1-W quasi-cw near-diffraction-limited semiconductor laser pumped optically by a fibre-coupled diode bar

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Abstract: We describe a diode-bar-pumped vertical-external-cavity surface-emitting semiconductor laser, which in quasi-cw operation emitted a peak power of >1 W at 1020 nm in a circular, near-diffraction-limited beam.

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Optical pumping of vertical-external-cavity surface-emitting semiconductor lasers (VECSELs) offers a way in which to overcome both the beam quality limitations of edge-emitting diodes, and the power restrictions of electrically pumped surface-emitting lasers. High-brightness single-stripe diodes have been used to pump these devices [1,2], yielding up to 0.5 W of output power in a circular, near-diffraction-limited beam [1]. Here we report a 1-W device pumped by a beam-shaped fibre-coupled diode bar.

Fig. 1. Schematic diagram of the diode-bar-pumped VECSEL

The arrangement of the VECSEL cavity is shown schematically in Fig. 1. The semiconductor laser wafer incorporates 12 compressively strained In$_{0.2}$Ga$_{0.8}$As/GaAsP quantum wells in a strain-compensated structure grown adjacent to a 27-repeat Al$_{0.1}$Ga$_{0.9}$As/AlAs mirror. Platelets of this wafer were lapped to a substrate thickness of ~200 µm, and soldered to a Peltier-cooled copper heat sink. In initial experiments the pump source was a commercial fibre-coupled diode bar, OptoPower OPC-D010, which delivered up to 10 W at 830 nm via a multi-mode fibre with core diameter 250 µm, numerical aperture 0.22. The fibre end was imaged at unit magnification onto the wafer surface at an incident angle of ~30°. Pump light absorbed in the GaAs/GaAsP barrier regions generated carriers that were subsequently trapped in the wells. A spherical output coupler, transmission 0.7% at the laser wavelength and radius of curvature 50 mm, completed the 2-mirror VECSEL cavity, which oscillated in a fundamental spatial mode at wavelengths over the range 1000 – 1040 nm. The incident pump intensity at threshold was typically ~3 kW cm$^{-2}$.

In continuously pumped operation the laser was limited by thermal effects to a maximum output of ~200 mW for a pump power of ~5.5 W incident on the wafer surface; with further increase in pump power the output dropped rapidly until lasing ceased. In quasi-cw operation the pump beam was chopped.
mechanically at 100 Hz with a duty cycle of ~10%. The peak laser output power was then found to increase monotonically up to 550 mW using the greatest available incident pump power of 8.5 W. Fig. 2 shows the time evolution of the laser power under these conditions. The characteristic structure is produced as the wafer heats up, the carrier distribution shifts, and the optical layer depths tune thermally [3].

![Graph showing time evolution of VECSEL output power under quasi-cw pumping with 8.5 W incident pump power.](image)

Fig. 2. Time evolution of VECSEL output power under quasi-cw pumping with 8.5 W incident pump power.

In further experiments the VECSEL was pumped by a 785-nm diode bar, which after beam shaping delivered up to 30 W via multi-mode fibre with the parameters specified above. By increasing the VECSEL output coupling to 2.5% we were able to observe a peak power output of 1.1 W for an incident pump power of 11.5 W.

Future work will investigate VECSEL designs with better transmission of the pump into the active region, and a less sharply peaked, and therefore less temperature-sensitive, gain spectrum for the composite layer. More effective substrate removal will in addition reduce the temperature excursion of the pumped spot by about an order of magnitude. We anticipate that these improvements will allow cw operation with improved overall conversion efficiency.