Self-pulsing oxide-confined vertical-cavity lasers with ultralow operating current

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Indexing terms: Vertical cavity surface emitting lasers, Semiconductor junction lasers

Selectively oxidised vertical-cavity lasers which exhibit self-pulsating lasing at currents as low as 470nA are reported. Characteristics including linearly polarised emission, narrow linewidths and coherent near- and far-field diffraction indicate that these devices operate as lasers at DC currents < 1µA. Although self-pulsating lasing initiates at submicroampere average current, the injection current during the optical pulse can be > 1mA.

Reduced active volume for lower threshold current has long been touted as a desirable characteristic of microcavity lasers. Oxide-confined vertical cavity surface emitting lasers (VCSELs) have recently effected dramatic reductions in threshold current from 225µA to < 10µA [1 – 4]. The lower threshold currents of the oxide-confined VCSELs result from enhanced coupling of spontaneous emission [5], improved electrical/optical confinement [6] and reduced optical loss [4] which have been accomplished using buried oxide layers [1, 7] selectively formed from AlGaAs [8]. Recently we have found that reducing the VCSEL cavity volume can also lead to new electronic effects, which can complicate the interpretation of low threshold lasing. We have fabricated and characterised small cross-sectional area (<4µm^2) oxide-confined VCSELs with two buried oxide apertures on each side of a high finesse optical cavity [9]. We report current-controlled self-pulsing laser operation that occurs at submicroampere DC injection currents. The self-pulsating laser operation arises from an electronic nonlinearity, rather than optical feedback, which allows injection of relatively high current densities over a short time interval resulting in low average current.

The 3inch diameter VCSEL wafers designed to emit at nominally 840nm are grown by metalorganic vapour phase epitaxy on a rotating susceptor. The lasers contain three GaAs quantum wells in the one wavelength thick optical cavity. The 26 period top and 40 period bottom monolithic distributed Bragg reflector mirrors consist of $Al_{0.16}Ga_{0.84}As/Al_{0.92}Ga_{0.08}As$ layers with parabolic heterointerface compositional grading. After growth, oxide current apertures are selectively fabricated in $Al_{0.98}Ga_{0.02}As$ layers on each side of the optical cavity [9] to funnel the current into the quantum wells. In this work we examine oxide-confined VCSELs with square oxide apertures which are < 2µm on a side.

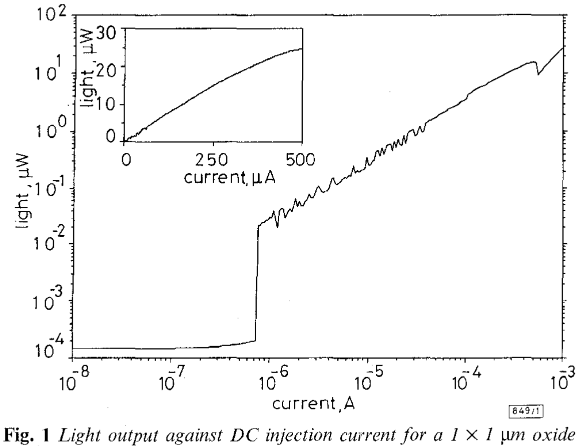

Fig. 1 *Light output against DC injection current for a 1 × 1 µm oxide-confined VCSEL*

Inset shows output characteristics on a linear scale

Fig. 1 shows the room temperature light output against injection current and Fig. 2 depicts the light spectra for a VCSEL with an ~1 × 1µm^2 oxide aperture. On a linear scale (see Fig. 1 inset) the VCSEL emission appears to arise from the origin with ~5% differential quantum efficiency. On a logarithmic scale an extremely abrupt transition at 700nA is observed. Above this transition the device is found to operate as a laser based on four characteristics: (i) the light emission has spectrometer limited linewidths (<0.04 nm) as shown in Fig. 2; (ii) the emission is linearly polarised as demonstrated in the inset of Fig. 2; (iii) the far-field profile exhibits coherent diffraction features; and (iv) the near-field profile exhjbits speckle patterns arising from coherent radiation. Note that due to cavity confinement the lasing spectra of these small area VCSELs are ~2nm shorter than adjacent larger area VCSELs. We observe many other VCSELs from this and other samples fabricated from several wafers to exhibit similar self-pulsing lasing at injection currents as low as 470nA.

