III-V compound semiconductor membrane quantum well waveguide lasers emitting at 1 µm

Stephen C. Richardson[1,*], *Jonathan R. C.* Woods[2], *Jake* Daykin[1], *Jon* Gorecki[3], *Roman* Bek[4], *Nicholas T.* Klokkou[1], *James S.* Wilkinson[5], *Michael* Jetter[6], and *Vasileios* Apostolopoulos[1]

[1]School of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ

[2]Aquark Technologies, Abbey Enterprise Centre Premier Way, Abbey Park Industrial Estate, Romsey, SO51 9AQ

[3]School of Engineering and Materials Science, Queen Mary University of London, Mile End Road, London, E1 4NS

[4]Twenty-One Semiconductors GmbH, Kiefernweg 4, 72654 Neckartenzlingen, Germany

[5]Zepler Institute, University of Southampton, Southampton, SO17 1BJ

[6]Institute for Semiconductor Optics and Functional Interfaces, University of Stuttgart, 70569 Stuttgart, Germany

Abstract. We demonstrate epitaxially grown semiconductor membrane quantum well lasers on a SiO_2/Si substrate lasing in a waveguide configuration, for potential uses as coherent light sources compatible with photonic integrated circuits. We study the emission characteristics of $In_{0.13}Ga_{0.87}As/GaAs_{0.94}P_{0.06}$ quantum well lasers, by using real and reciprocal space imaging. The laser cavity length is 424 µm, it emits light at 1 µm, and lasing thresholds as low as 211 mW were recorded. Control over the position and size of the laser spots by the pump was demonstrated.

Introduction

Vertical external-cavity surface-emitting lasers (VECSELs) are semiconductor structures with an active region consisting of multiple quantum wells (QWs) sandwiched between air and a distributed Bragg reflector (DBR). Research on this type of laser began in the mid-90s when their potential capabilities for high power and excellent beam quality were first fully demonstrated [1]. Membrane external-cavity surface-emitting lasers (MECSELs) were recently developed [2] to demonstrate lasing without a DBR. MECSELs can exhibit edge emitting lasing because the excitonic dipole in a semiconductor QW lies on the plane perpendicular to the growth direction and parallel to the surface of the epitaxial substrate [3]. In this work, we investigate the characteristics of this parasitic effect. We present optically pumped membrane quantum well lasers (MQWLs), lasing in-plane as a single laser without the use of an external cavity. The absence of a DBR offers quicker and higher quality growth, flexible wavelength design, and efficient heat extraction when contact bonded to Al_2O_3 or SiC heat spreaders. Finally, high index contrast between the membrane and substrate ensures a high overlap of the guided mode with the QW gain region.

Materials and Methods

In-plane lasing is achieved by pumping non-resonantly at 808 nm on top of a 1.57 µm thick membrane sample, consisting of ten 10 nm thick $In_{0.13}Ga_{0.87}As/GaAs_{0.94}P_{0.06}$ QWs on a SiO_2/Si substrate. The device is similar to the one reported in [4] and emits light at ~1 µm. The experimental setup collects the emitted light and then splits the beam into the real and reciprocal space paths (Fig. 1). A dichroic mirror and long pass filter cut out the pump wavelength. A thermoelectric cooler (TEC) is used to maintain temperature at 14 °C. The frequency output is measured with an optical spectrum analyser (OSA).

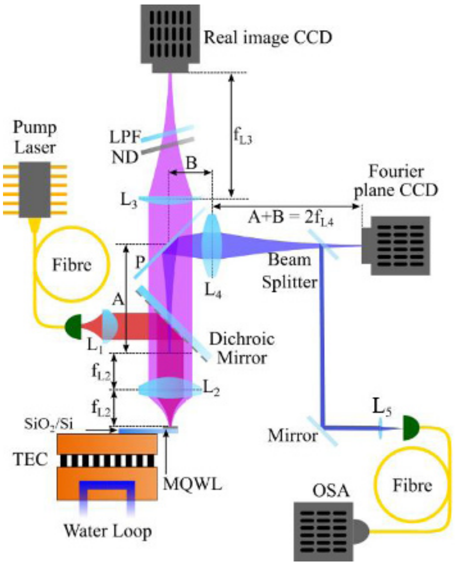

Fig. 1. MQWL experimental setup (modified from [3]).

Results

The real and reciprocal space images of the laser are shown in Figures 2a and 2b respectively. Real space

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[*] Corresponding author: scr1n19@soton.ac.uk

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images show the membrane's top view, fluorescence from the pumped region and laser spots at the end facets. Reciprocal space images display the interference patterns formed by the laser spots and strongly indicate laser threshold. From these figures, the length of the cavity can be measured to be 424 µm.

