Fabrication and Characterization of 980 nm Bottom-Emitting VCSELs

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In this article we report on the fabrication of 980 nm bottom-emitting vertical-cavity surface-emitting lasers (VCSELs). Devices with different oxide apertures have been fabricated and characterized. After a fabrication overview, measurement results such as light–current–voltage (LIV) curves, spectra, and beam quality will be presented.

1. Introduction

Various applications like pumping of optical amplifiers, pumping of solid-state lasers and frequency doubling for visible laser light generation require high-power laser sources. VCSELs are an attractive light source for such applications, where in addition to high power a good beam quality or even single-mode operation is required. VECSELs [1] which are similar to VCSELs but use an extended cavity can achieve high power in a fundamental spatial mode. Fabrication of such devices requires first an investigation of bottom-emitting VCSELs. In the following we present the properties and characteristics of such devices emitting in the 980 nm spectral region.

2. Device Fabrication

Figure 1 shows a schematic drawing of a typical bottom-emitting VCSEL. The sample consists of InGaAs quantum wells separated by GaAs barrier layers, p- and n-type AlGaAs Bragg mirrors, and an AlAs layer for oxide confinement. After mesa etching, selective oxidation of the AlAs layer is performed to define the current aperture. Metallization layers are then evaporated to form a round p-type contact on top of the mesa. Normally the substrate is thinned to reduce absorption and to ease cleaving in case of device mounting on a heatsink. An anti-reflection (AR) coating layer is then deposited in the opening of the n-type contact on the substrate side.

3. Characterization

Bottom-emitting VCSELs with different oxide apertures have been characterized. The active diameters vary from 5 to 134 μm. On-wafer tested VCSELs with diameters of 5 μm have a maximum output power of about 8 mW and 1 . . . 2 mW in single-mode operation. In Fig. 2, LIV characteristics of a 8 μm device are plotted. The laser is measured on-wafer

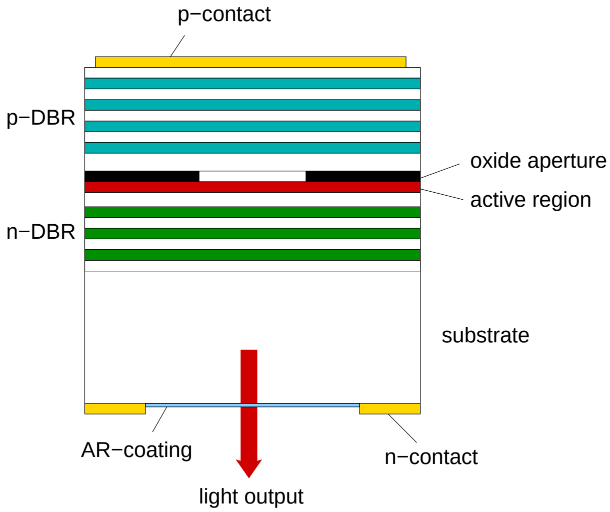

Fig. 1: Schematic cross-section of a bottom-emitting VCSEL.

at different temperatures from 0 to 50°C. The spectra are shown in Fig. 3 for different currents, measured at room temperature. When increasing the temperature, the maximum output power at thermal rollover decreases and shifts towards smaller currents. The ripples in the output power curve arise from the non-perfectly AR-coated substrate side. At room temperature the emission wavelength is about 980 nm, as can be seen in Fig. 3. The lowest threshold current of about 1 mA is measured at 50°C. At this temperature, the gain curve has shifted to longer wavelengths and matches the resonator design wavelength of 980 nm. Figure 4 shows the wavelength as a function of dissipated power. From the slope of the fit line and the known thermal wavelength shift (∼ 0.07 nm/K), a thermal resistance of 910 K/W is calculated. Devices with an active diameter of 28 µm have also been characterized (Fig. 5). The maximum output power is 32 mW and the threshold current is about 4 mA. The device has a quantum efficiency of 43 %. The room temperature emission wavelength is about 963 nm. In general with the given quantum well material, at this wavelength we obtain the highest efficiency and the lowest threshold current.