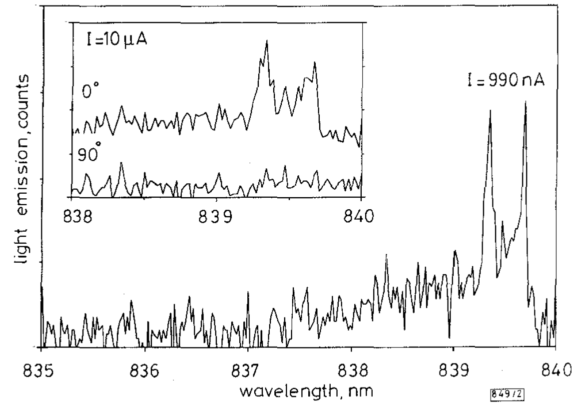

Fig. 2 *Spectra of a VCSEL obtained at < 1µA showing spectrometer limited linewidths (<0.04nm)*

Inset shows polarised spectra taken at 10µA injection current which shows that laser emission is linearly polarised

The abrupt transition in Fig. 1 does not correspond to a continuous wave threshold condition. Instead, above the transition we find the VCSEL emission to be oscillating in time at a constant frequency under DC current injection. We show in Fig. 3 a plot of the light output versus time from a VCSEL with a DC injection current of 10µA. The VCSEL emission in Fig. 3 oscillates at 3.8kHz with a pulse duration of 812ns. As the injection current is increased, the output oscillation frequency increases until a DC current of 500µA where a continuous wave mode arises and the self-pulsation ceases. The self-pulsation arises due to an electronic nonlinearity which causes injection of relatively high current densities in a short time interval producing low average current. From Fig. 3 we calculate that the instantaneous current can be as high as 1mA, which is greater than the threshold of the continuous wave lasing mode which eventually arises. As the average injection current is increased, the self-pulsation frequency increases. Thus these self-pulsing VCSELs can be used as low power current-controlled light oscillators. Larger area VCSELS (> 50µm^2) are less prone to exhibit self-pulsating laser operation. A quantitative model of the self-pulsating VCSEL operation arising from an electronic nonlinearity will be presented elsewhere [10].

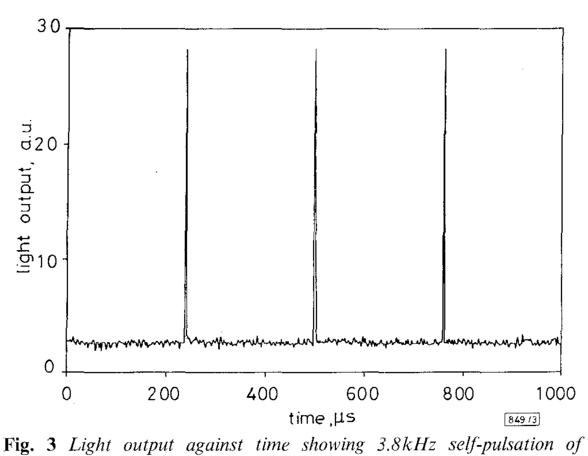

Fig. 3 *Light output against time showing 3.8kHz self-pulsation of VCSEL emission which occurs at 10µA injection current*

In conclusion, submicroampere self-pulsation laser operation is obtained from small oxide-confined VCSELs. Laser operation at an average DC current of < 1μA is established from narrow spectral linewidths, polarised emission and coherent diffraction features in the near and far field of the laser emission. However, the VCSELs operate in a self-pulsation mode, where the oscillation frequency of the laser emission depends on the average injection current, which can be submicroampere. This phenomena arises in these small VCSELs as a consequence of nonlinear electronic rather than optical effects. Our results show that care must be taken to identify true continuous wave lasing at low threshold currents in VCSEL diodes.

