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VERY HIGH MODULATION EFFICIENCY OF ULTRALOW THRESHOLD CURRENT SINGLE QUANTUM WELL InGaAs LASERS

T. R. Chen, B. Zhao, L. Eng, Y. H. Zhuang, J. O'Brien and A. Yariv

Indexing terms: Semiconductor lasers, High-speed optical techniques

A record high current modulation efficiency of 5GHz/$\surd$(mA) has been demonstrated in an ultralow threshold strained layer single quantum well InGaAs laser.

The key for high density applications, such as optical interconnects between future supercomputers, is the ability to handle multigigabit per second data streams at reasonably low power consumption. This translates to the following requirements for semiconductor lasers which are considered to be the most promising candidate for this kind of application: the individual laser must be capable of operating under low drive current (milliamp to microamp region), yet with a very large bandwidth (multi-gigahertz); the lasers can be integrated at a high density to allow parallel processing. Wavelength division multiplexing (WDM) or other multiplex technologies may also be applicable to such applications.

To characterise such an ultralow threshold and ultrahigh speed laser, we suggest a figure of merit, i.e. the modulation-current efficiency factor (MCEF), defined as

$$MCEF = f_{3\,dB}/\surd(I - I_{th}) \tag{1}$$

where $f_{3\,dB}$ is the 3dB bandwidth of the laser under direct current modulation, I is the bias current at which the modulation bandwidth is measured and I_{th} is the threshold current of the laser. It is clear that the desirable laser should have as low as possible I_{th} and as high as possible MCEF.

The 3dB bandwidth of a damping-free, parasitic-free semiconductor laser under small signal direct current modulation can be expressed as [1, 2]

$$f_{3\,dB} \simeq 1{\cdot}55 f_r = \frac{1{\cdot}55}{2\pi}\sqrt{\left(\frac{G'P}{\tau_p}\right)} \tag{2}$$

$$= \frac{1{\cdot}55}{2\pi}\sqrt{\left[\frac{G'v_g\eta_i}{eV_{opt}}(I - I_{th})\right]} \tag{3}$$

where f_r is the resonance frequency, G' is the differential gain, τ_p is the photon lifetime, and P is the photon density at the active region which is proportional to the optical power. Eqn. 3 can be derived directly from eqn. 2 under the assumption that optical power is linearly related to the injection current above threshold. The MCEF is therefore expressed as

$$MCEF \simeq \frac{1{\cdot}55}{2\pi}\sqrt{\left(\frac{G'v_g\eta_i}{eV_{opt}}\right)} \tag{4}$$

where v_g is the photon velocity inside the capacity, η_i is the internal quantum efficiency, e is the electron charge and V_{opt} is the volume of the optical mode which is equal to wLt, w is the lateral width of the active stripe, L is the cavity length and t is the effective transverse width of the optical mode. It is noted that eqn. 3, and therefore eqn. 4, is valid only within the linear regime of the $L - I$ relation. Also the damping and/or parasitic capacitance render the $f_{3\,dB}$ always smaller than $1{\cdot}55 f_r$, especially at high bias current.

Eqn. 4 tells us that a strained layer quantum well laser would be superior to a bulk material semiconductor laser due to its higher differential gain. An improvement in the internal quantum efficiency and a reduction in optical mode volume (tight confinement) would also be desirable in obtaining high MCEF.

The device used in this work is the ultralow threshold strained layer (SL) single quantum well (SQW) InGaAs/AlGaAs laser developed recently in our laboratory. We adopted a graded-index separate confinement heterostructure (GRINSCH) and buried heterostructure (BH) to obtain tight optical confinement in the transverse and lateral directions, respectively. The width of the InGaAs SQW is 80Å and the width of the active stripe w is $\sim 1{\cdot}5\,\mu m$. The threshold currents for as-cleaved lasers are below 1·5mA in the cavity length range 250–600μm. The lowest threshold current measured was 1mA. Details of the laser structure and fabrication will be presented elsewhere.

To examine the high speed performance of the lasers, a mesa of 10μm was etched around the active stripes to reduce the parasitic capacitance. We used a short cavity laser (120μm) to demonstrate the high modulation efficiency. The threshold current of the laser was 3·5mA; it dropped to 2·4mA when the back facet mirror was dielectrically coated to $R \simeq 0{\cdot}95$. The $L - I$ characteristics of the laser are shown in Fig. 1. The laser displayed excellent dynamic performance.

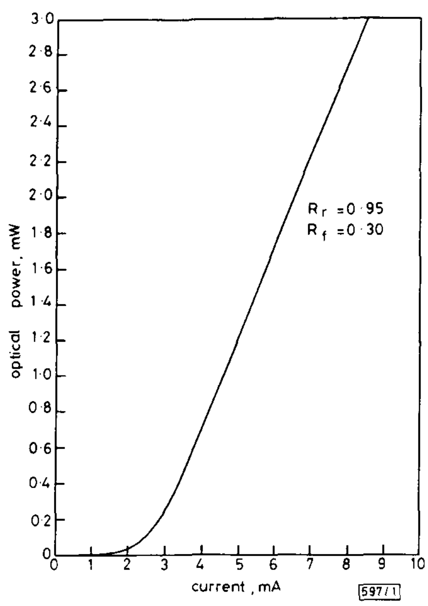

Fig. 1 *L–I characteristics of low threshold InGaAs SQW laser*
Cavity length $L = 120\,\mu m$

Small signal direct current modulation response curves at different bias current are shown in Fig. 2. A 3dB bandwidth of 5GHz was evident at a bias current of only 1mA above threshold. At a bias of 10mA above threshold, a bandwidth of 13GHz was demonstrated.

