High power VECSEL prototype emitting at 625 nm

Jussi-Pekka Penttinen, Tomi Leinonen, Antti Rantamäki, Ville-Markus Korpijärvi, Emmi Kantola and Mircea Guina
Optoelectronics Research Centre, Tampere University of Technology, Korkeakoulunkatu 3, 33720 Tampere Finland
jussi-pekka.2.penttinen@tut.fi

Abstract: We demonstrate an OP-VECSEL prototype emitting more than 6W of CW output power at 625 nm. We employ dilute nitride (GaInNAs) quantum wells emitting fundamentally at 1250 nm together with intracavity frequency doubling.

OCIS codes: (140.7300) Visible lasers; (250.5960) Semiconductor lasers

1. Introduction

Vertical-external-cavity surface-emitting lasers (VECSELs) [1] are unique lasers combining the wide spectral coverage of semiconductor gain media together with the benefits of optically pumped external-cavity solid-state disk lasers, particularly power scalability and high brightness. Owing to the disk shaped gain geometry, the acronym SDL (semiconductor disk laser) is also interchangeably used with VECSEL among others, such as OPSL (optically pumped semiconductor laser).

The fundamental wavelength coverage of VECSELs spans from 665 nm with 2.5 W of output power [2], to 1030 nm with 106 W [3], to 1180 nm with 50 W [4], to 1275 nm with 33 W [5], and to above 2 µm with 20 W [6]. However, high power fundamental operation below ~650 nm remains challenging due to poor carrier confinement in mature GaInP on GaAs quantum wells (QWs). Thanks to the external cavity geometry, the wavelength coverage of VECSELs can be increased by more than an octave with intracavity frequency down conversion. In the visible spectral range, high output powers have been demonstrated with second harmonic generation (SHG) at green 532 nm [7] and yellow 590 nm [8] wavelengths with GaInAs on GaAs QWs. Above 1200 nm, the high lattice strain of GaInAs/GaAs QWs renders the fabrication of such gain mirrors more difficult, and the results at orange-red 615 nm has been demonstrated with the so-called dilute nitride GaInNAs on GaAs QWs [9].

In this work, we demonstrate a multiwatt VECSEL prototype based on the dilute nitride material system and operating at a 625-nm red wavelength. Lasers emitting in the 625–635 nm spectral range are in demand in laser shows and infinite focus laser projection, where high luminosity and slow diverging laser beams are needed. The bright 625-nm red wavelength is particularly beneficial for these applications since its lumen efficacy (~200 lm/W) is approximately three times the lumen efficacy of the longer 650-nm red wavelength (~70 lm/W) [10].

2. VECSEL prototype for red emission

To enable fundamental emission at 1250 nm, a top-emitting resonant periodic gain structure was grown by plasma-assisted molecular beam epitaxy. The resonant periodic gain structure (illustrated in Fig. 1.) incorporated five pairs of 7-nm thick GaInNAs QWs located in the field antinodes and surrounded by GaAs barrier layers.

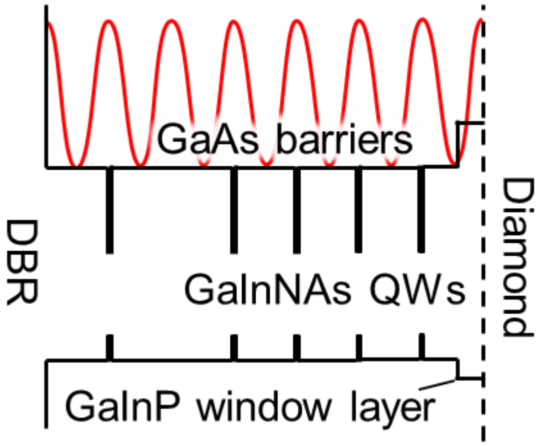

Fig. 1. Schematic illustration of the resonant periodic gain structure.

The gain mirror was liquid capillary bonded to a 300-µm thick flat single-crystal diamond heatspreader for efficient heat removal. The diamond heatspreader was soldered to a TEC-cooled copper heatsink stabilized at 20 °C. The VECSEL employed a V-shaped cavity depicted in Fig. 2. An 808-nm diode laser with ~450-µm spot diameter was used for pumping the gain mirror. Wavelength selection was achieved by inserting a 3-mm thick birefringent filter (BRF) in the first cavity arm, and a 10-mm long critically phase matched (CPM) lithium triborate (LBO) crystal was placed in the second cavity arm for frequency conversion. Both the BRF and the LBO crystal were temperature stabilized above room temperature. The laser output was taken from the folding HR/AR mirror.

