Beam Properties and M^2 Measurements of High-Power VCSELs

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In this article, a measurement method to determine the beam quality factor of high-power VCSELs is presented. The experimental setup und the analysis method to calculate the beam parameters, M^2 factor, divergence angle, and the beam waist are described.

1. Introduction

For many industrial and scientific laser applications such as material processing, it is necessary to have a good laser beam quality for ease of fiber coupling, beam collimation, and beam focusing. In general, propagating laser beams deviate from an ideal Gaussian intensity distribution. The degree of deviation is conveniently quantified by a quality factor M^2 (called the "M-squared" factor or the "times diffraction limit number"). This factor has been defined so that $M^2 = 1$ for an ideal Gaussian beam. Real laser beams have factors greater than one. For example helium–neon lasers typically have $M^2 < 1.1$ while high-power vertical-cavity surface-emitting lasers (VCSELs) have M^2 values that can be as high as 20 and more due to their transverse multi-mode emission which results from large active diameters. Recently there has been some interest in applying high-power VCSELs for high-resolution printing and free-space optical data communication. Such applications require high optical output power and good beam quality, in other words specific M^2 factors at certain output powers. These characteristics are investigated in the present article.

2. Measurement Method and Setup

Figure 1 shows the experimental setup for the beam quality characterization. The laser beam of a mounted VCSEL is transformed through a lens system such as to form a beam waist along the propagation axis. A highly linear CCD camera is used to capture the beam image at different propagation distances. According to a procedure defined by the ISO [1], ten measurements along the propagation axis must be performed at least, where half of them should be within the Rayleigh length on both sides of the beam waist. The captured images are analyzed using a mathematical program which determines the pixel intensity from the bitmap image files and calculates the beam diameter using the second-moment

*Work performed in collaboration with U-L-M photonics GmbH, www.ulm-photonics.com definition, where the beam diameter is four times the standard deviation. The beam radii are plotted versus the propagation distance. A Gaussian fit is used to determine the M^2 factor. In addition, the laser beam waist W_0 and the divergence angle Θ can be calculated when considering the magnification factor of the optical system. Figure 2 shows typical images from the CCD camera at different propagation distances around the beam waist.

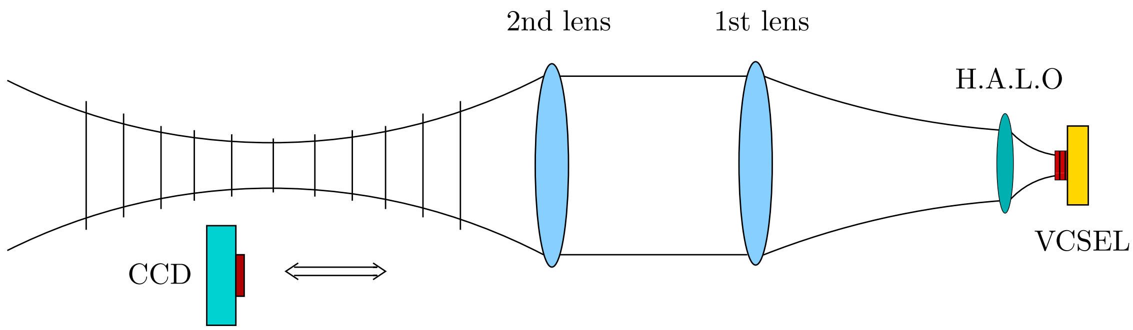

Fig. 1: Setup for the measurement of the beam quality of VCSELs. The laser beam is collimated using a high aperture laser objective lens (H.A.L.O) and a biconvex lens (1st lens). The second lens focuses the beam and thus generates a beam waist along the propagation axis.

Fig. 2: Captured images of a 80 μm active diameter VCSEL beam at different positions from the beam waist.

3. Experimental Results

Beam properties of 980 nm oxide-confined multi-mode VCSELs have been investigated. In this section we present measurement results of a 80 μm active diameter device. In Fig. 3 the light–current–voltage (LIV) and spectral characteristics are plotted. The maximum output power and the threshold current are about 190 mW and 70 mA, respectively. The spectral characteristic in Fig. 3 show a wide spectra with mode groups at different wavelengths. The mode groups at higher wavelength correspond to donut mode structures with higher intensity, while mode groups at lower wavelength correspond to outer ring structurs with lower intensity as can be seen in Fig. 2. The calculated beam radii versus the propagation distance are shown in Fig. 4. We use the Gaussian formula

$$w(z) = w_0 \sqrt{1 + \left(\frac{z - z_0}{z_{\mathrm{R}}}\right)^2}$$

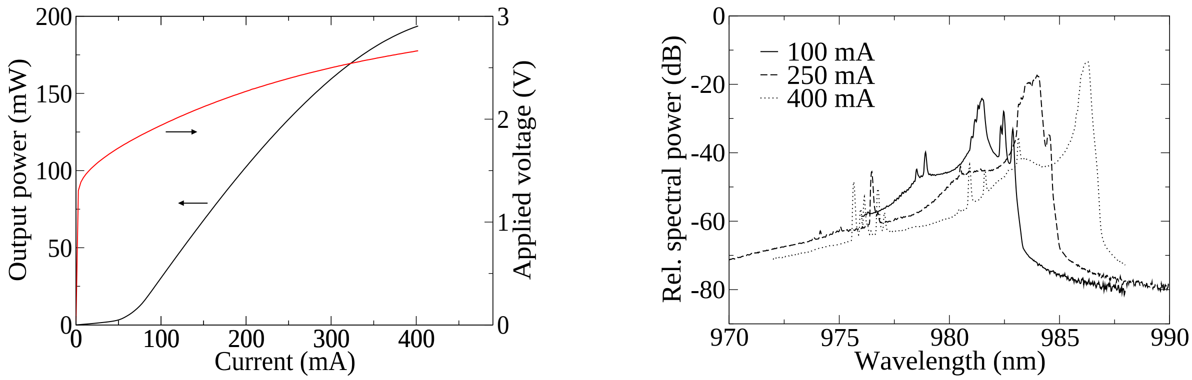

Fig. 3: LIV characteristics (left) and spectra (right) of the measured 80 μm device.