$f_{3\,dB}$ as a function of square root of the incremental current above threshold is plotted in Fig. 3. At low bias, $f_{3\,dB}$ increases linearly with $\surd(I - I_{th})$. The relation becomes sublinear when the bias current increases further, indicating that damping and/or parasitics can no longer be neglected. A very high value of MCEF of 5GHz/$\surd$(mA) was deduced from the linear part of the curve. To our knowledge, this is the highest value ever reported in edge emitting semiconductor lasers. In previous work, the MCEF values are 2–3 GHz/$\sqrt{(mA)}$ in high speed bulk lasers [3, 4] and 2·4 GHz/$\sqrt{(mA)}$ in high speed QW lasers [5–7]. f_{3dB} was also plotted as a function of the square root of the average output power in Fig. 4. A slope of 10 GHz/$\sqrt{(mA)}$ was obtained.

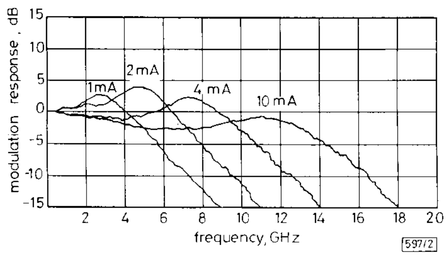

Fig. 2 *Modulation response curves of SQW laser at different bias current*

Bias current above threshold indicated next to curves

For different cavity length and different mirror coatings, the measured MCEF is somewhat different due to the variation in V_{opt} and G'. In a laser with a cavity length of 150 μm and threshold current of 1·85 mA, an MCEF of 4·6 GHz/$\sqrt{(mA)}$ was measured.

In conclusion, a very high modulation-current efficiency factor (MCEF) of 5 GHz/$\sqrt{(mA)}$ was demonstrated in a very low threshold short cavity SL-SQW InGaAs/AlGaAs laser.

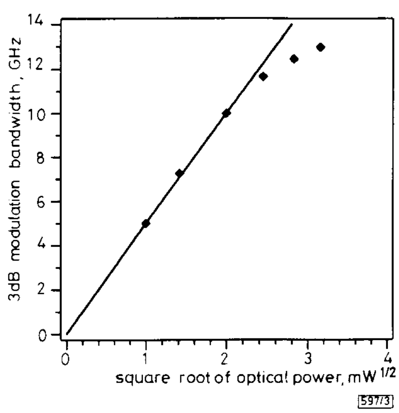

Fig. 3 *3 dB modulation bandwidth f_{3dB} as function of square root of incremental current $\sqrt{(I - I_{th})}$, with MCEF = 5 GHz/$\sqrt{(mA)}$*

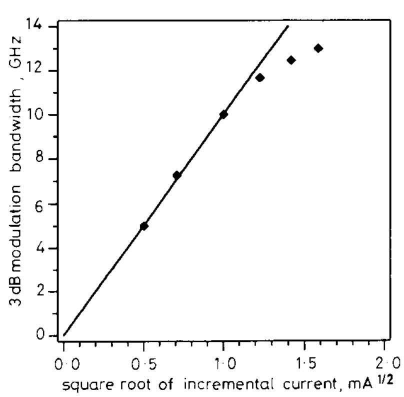

Fig. 4 *3 dB modulation bandwidth f_{3dB} as function of square root of average optical output power, with modulation power efficiency of 10 GHz/$\sqrt{(mW)}$*

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FAST ADAPTIVE PREDISTORTION LINEARISER USING POLYNOMIAL FUNCTIONS

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Indexing terms: Power amplifiers, Linearisation techniques, Polynomials

Adaptive predistortion is an effective method for linearising high power amplifiers. An important problem faced in the optimisation of a predistortion lineariser is that of convergence into a local minimum. In the Letter, a global optimisation algorithm is presented which uses polynomial predistortion and postdistortion. By using postdistortion of the demodulated signals, objective functions of quadratic shape are obtained and fast convergence to the global minimum is ensured. Computer simulation results are presented which show fast convergence and high spectral improvement.

Introduction: High spectral efficiency modulation methods such as QAM are highly sensitive to power amplifier nonlinearities. An effective solution is to linearise the power amplifier by using predistortion of the input signal [1, 2]. Because of changes with time, temperature and because of different operating channels, it is necessary that the predistorter be adaptive. Adaptive linearisation methods with polynomial functions have been previously reported [2]. These methods employ out-of-band intermodulation distortion (IMD) to estimate the predistorter polynomial coefficients. It has been shown [2] that the 3rd and 5th order components of IMD are quadratic functions of the coefficients. However, higher order components of IMD are not quadratic functions of the coefficients and thus stability and convergence to the global minimum may not be guaranteed. Only a limited spectral improvement can be achieved using local minimisation of IMD.