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.

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 InGaAs/GaAs quantum wells embedded in 8 nm-thick GaAs/AlGaAs barriers. The carbon-doped p-type DBR consists of 35.5 pairs of Al0.12Ga0.88As/GaAs. A 30 nm-thick Al0.98Ga0.02As layer located between the active region and the top p-type mirror is oxidised and converted to Al2O3 in the fabrication process for current confinement. The silicon-doped n-type DBR has only 25.5 pairs of Al0.9Ga0.1As/Al0.98Ga0.02As. A simple butt-coupling arrangement.

Device performances: The device operates in CW condition at room temperature (24°C). Fig. 1 shows L-I-V characteristics. Threshold current (Ith) 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 Lasing spectra and far-field patterns of laser at different currents of 1, 3, 5 A

a) Lasing spectra
b) Far-field patterns

Reliability is also a critical issue. Fig. 3 shows the life test of randomly-picked VCSEL. During life test, it is driven by 1.5 A constant current and temperature controlled at 70°C.

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. 2b. 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 an important 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 = 2Ith), 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/cm², 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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