for fitting the measurement results, where $w(z)$ is the beam radius, w_0 the radius of the beam waist, z_0 the beam waist location, and

$$z_{\mathrm{R}} = \frac{\pi w_0^2}{M^2 \lambda}$$

the Rayleigh length.

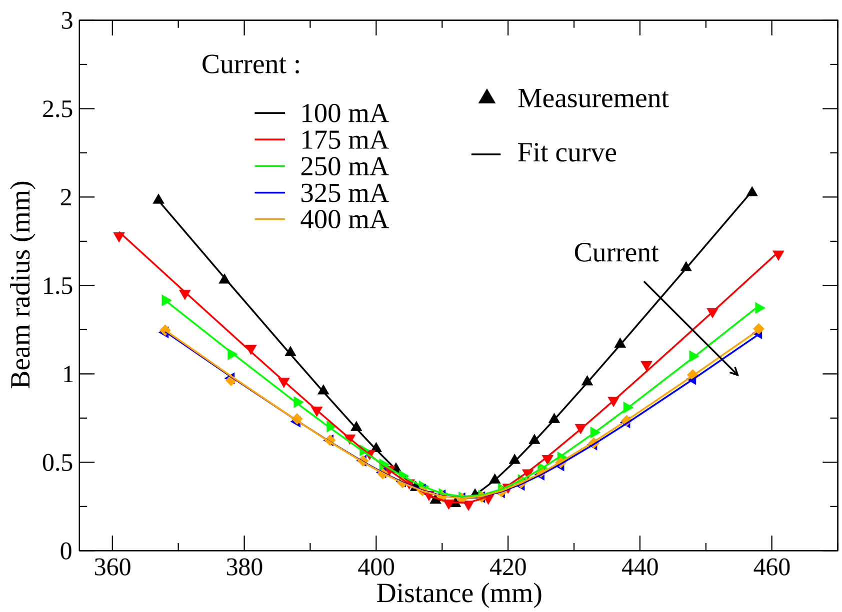

Fig. 4: M^2 measurement results for different currents.

Fitting parameters are M^2, w_0, and z_0. When considering the magnification factor m of the optical system, the far-field angle Θ of the VCSEL is approximated as

$$\Theta \approx m \frac{w_0}{z_{\mathrm{R}}} \, ,$$

and for the beam waist W_0 we obtain

$$W_0 = \frac{w_0}{m}\,.$$

Measurement results of beam quality factors and far-field angles at different currents are plotted in Fig. 5.

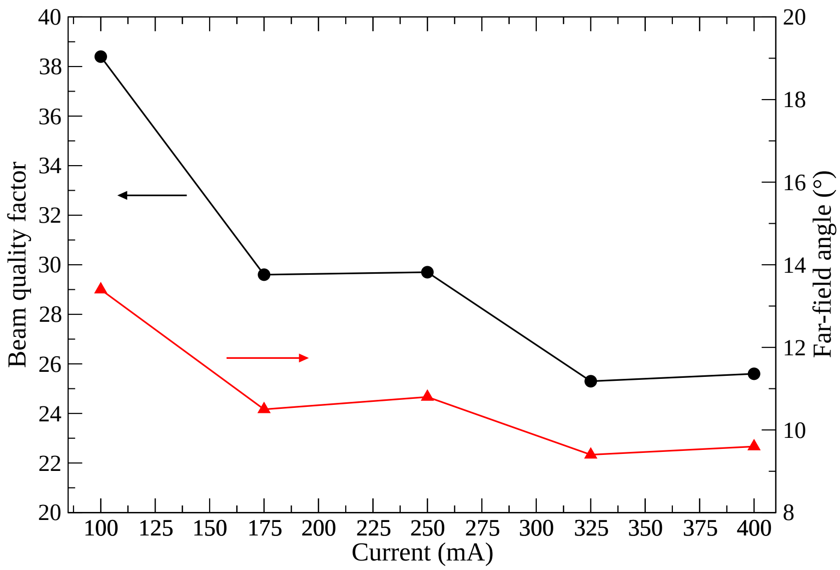

Fig. 5: M^2 values and far-field angles versus the laser current.

4. Conclusion

We have characterized high-power VCSELs regarding the beam quality. Measurement setup und analysis method have been developed to measure the M^2 factor. Beam properties of a 80 μm active diameter device have been investigated. M^2 measurements yield values ranging from about 25 to 38, where M^2 tends to decrease with increasing current. This trend is specific for this device, where other similar devices show a rather constant M^2. The far-field angle has a maximum of about 13° at 100 mA and a minimum of about 9° at 325 mA, corresponding to 170 mW optical power. The beam diameter $2W_0$ is 98 μm on average. Our aim is to get M^2 values of about 20 at output powers of around 150 mW, which is interesting, e.g., for high-resolution printing.

References

[1] International Organization for Standardization, *Lasers and laser-related equipment. Test methods for laser beam parameters, beam widths, divergence angle and beam propagation factor. ISO 11146*, 1996.