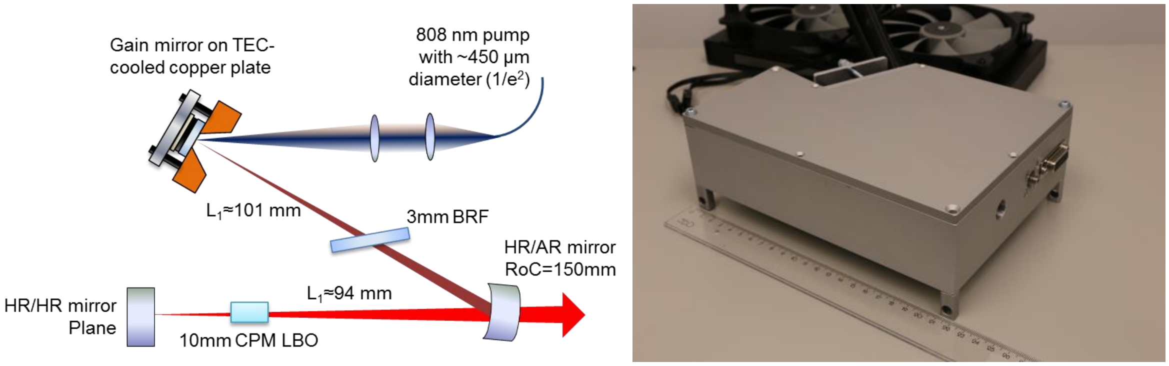

Fig. 2. The VECSEL cavity (left) and photo of the prototype casing (right).

The VECSEL cavity was sealed inside a relatively compact air-cooled aluminum casing (220 mm x 160 mm x 77 mm) shown in Fig. 2. The casing has a D-sub input for the control electronics and an SMA input for the pump fiber. In this work, the output beam of the laser was delivered in free-space, but the casing has enough room for fiber coupling the beam into an SMA fiber.

3. Prototype characterization

The prototype VECSEL was able to deliver a maximum of 6.6 W of output power at 625 nm. The output power curve as a function of the incident pump power is shown in Fig. 4. Maximum output power was achieved with approximately 10% optical-to-optical efficiency and with ~0.75% single-pass conversion efficiency in the LBO crystal. The overall wall-plug efficiency, which takes into account the efficiency of the pump laser, is estimated to be below 5%. The output spectrum was centered at 624.8 nm with a FWHM of 0.4 nm at 6 W of output power, as shown in Fig. 4.

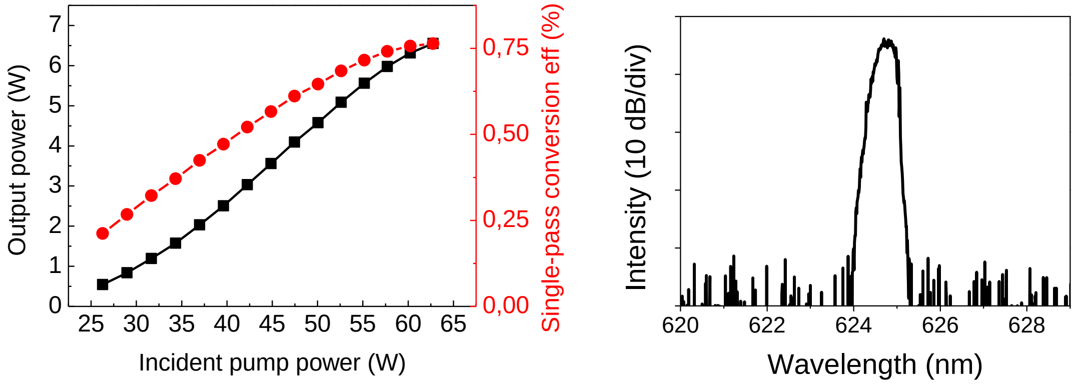

Fig 4. Output power and single-pass conversion efficiency curves (left) and spectrum at 6 W of output power (right).

The output beam had a circular Gaussian shape as shown in Fig. 5. The M^2-mean value was 1.96 at 6 W of output power.

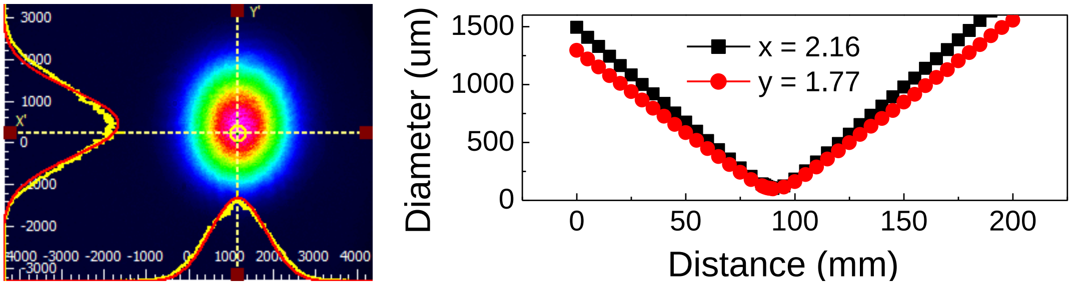

Fig 5. Shape and profile of the output beam (left) and M^2-measurement (right).

4. Summary

In summary we present a VECSEL prototype delivering a maximum of 6.6 W of CW output power at 625-nm short red wavelength. We employ 1250 nm fundamental emission of optically pumped dilute nitride quantum wells together with intracavity frequency doubling to reach the desired wavelength.

5. References

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