power. At sufficiently high incident power, the condition $\kappa L = \pi/2$ will be violated and thus most of the power will remain in the original waveguide. In other words, nonlinear optical effect in coupled waveguides can be used to clip off the wings (the low power parts) of an optical pulse through power transfer to the other guide while the high power part of the pulse is retained in the original guide. Our analysis shows that a maximum reduction of pulse width to 15% of its original pulse width should be achievable in GaAs/(GaAl)As coupled waveguides at a power level about 700 mW (paper A12). This peak power is easily obtainable with semiconductor laser arrays and with mode-locked semiconductor lasers. Experiments to demonstrate this effect are in preparation.

Finally, our effort on MBE has completed its initial stage of establishing the growth procedure and optimizing the growth conditions. Photoluminiscence and x-ray diffraction experiments have shown that the MBE grown films have high luminescent efficiency and high crystalline quality. Recently we have succeeded in making both double heterostructure (DH) and multiple quantum well (MQW) lasers over etched channels. Two-dimensional waveguides of channel substrate (CS), terraced substrate (TS) and raised ridge (RR) types have been incorporated into the DH and MQW lasers. We believe that this is the first time that MBE lasers have been grown with built-in two-dimensional waveguides. The results are in the process of being analyzed and organized so that they can be submitted for publication. Once we have demonstrated our ability to grow thin films, on the order of 60 to 120 Å in various MQW lasers, we can and will extend our MBE activities to FET's.

PUBLICATIONS

(A) Journal Articles Published

1. C. Y. Chen and S. Wang, "Narrow Double-Current-Confinement Channeled-Substrate Planar Laser Fabricated by Double Etching Technique," Applied Physics Letters, vol. 36, pp. 634-636, April 15, 1980.

2. A. S. H. Liao and S. Wang, "Semiconductor Injection Lasers with a Circular Resonator," Applied Physics Letters, vol. 36, pp. 801-803, May 15, 1980.

3. C. Y. Chen and S. Wang, "Near-Field and Beam-Waist Position of the Semiconductor Laser with a Channeled-Substrate Planar Structure," Applied Physics Letters, vol. 37, pp. 257-260, August 1, 1980.

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6. S. Wang, H. K. Choi, and I. H. A. Fattah, "Studies of Semiconductor Laser of the Interferometric and Ring Types," IEEE Journal Quantum Electronics, vol. QE-18, pp. 610-617, April 1982.

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8. I. H. A. Fattah and S. Wang, "Semiconductor Interferometric Laser," Applied Physics Letters, vol. 41, pp. 112-114, July 15, 1982.

9. A. Antreasyan and S. Wang, "Semiconductor Integrated Etalon Interference Laser with a Curved Resonator," Applied Physics Letters, vol. 42, pp. 562-564, April 1, 1983.

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13. H. K. Choi and S. Wang, "Anomalous Behavior of Deep Zn-Diffused GaAs/GaAlAs Injection Lasers," Applied Physics Letters, vol. 43, pp. 427-429, Sept. 1983

14. T. Sugino and S. Wang, "Twisted Double-Heterostructure GaAs-(AlGa)As Laser," Applied Physics Letters, vol. 43, pp. 427-429, September 1, 1983.

15. A. Antreasyan and S. Wang, "Electronic Wavelength Tuning with Semiconductor Integrated-Etalon Interference Laser," Applied Physics Letters, vol. 43, pp. 530-532, September 15, 1982.

16. A. Antreasyan and S. Wang, "Temperature Characteristics of Wavelength Tuning in Separately Pumped Integrated-Etalon-Interference Lasers," Electronics Letters, vol. 19, pp. 876-877, October 13, 1983.

17. I. H. A. Fattah and S. Wang, "Electrical Tuning of Semiconductor Interferometric Laser," Electronics Letters, vol. 19, pp. 926-927, October 27, 1983.

18. K. Kitayama, I. H. A. Fattah, and S. Wang, "Interferometric Coupled-Waveguide Semiconductor Laser: Structure Optimization and its Performance," Applied Physics Letters, vol. 43, pp. 816-818, November 1, 1983.

19. T. Sugino and S. Wang, "Stable Longitudinal Mode Operation in Multiple Twisted Double-Heterostructure Laser," Applied Physics Letters, vol. 43, pp. 889-891, November 15, 1983.

(B) Journal Articles Accepted

1. H. K. Choi, K. L. Chen, and S. Wang, "Analysis of Two-Section Cavity Semiconductor Lasers," to appear in IEEE Journal of Quantum Electronics.

(C) Conference Papers Presented

1. S. Wang, "Novel Semiconductor Lasers for Integrated Optics," SPIE Conference on Integrated Optics and Millimeter and Microwave Integrated Circuits, Huntsville, Alabama, November 16-19, 1981.
2. I. H. A. Fattah, and S. Wang, "Semiconductor Interferometric Laser," Topical Meeting on Integrated and Guided-Wave Optics, Pacific Grove, California, January 6-8, 1982.
3. H. K. Choi and S. Wang, "GaAs/GaAlAs Deep Zn-Diffused Channeled-Substrate Laser," Conference on Lasers and Electro-Optics (CLEO), Baltimore, Maryland, May 17-20, 1983.
4. K. Kitayama, I. H. A. Fattah, and S. Wang, "Structure Optimization for Interferometric Coupled-Waveguide Semiconductor Laser," Conference on Lasers and Electro-Optics (CLEO), Baltimore, Maryland, May 17-20, 1983.
5. I. H. A. Fattah, and S. Wang, "Tuning of Semiconductor Interferometric Laser," IV International Conference on Integrated Optics and Optical Fiber Communication, Tokyo, Japan, June 27-30, 1983.

6. A. Antreasyan and S. Wang, "Semiconductor Integrated-Etalon-Interference Laser," IV International Conference on Integrated Optics and Optical Fiber Communication, Tokyo, Japan, June 27-30, 1983.

7. A. Antreasyan and S. Wang, "Wavelength Tuning with Semiconductor Integrated-Etalon Interference Lasers," IV International Conference on Integrated Optics and Optical Fiber Communication, Tokyo, Japan, June 27-30, 1983.

SCIENTIFIC PERSONNEL

1. A. S. H. Liao, Ph.D., June 1981
2. I. H. A. Fattah, Ph.D., December 1983
3. Y. H. Wu (Ph.D. candidate, partial support)
4. M. H. Hong (partial support)
5. L. Parechanian (partial support)

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