High-power vertical cavity surface emitting laser with good performances

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Fabrication and performance of a high-power bottom-emitting InGaAs/GaAsP vertical cavity surface emitting laser with 430 μm diameter are described. The device realises the maximum room temperature CW output power 1.52 W at 987.6 nm with FWHM 0.8 nm. The far-field divergence angle is below 20°. Reliability test shows at 70°C an output power 0.35 W over 500 h.

Introduction: High power of vertical cavity surface emitting lasers (VCSELs) is important for many applications such as pumped fibre amplifiers or fibre lasers or solid-state lasers [1, 2]. The continuous wave (CW) optical power 0.89 W at room temperature has been reported for a single large-area (320 μm diameter) VCSEL with InGaAs/GaAs quantum wells (QWs) [3]. More than CW optical power of 1 W at room temperature for a VCSEL array consisting of 19 elements has been also realised [4]. At the same time, a novel vertical external cavity surface emitting laser (VECSEL) is also reported in the watt regime using an extra cavity mirror [5]. The single large-area device or arraying of elements or the novel VECSEL provides choices for achievement of high-power surface emitting lasers. For the advantages of the monolithic VCSEL in fabrication and application, to fabricate a single large-area VCSEL, which combines high optical output power in the watt regime, narrow spectral width, and good quality laser beam in CW operation at room temperature is a practical aim. By employing larger aperture and further improved device processing, a single VCSEL can be promising for higher output power, and we put our efforts on this aspect. In this Letter, we report a high-power bottom-emitting InGaAs/GaAsP VCSEL with 430 μm diameter. The device produces the maximum CW optical output power of 1.52 W at 987.6 nm wavelength with full-width at half-maximum (FWHM) of 0.8 nm at room temperature.

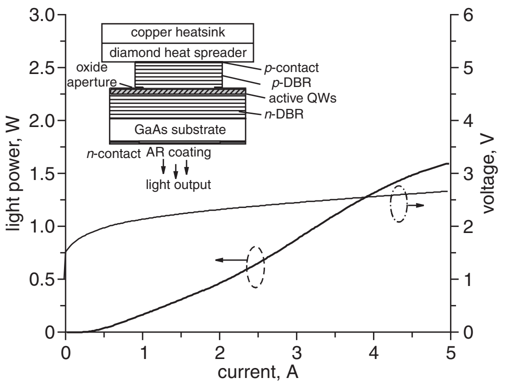

Fig. 1 *L-I-V characteristics of fabricated high-power VCSEL*
Inset: Schematic diagram of device structure

Device structure and processing: The device structure consists of a multiple quantum well active region sandwiched in between *n*- and *p*-distributed Bragg reflector (DBR) mirrors (see inset of Fig. 1). The active region contains three 6 nm-thick $In_{0.2}Ga_{0.8}As$ quantum wells embedded in 8 nm-thick $GaAs_{0.92}P_{0.08}$ barriers. The carbon-doped *p*-type DBR consists of 35.5 pairs of $Al_{0.9}Ga_{0.1}As/Al_{0.12}Ga_{0.88}As$. A 30 nm-thick $Al_{0.98}Ga_{0.02}As$ layer located between the active region and the top *p*-type mirror is oxidised and converted to Al_xO_y in the fabrication process for current confinement. The silicon-doped *n*-type DBR has only 25.5 pairs of $Al_{0.9}Ga_{0.1}As/Al_{0.12}Ga_{0.88}As$ for light bottom emission through the GaAs substrate. The device structure is grown on (100) GaAs substrate using metal organic chemical vapour deposition (MOCVD).

Wet chemical etching is used to define a circular mesa. A 430 μm-diameter current aperture is defined by selective wet oxidation of the exposed $Al_{0.98}Ga_{0.2}As$ layer. After oxidation, the surface is passivated with Al_2O_3 passivation layer, and *p*-type Ti-Pt-Au contact on top of the mesa is evaporated to provide a homogeneous current distribution and serves as a metal pad for soldering. The GaAs substrate is thinned and polished down to about 130 μm, and an antireflection (AR) coating of Zr-Si-O is deposited. Self-aligned lithography is used to define *n*-type Au-Ge-Ni electrical contact surrounding the emission windows. The chip is annealed at 380°C in nitrogen environment condition for 60 s, and the single device is separated by cleaving. The device is soldered junction down on a metallised diamond heat spreader with Au-Sn solder, then the whole chip is attached onto a copper heatsink with In-Sn solder for mechanical stability, good thermal and electrical conductivity.

Device performances: The device operates in CW condition at room temperature (24°C). Fig. 1 shows *L-I-V* characteristics. Threshold current (I_{th}) of the 430 μm-diameter device is about 0.7 A with a differential resistance of 0.11 Ω. The maximum CW optical output power is up to 1.52 W at current 5 A. The maximum conversion efficiency is 12.0%, and the slope efficiency is up to 0.39 W/A.