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Spectral control of a laser diode with a Michelson external cavity

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Indexing terms: Semiconductor junction lasers, Laser tuning

The authors present experimental results of spectral control of a laser diode with a Michelson external cavity. With this new method the spacing and the number of the oscillating modes can be controlled by changing the optical path difference of the external cavity. The reduction of the spectral bandwidth and the extension of the tuning range of the laser diode were observed.

There has been a great deal of interest in semiconductor laser diodes recently because they provide an economic and efficient source of coherent radiation. In addition they exhibit desirable modulation and scanning performance. Several techniques involving optical feedback from Fabry-Perot cavities [1], diffraction gratings [2] and various simple reflectors [3] have been used to induce diode lasers to tune continuously over an extended range of wavelength, thus eliminating the problems such as mode hopping and wide bandwidth at lower injection currents. However, many of these methods are difficult to implement or require expensive components, including a higher power laser with antireflection-coated output facets. Furthermore, nearly all these techniques narrow the spectral width of the laser. While such reduction is often useful, it can also be undesirable in certain applications such as some experiments in atomic spectroscopy.

In this Letter we report our initial results obtained with a new approach which is using a Michelson external cavity to control the spectrum of the laser diode. In this system the spacing between two reflection mirrors of the external cavity is substantially less than the spacing between the two laser facets. Thus, the external cavity mode spacing is several times greater than that of the laser alone. This allows us to narrow the spectral bandwidth and control the number of the oscillating modes.

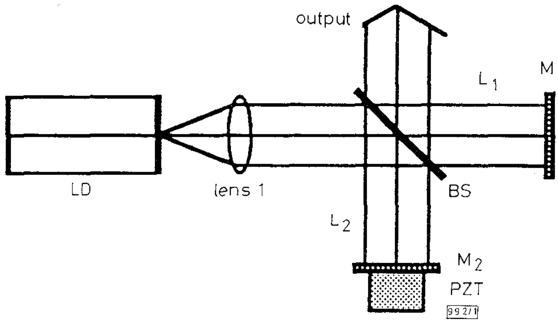

Fig. 1 *Schematic diagram of laser diode system with a Michelson external cavity*

The experimental setup is shown schematically in Fig. 1. The laser used was a commercially available MM413N AlGaAs laser (Mitsubishi Electronic Corp.) with a free-running wavelength of ~782nm and output ~5mW under standard operation conditions. The threshold value of the injection current is 33mA. The end facets of the laser were coated with SiO for protection. Thus we could not fabricate desirable antireflection coatings on them. A commercially available collimation optics Lens-1 is employed to collimate or focus the laser beam. The output beam of the laser diode is then entering into a Michelson external cavity, where a beam splitter BS and two mirrors M1, M2 are used to form the external cavity. The mode spacing determined by the Michelson external cavity is expressed in the general form $c/2(L_1 - L_2)$ [4], where L_1 and L_2 are the arm lengths of the Michelson external

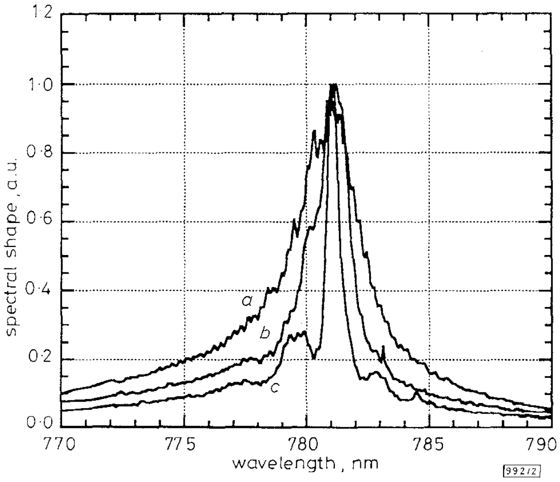

Fig. 2 *Optical spectra of the laser diode*

a Free running
b With Michelson external cavity, $\Delta L = L_1 - L_2 \simeq 0$
c With Michelson external cavity, $\Delta L = L_1 - L_2 \simeq 0.15$mm
Injection current of laser diode = 36.5mA