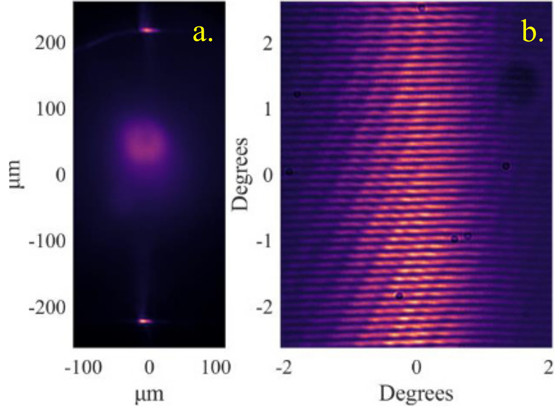

Fig. 2. MQWL (a) top down real space image, and (b) reciprocal space image that shows interference from the laser's end facets.

In order to achieve the lowest pump power, we translate the collimation lens, L_1, of the pump (Fig. 1). Such an action changes the pump spot's full width half maximum (FWHM) which in turn affects threshold pump power as shown in Figure 3. Furthermore, the laser spot width can be increased by broadening the pump spot as it is shown in Figure 4. As expected, the increased laser spot along the end facet is subjected to less diffraction resulting in a narrower interference pattern as it can be seen again in Figure 4.

Threshold values shown in Fig. 4 reach as low as 309 mW, however, 211 mW were achieved on a different area of the sample [3] for a 424 µm long laser cavity. As it is expected from the waveguide configuration, these values are significantly lower than the threshold pump power of ~0.7 W for a MECSEL with the same QW design as our membrane sample [4]. The laser emits at a wavelength of 1013.47 nm at 14 °C and 385.2 mW pump power. As temperature rises, the laser wavelength increases by $(7.92 \pm 0.04) \times 10^{-2}\ \mathrm{nm/°C}$ from 12 °C to 17.7 °C, achieving a 0.43 nm tuning range.

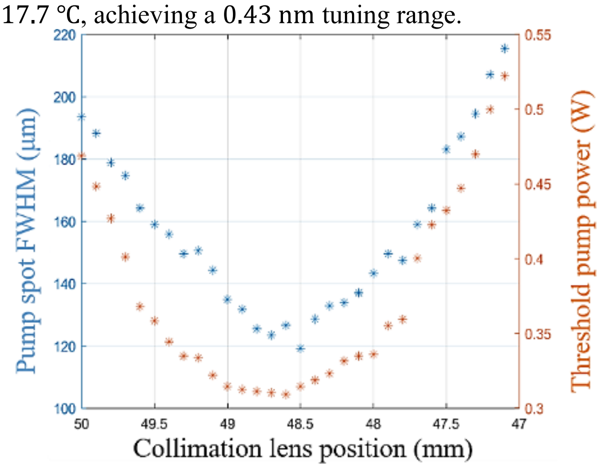

Fig. 3. Evolution of pump spot FWHM and threshold pump power with respect to collimation lens position away from the fibre's end facet (L_1 in Fig. 1).

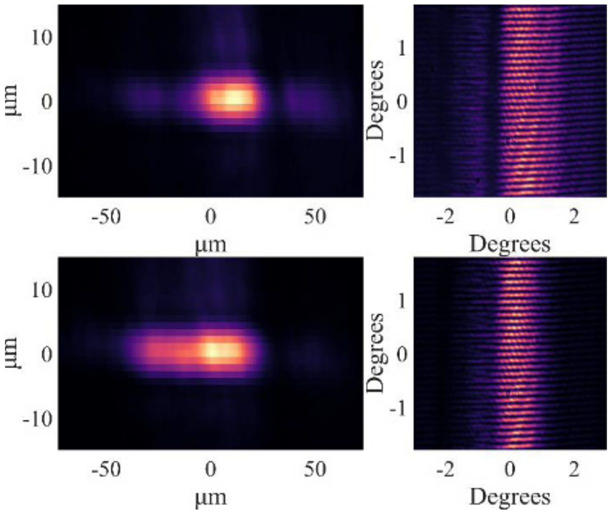

Fig. 4. Control of MQWL spatial mode width and corresponding interference pattern (modified from [3]).

Conclusions

In-plane lasing in waveguide membrane samples by a single laser on a standard SiO_2/Si substrate is realised with 211 mW threshold pump power. The pump spot's location and size allows us to control the shape and position of the waveguide laser's spatial mode, which shows potential for on-chip integration with photonic circuits. Reciprocal imaging displayed the interference between the coherent laser emission of the waveguide cavity's end facets. In [3] we demonstrate coherent laser array operation on a SiC substrate recording thresholds down to 60 mW for 70 µm long cavities. Future work will involve micro structuring of the membranes for novel cavity geometries, and the implementation of a spatial light modulator (SLM) to investigate laser arrays by varying pump illumination patterns. Pump shaping will allow control of the position and coherence of laser arrays and lead to on-chip integration with other photonic devices.

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