Fig. 2*a* shows the lasing spectra of the device at different currents of 1, 3 and 5 A. The lasing peak wavelength is 987.6 nm with FWHM 0.8 nm at 5 A. The wavelength shift between 3 and 5 A is 1.9 nm. This is equivalent to a temperature increase of 31K assuming a wavelength-temperature correlation of $d\lambda/dT = 0.06$ nm/K. This value is obtained by running the device with constant current, but different heatsink temperatures.

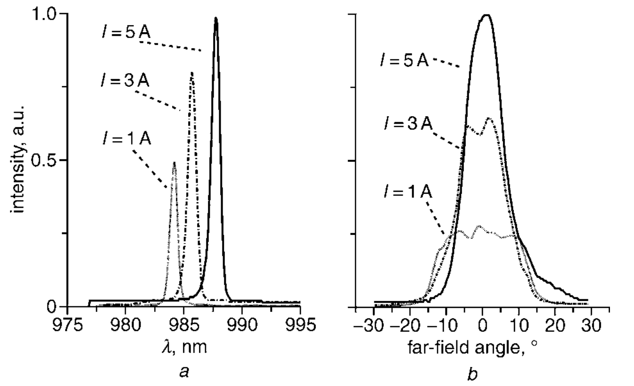

Fig. 2 *Lasing spectra and far-field patterns of laser at different currents of 1, 3, 5 A*
a Lasing spectra
b Far-field patterns

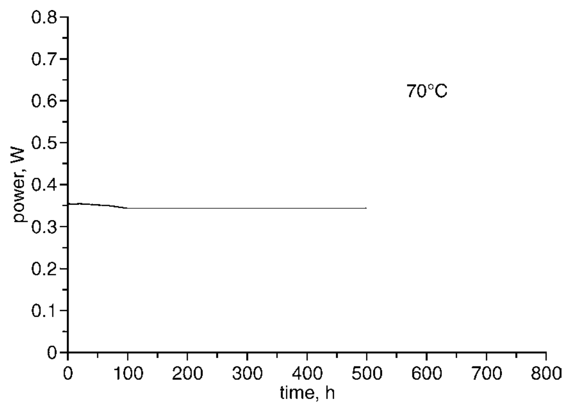

Fig. 3 *Life test of randomly-picked VCSEL*
During life test, it is driven by 1.5 A constant current and temperature controlled at 70°C

Far-field patterns are also measured at the different currents as shown in Fig. 2*b*. The divergence angle is below 20° for all injection currents, and the intensity maximum is on the symmetry axis. Owing to the circularly symmetric far-field patterns with low beam divergence angle, the beam of the device can be easily focused or collimated into a fibre in a simple butt-coupling arrangement.

Reliability is also a critical issue. Fig. 3 shows the life test of output power measured from a randomly-picked VCSEL. During test, the device is driven by a 1.5 A constant current ($I = 2I_{th}$), and the temperature is controlled at 70°C. At the beginning, the optical output power is about 0.35 W. Our preliminary result shows that the total degradation of output power is less than 10% after 500 h burn-in test. This life test is still undergoing.

Conclusion: We have reported a high-power InGaAs/GaAsP VCSEL with 430 μm diameter. The device produces room temperature CW maximum optical output power 1.52 W, corresponding to a power density 1 kW/cm^2, at 987.6 nm. The far-field divergence is below 20°. The initial reliability test at 70°C shows that the total degradation of output power is less than 10% after 500 h. These preliminary results predict strongly the potential of the large aperture VCSEL as high-power, surface emitting, and practical laser sources.

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References

1 Bouwmans, G., Percival, R.M., Wadsworth, W.J., Knight, J.C., and Russell, P.St.J.: 'High-power Er:Yb fiber laser with very high numerical aperture pump-cladding waveguide', *Appl. Phys. Lett.*, 2003, **83**, pp. 817–818

2 Wu, J., Lordache, G., Summers, H.D., and Roberts, J.S.: 'Optical characteristics of VCSEL pumped microchip lasers', *Opt. Commun.*, 2001, **196**, pp. 251–256

3 Miller, M., Grabherr, M., King, R., Jäger, R., Michalzik, R., and Ebeling, K.J.: 'Improved output performance of high-power VCSELs', *IEEE J. Sel. Top. Quantum Electron.*, 2001, **7**, pp. 210–216

4 Miller, M., Grabherr, M., Jäger, R., and Ebeling, K.J.: 'High-power VCSELs arrays for emission in the watt regime at room temperature', *IEEE Photonics Technol. Lett.*, 2001, **3**, pp. 173–175

5 McInerney, J.G., Mooradian, A., Lewis, A., Shchegrov, A.V., Strzelecka, E.M., Lee, D., Watson, J.P., Liebman, M., Carey, G.P., Cantos, B.D., Hitchens, W.R., and Heald, D.: 'High-power surface emitting semiconductor laser with extended vertical compound cavity', *Electron. Lett.*, 2003, **39**, pp. 523–525