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**Final Report**  
**November 1, 1990 through October 31, 1993**

**Grant No.:** N00014-91-J-1195

**Title:** Optical, Electronic and Optoelectronic Material and Device Research

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## Final report for ONR grant, contract period 1990-1993

During the contract period of 1990-1993 we have continued our research effort on semiconductor lasers (SCLs) by investigating the fundamental limits of SCLs, which are often the limiting factors in applications. Our research concentrated on reducing the threshold current, increasing the wavelength tunability, reducing the linewidth, increasing the modulation bandwidth, reducing the chirp under modulation, and generation of ultra short light pulses.

We have investigated threshold properties of buried heterostructure (BH) strained InGaAs quantum well lasers grown by a combination of molecular beam epitaxy (MBE) and liquid phase epitaxy (LPE). By improving the crystal growth and device fabrication we have improved on our earlier results and achieved minimum threshold currents of 1.0 mA for lasers with as cleaved facets and 0.35 mA with 90% high reflectivity coatings for single quantum well material. These values are record low threshold currents for single quantum well lasers in any material system.

To investigate compatibility with low temperature physics and to further reduce the threshold current we have measured lasers at cryogenic temperatures (5K), achieving record low threshold currents of 120  $\mu$ A for GaAs and 160  $\mu$ A for strained InGaAs quantum well lasers.

We have investigated broad-band tunability of GaAs and InGaAs single quantum well lasers. Using an external grating we have tuned optimized GaAs quantum well lasers over 125 nm and InGaAs quantum well lasers

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over 170 nm. Both values are record high tuning ranges for semiconductor lasers. With these two lasers the entire wavelength region between 740 nm and 1100 nm can be spanned. In addition we have observed qualitative differences between GaAs and InGaAs gain spectra which can be explained by the difference in valence band structure due to the strain in the InGaAs lasers. Since our demonstration of broad-band wavelength tunability several companies have come out with commercially available broad-band wavelength tunable laser diodes.

We have also continued our research on reduction of the laser linewidth due to its consequences for high data rate and long haul fiber communication systems. Our research results include theoretical and experimental work on the frequency stabilization of semiconductor lasers using optical and electronic feedback. Using frequency selective optical feedback from a Doppler-free atomic resonance in Cs vapor, the linewidth of a semiconductor laser was reduced by more than three orders of magnitude from 20 MHz to 10 kHz. Under conditions of optical feedback it was found that low frequency  $1/f$  noise made the dominant contribution to the laser linewidth and that for this reason the linewidth was reduced by less than the expected amount. A detailed study of the effects of optical feedback on this  $1/f$  noise component was performed. An electronic feedback scheme using FM sideband modulation has resulted in a linewidth of 1.6 kHz, as well as excellent absolute stability (root Allen variance of  $2 \times 10^{13}$  at an integration time of 1 s) due to the locking to an atomic transition.

In a parallel effort we investigated frequency stabilization in semiconductor

lasers by incorporation of multiple sections in a distributed feedback (DFB) laser. In theory this device operates under the same principles of frequency selective feedback described above, but offers the advantage of a compact integrated device. The structures have been fabricated and tested and a spectral linewidth of 900 kHz at an output power of 4 mW was measured. We also demonstrated a new measurement technique for evaluating the linewidth enhancement factor and the adiabatic chirp in semiconductor lasers. The results show the promise of these devices for achieving low frequency chirp under AM modulation, as required for high bit rate long haul fiber communication.

Our work on short pulse generation was concentrated on passive mode-locking of custom designed semiconductor lasers. We have demonstrated the first passive mode-locking of multi-section monolithic devices with one section reverse biased to act as a fast saturable absorber, and have demonstrated pulse repetition rates above 100 GHz.

By coupling a two-section multiple quantum well (MQW) laser to an external cavity we have demonstrated that such devices can be used as reliable sources of wavelength tunable near transform limited sub-picosecond pulses. Pulse repetition rates ranging from 500 MHz to 7 GHz were demonstrated for these devices. We have measured a very low timing jitter of 5.5 ps above 50 Hz (1.4 ps above 200 Hz) and pulse energy fluctuations below 0.52% for pulse repetition rates of 546 MHz. We have also demonstrated broad-band wavelength tuning up to 26 nm using a grating as external cavity reflector, and have measured compressed pulse widths below 600 fs for a tuning range of 16 nm, and compressed pulse

**widths as low as 260 fs. All the measured values are to date still records in noise performance, wavelength tuning and pulse widths for multi-section MQW GaAs lasers.**

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