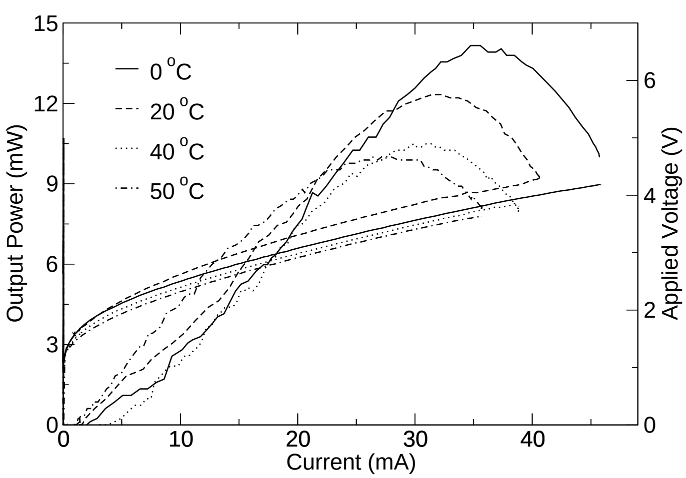

Fig. 2: LIV characteristics of a VCSEL with 8 µm active diameter, measured at different temperatures.

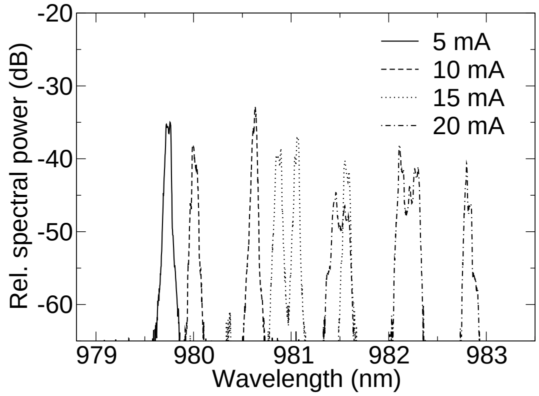

Fig. 3: Spectra at different currents of the measured 8 μm device (20°C).

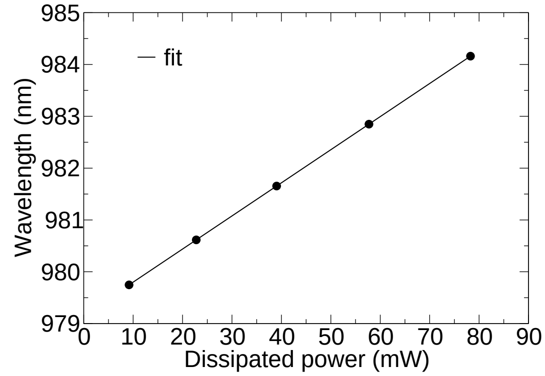

Fig. 4: Wavelength shift versus dissipated power, as determined from Fig. 3.

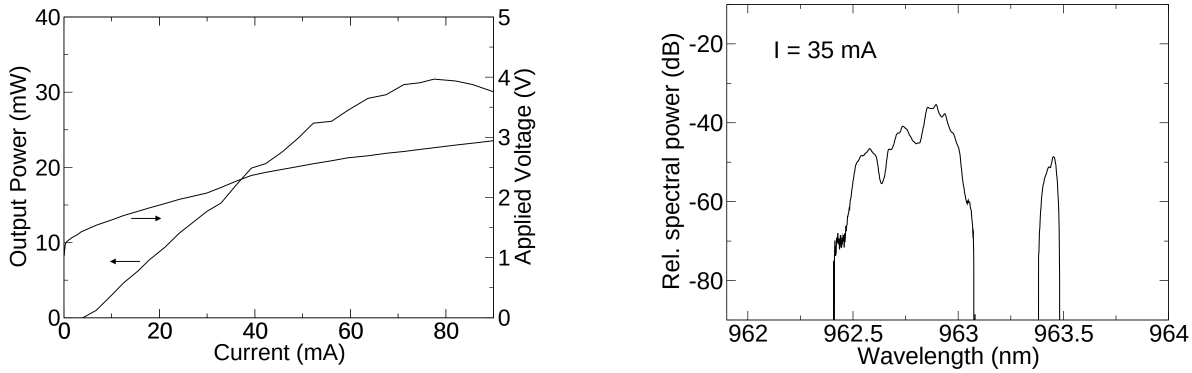

Fig. 5: LIV characteristics (left) and spectra (right) of bottom-emitting VCSELs with 28 μm active diameter.

