A fiber-based vertically emitting semiconductor laser at 850 nm

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The possibility of wavelength tuning and insertion of intra-cavity control elements makes Vertical External Cavity Surface Emitting Lasers (VECSEL) a useful tool for telecommunication and spectroscopic applications. Very small cavity lengths are desirable for achieving continuous single mode tuning and the fiber-based VECSEL[2] is a simple device which avoids the complicated post-growth processing involved in the fabrication of membrane-type laser[1]. We report here on the successful operation of an optically-pumped fiber-based VECSEL in the 850nm wavelength region. The device comprises a half cavity Periodic Gain Structure made of 15 $Al_{0.2}Ga_{0.8}As/GaAs$ quantum wells designed to be at the anti-nodes of the electric field standing wave, with a 30 pairs $Al_{0.2}Ga_{0.8}As/AlAs$ distributed Bragg reflector (DBR) as the bottom mirror. The structure is similar to the one described in[3], used in a macroscopic external cavity geometry. The top mirror of our cavity is a dielectric DBR deposited onto the cleaved end of a single mode fiber whose distance from the semiconductor can be controlled via a piezoelectric actuator to allow for wavelength tuning. The aim of this work is to contribute to the understanding of the operation of this optically pumped fiber-based laser. By comparing the laser performance with the *Finesse* of an empty cavity with otherwise identical geometry, we are able to conclude that the dominant photon loss mechanism is due to fundamental diffraction limits.

We measure the *Finesse* of an empty cavity formed with a dielectric DBR coated glass substrate and the fiber mirror by coupling white light into the fiber. The transmission is spectrally dispersed, allowing us to measure the linewidths and separations in wavelength of the cavity modes. The angle between fiber and substrate is carefully adjusted with a specially designed gimbal mount, capable of 10^{-5} deg. angular resolution. When there is just one optical mode, we find a *Finesse* of 300, less than the theoretical maximum of 1500 for the reflectivity used here, suggesting that diffraction losses reduce the available *Finesse*. This is confirmed by the fact that the *Finesse* decreases monotonically with increasing cavity length, as shown in Fig. 1. Laser emission of the VECSEL is achieved by optically pumping the quantum wells either through absorption in the barrier layer or by directly exciting the quantum wells. Fig. 2 shows a nonlinear dependence of the output power on the input power, characteristic of laser emission, and illustrates also the smallest threshold we have achieved ($P_{th} = 8.5mW$ at 715nm pumping wavelength). The related collapse of the emission linewidth down to the instrumental resolution limit of 0.04nm has also been observed in correspondence with the threshold in the power curve. Fig.3 shows how the VECSEL power-in versus power-out plots change, from curves with a clear kink marking the onset of stimulated emission to a linear trend typical of spontaneous emission, as the number of anti-nodes in the cavity is gradually increased. The increase of P_{th} with increasing cavity length is shown in the inset of fig.3. This behavior proves that diffraction losses due to the finite size of the fiber mirror play a dominant role in the lasing process.

We can convert P_{th} into a current density by assuming an excitation area of 44μm^2, the mode area in the fiber. We find a current density at threshold of J_{th}^{exp}=8.9kA/cm^2 which is higher than expected from the standard threshold equation with our average mirror reflectivity of $R = 99.8\%$. This too is consistent with large diffraction losses whose effects on the laser performance are estimated by expressing the real cavity *Finesse* (Fig. 1) as an effective decrease in the mirror reflectivity. For the smallest laser cavity length, the measured *Finesse* implies $R = 94\%$. In a quantitative analysis of the minimum threshold current density, we obtain agreement between the experimental J_{th}^{exp} and the calculated J_{th} for a device internal quantum efficiency $\eta \approx 8.9\%$ by taking the effective mirror reflectivity and the well known phenomenological expression for quantum well gain as a function of the current density[4]. In this model, the increase in threshold with cavity length (Fig. 3) is entirely consistent with the decrease in *Finesse* (Fig. 1). In summary, we have demonstrated the successful operation of a fiber-based VECSEL. We measure a critical current density of 8.9kA/cm^2. Our results show that this value could be significantly reduced by reducing the diffraction losses.

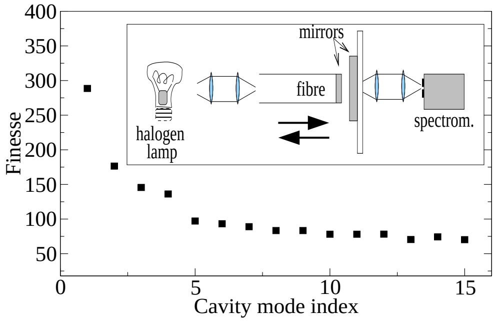

figure 1: Variation of the empty cavity *Finesse* with cavity mode index. Inset: sketch of the experimental set-up for the white light transmission experiment.

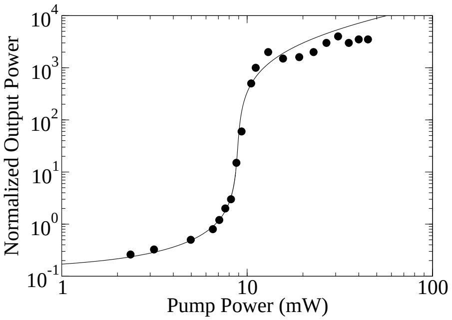

figure 2: Output power vs pump power for the VECSEL: the solid line is a guide to the eye. The vertical axis is normalized to be unity at threshold. The maximum output power achieved is $P_{max} \approx 10\mu W$ at 845nm.

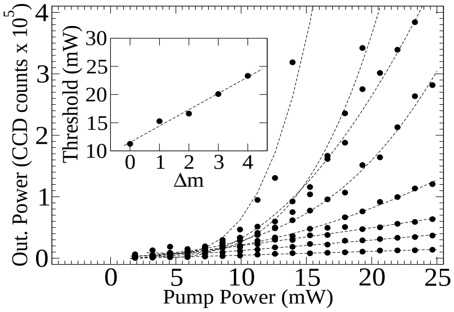

figure 3: Variation of the behavior of the output power vs pump power curve increasing the cavity length from top curve to bottom one. Inset: corresponding variation of the laser threshold with cavity mode index normalized to zero for 0nm air gap.

References

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