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13. ABSTRACT (Maximum 200 words) The purpose of this program was to demonstrate the integration of InP-based lasers and other optical devices using a simple, platform integration technology. During this program, we successfully implemented the novel concept of a twin waveguide structure with loss layer which demonstrated nearly 50% coupling between the active laser devices and the integrated waveguide. This coupling, which is cavity-length independent, allows for the integration of lasers, optical amplifiers, waveguides and modulators on a single epitaxial structure.				
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Final Report

During the course of this program, we demonstrated several extremely high performance devices based on gas source molecular beam epitaxially grown InGaAsP. Among those devices, we report the following results:

- Low threshold, strained InGaAsP MQW Fabry Perot lasers. These devices exhibited the lowest threshold current densities ever achieved for GSMBE grown material operating at a wavelength of 1.3 μm . This result was a direct consequence of our ability to grow atomically abrupt heterointerfaces using a novel growth method.
- High gain (25dB) semiconductor optical amplifiers.

All of these devices were designed and fabricated such that we could demonstrate the integration of multifunctional photonic integrated circuits (PICs) employing one or more of these devices in any combination needed for a given application. This led to our demonstration of a very simple, and flexible integration technology based on a modified twin waveguide (TG) structure. We developed this TG technology to completely eliminate complicated regrowth processing, such that we can ultimately realize an integration "platform" whereby any combination of active (i.e. SOAs, lasers) and passive (i.e. waveguides, modulators) optical devices can be arbitrarily combined with different PICs on a single, multipurpose wafer structure.

The basic concept of the TG structure is that an active MQW region is grown above a passive waveguide/modulator region, separated by an intermediate "cladding" region. A laser or SOA is then defined in the active region by etching down into the clad. The difference between these two devices is simply the facet reflectivity: an SOA has anti-reflection coated facets, whereas a laser has high reflection coatings. To realize this device, we also needed to develop very high quality facet formation processes based on $\text{CH}_4:\text{H}_2$ reactive ion etching.

The light generated in the active region is evanescently coupled into the passive, or waveguide region located directly below. As in any directional coupler, the coupling efficiency is a sensitive function of length. For this reason, previous results for such TG structures report a maximum coupling efficiency of 13%. To eliminate this length dependence, hence making the TG a practical integration scheme for the first time, we grew a thin ($\sim 100\text{\AA}$ - 500\AA) InGaAs absorbing, or "loss" layer in the center of the intermediate InP cladding layer. This loss layer is grown since we recognize that the length dependence of the coupling arises from an interplay between the odd and even modes propagating in the structure. Due to the different effective indices of these two modes, their velocities are different, and hence they are in and out of phase at different positions within the active cavity. The loss layer effectively eliminates the even mode, hence eliminating this energy exchange with its concomitant length dependence.

Using our modified TG structure, we find that we completely eliminate the even mode, resulting in complete elimination of any length dependence in the structure. *Furthermore, in our first test device (a laser coupled to a waveguide Y-junction) we measured a 50% coupling between the laser and the waveguide. This is equal to the theoretical maximum coupling allowed in this structure, far exceeding all previous reports for coupling efficiency in such integrated devices.*

Hence, the TG structure with loss layer developed under this program (and detailed further in the preprint attached) provides a radical new approach to integrating passive and active optical devices on a single epitaxial wafer structure. Hence, we succeeded in this program in demonstrating a practical "platform" PIC technology which is free from sensitivity to fabrication and epitaxial growth variations, and does not employ highly complex and costly regrowth methods. For the first time, we can look forward to generating a wide range of PICs on a single wafer, similar to what is accomplished using a single Si wafer to generate a wide range of integrated circuits and codes.

Publications Made Possible in Part to Support from this Program:

16. "Monolithic Integration of an InGaAsP/InP MQW Laser/Waveguide Using a Twin-Guide Structure with a Mode Selection Layer", L. Xu, M. R. Gokhale, P. Studenkov, J. C. Dries, C.-P. Chao, D. Garbuzov and S. R. Forrest, *IEEE Photonics Technology Lett.*, **9**, 569 (1997).
17. "Technologies for Large Scale InP-based Optoelectronic Integrated Circuits", S. R. Forrest, D. S. Kim, S. Yu, J. Thomson, L. Xu, M. Gokhale, J. C. Dries, M. Lange, G. H. Olsen, and M. Cohen, SPIE Conf. on Optoelectronic Integrated Circuits, invited, **3006**, 186, San Jose, CA (Feb., 1997)
18. "Monolithic Integration of Laser and Waveguide Using a Twin-Guide Structure with Absorption Layer", P. Studenkov, M. Gokhale, L. Xu, J. C. Dries, C.-P. Chao, D. Garbuzov and S. R. Forrest, 9th In. Conf. on InP and Related Materials, Hyannis, MA (May, 1997).

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