3.1 High-power VCSELs

To get higher output power, VCSELs with an active diameter of 134 μm have been fabricated. The high-power devices are cleaved and soldered p-side down onto a diamond heatspreader, which is attached to a copper heatsink. On-wafer testing is not possible due to insufficient heat removal. Figure 6 shows the LIV characteristics and the emission spectra of such a laser. The threshold current is 74 mA and the maximum output power at thermal rollover is 275 mW. The emission wavelength is about 963 nm and the differential quantum efficiency is about 40 %. Mounted devices with large active diameters have lower thermal resistances than smaller devices. For the measured high-power laser we obtain about 40 K/W. For beam quality investigations a setup as described in [2] is used. Calculated beam diameters are plotted versus the propagation distance and fitted to obtain the beam parameters, namely the beam quality factor, the far-field angle, and the beam waist (Fig. 7). The VCSEL is driven at 400 mA and a beam waist of 168 μm is calculated. The far-field angle is 24.5°. Due to the large active diameter, multimode emission occurs, which affects the beam quality. For this device a beam quality factor of $M^2 = 57.8$ is determined.

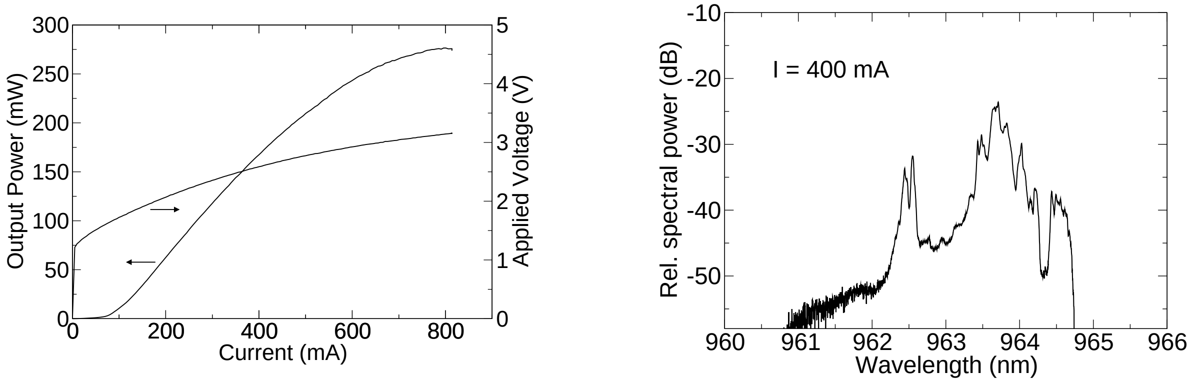

Fig. 6: LIV characteristics (left) and spectra (right) of a VCSEL with 134 µm active diameter.

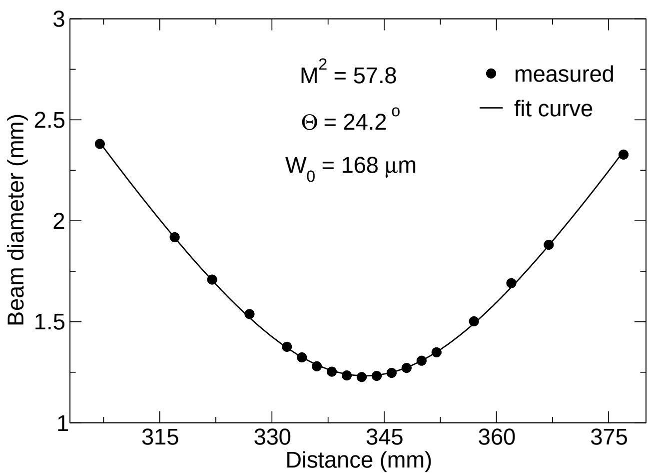

Fig. 7: M^2 plot of the high-power VCSEL from Fig. 6.

4. Conclusion

We have successfully fabricated and characterized 980 nm bottom-emitting VCSELs. Devices with active diameters of a few micrometers have a small threshold current of about 1 mA and can reach a maximum output power of more than 12 mW. Output power of about 32 mW and a threshold current of 4 mA from 28 µm devices have been measured. High-power VCSELs with 134 µm active diameter have an output power of 275 mW and a threshold current of 74 mA. In addition to the LIV characteristics and spectra, thermal properties and beam quality have been analyzed. The high-power device has a thermal resistance of 40 K/W. The M^2 factor increases for VCSELs with larger active diameter and can even exceed 50. The sample shows best efficiency close to 963 nm wavelength.

References

[1] A. Mooradian et al., "High power extended vertical cavity surface emitting diode lasers and arrays and their applications", in Proc. *11th Microoptics Conf., MOC '05*. Tokyo, Japan, Nov. 2005.

[2] I. Kardosh and F. Rinaldi, "Beam properties and M^2 measurements of high-power VCSELs". Annual Report 2004, Ulm University, Optoelectronics Department.