Visible Red Single-Mode Vertical-Cavity Top-Surface-Emitting Lasers with GaAs Quantum Wells

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We have designed and fabricated vertical-cavity surface-emitting lasers (VCSELs) for 700 nm to 800 nm wavelength emission range using four 6 nm GaAs quantum wells (QWs). A 3 μm active diameter laser exhibits a threshold current of 3.5 mA in continuous-wave (CW) operation at an emission wavelength of 749.5 nm. Using pulsed operation condition with a pulse length of 8 nsec. and a duty cycle of 0.8 % a 2 μm active diameter laser shows a threshold current of 20 mA at an emission wavelength of 710.5 nm.

1. Introduction

Visible red emitting VCSELs are promising devices for use in numerous applications such as plastic optical fibre communications, barcode readers, chemical sensing, laser printing and displays. Most of the reported VCSELs for the 700 nm to 800 nm range use AlGaAs QWs [1]-[3] or GaAs/AlAs Superlattices [4, 5] providing the gain maximum well matched to the resonance wavelength. Due to the high chemically activity of aluminum atoms to the rest gases in the growth chamber the quality of AlAs or AlGaAs is reduced by nonradiative traps. This influences fundamental laser characteristics and especially the aging behaviour. To overcome this problem we have designed and fabricated a VCSEL structure based on four 6 nm GaAs QWs showing the gain maximum at nominally 830 nm. To reach visible wavelengths, the optical cavity of the VCSEL is designed for emission below 800 nm. Due to the high quality of the GaAs QWs, the sampled gain on the short wavelength side of the gain spectrum is comparable to the low optical gain of Aluminum containing QW’s.

2. VCSEL design and fabrication

Fig. 1 shows a schematic of a selectively oxidized top-emitting VCSEL. The layers are grown by solid source molecular beam epitaxy. The active region consists of four 6 nm thick GaAs quantum wells embedded in Al$_{0.3}$Ga$_{0.7}$As barriers. The nominal gain maximum of this active zone is 830 nm [6]. To prevent fundamental absorption in the laser structure only Al$_x$Ga$_{1-x}$As layers with a minimum AlAs content of 30 % can be used. The lower n-type Si-doped and the
upper p-type C-doped Bragg reflectors consist of 38 and 27 Al$_{0.3}$Ga$_{0.7}$As-Al$_{0.6}$Ga$_{0.4}$As quarter wavelength layer pairs, respectively, with graded interfaces and $\delta$-doping to reduce series resistance. Lateral current confinement is achieved by selective wet oxidation of a 30 nm thin AlAs layer after wet-chemical mesa etching. Single-mode operation is enforced by a small oxide aperture. Shifting the AlAs layer towards the node of the standing wave pattern in the cavity reduces the built-in effective index guiding and the optical losses resulting in increased single-mode output power. After selective oxidation a Ti/Pt/Au ring contact is deposited on the top of the mesa. A broad area Ge/Au/Ni/Au n-contact is evaporated on the backside of the substrate and both contacts are annealed at 410 °C.

### 3. Characteristics

Fig. 2 shows the optical and electrical characteristics of a VCSEL with 3 $\mu$m diameter oxide aperture under CW operation. Threshold current and threshold voltage amount to 3.5 mA and 3.0 V, respectively. The maximum optical output power of 0.3 mW is restricted by thermal roll-over. The differential resistance of 180 $\Omega$ at a driving current of 4 mA is typical for these small area devices. The driving voltage of the array is fully compatible with advanced 3.3 V CMOS technology.

Fig. 3 shows emission spectra in CW operation. The emission wavelength of the VCSEL is 749.5 nm on the fundamental transverse mode showing single-mode operation. The side-mode suppression ratio (SMSR) is more than 20 dB.
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Fig. 2. Optical and electrical characteristics of a typical VCSEL with 3 μm diameter oxide aperture under CW operation. The threshold current is 3.5 mA.

Fig. 3. Optical spectrum of the VCSEL with a current aperture of 3 μm. The laser oscillates at a wavelength of 749.5 nm on the fundamental transverse mode showing single-mode operation.

Fig. 4. Optical and electrical characteristics of a VCSEL with 2 μm diameter oxide aperture under pulsed operation with a pulse length of 8 nsec. and a duty cycle of 0.8%. The threshold current is 20 mA.

Fig. 5. Optical spectrum of the 2 μm current aperture VCSEL under pulsed operation. The laser oscillates at a wavelength of 710.5 nm on the fundamental transverse mode.

Fig. 4 shows the optical and electrical characteristics of a 710.5 nm VCSEL in pulsed operation with a pulse length of 8 nsec. and a duty cycle of 0.8%. Threshold current is 20 mA. Fig. 5 shows emission spectra of this VCSEL. The emission wavelength is 710.5 nm on the fundamental transverse mode showing single-mode operation with a SMSR of more than 20 dB.
4. Conclusion

In summary, we have fabricated 710.5 nm and 749.5 nm emission wavelength VCSELs in pulsed and CW operation, respectively, showing more than 0.2 mW transverse single-mode output power. In spite of the large shift between the gain maximum of AlAs free QWs and cavity resonance it was possible to demonstrate CW operation up to a mismatch of 80 nm. Under pulsed condition this shift was even higher reaching a value of 120 nm. This is, to our best knowledge, the highest ever reported detuning for VCSEL operation.

References


