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Measuring M^2 values for On-Wafer Vertical Cavity Surface Emitting Lasers

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Abstract: We report on M^2 measurements taken for on-wafer vertical cavity surface emitting lasers (VCSELs). We measured M^2 for oxide-confined VCSELs and photonic crystal (PhC) VCSELs of similar lasing aperture sizes.
OCIS codes: (250.7260) Vertical Cavity Surface Emitting Lasers; (140.3295) Laser Beam Characterization

1. Introduction

Vertical cavity surface emitting lasers (VCSELs) can have many desirable device qualities, such as low threshold currents, small beam divergence, and a limited number of propagating modes [1]. The number of modes emitted is determined by examining the spectral content [2]; however, this observation alone may be insufficient in describing the beam quality, such as how the VCSEL lasing beam compares to the ideal Gaussian beam.

In this paper, we further investigate the beam quality of VCSELs by measuring the beam propagation factor M^2. We present the setup we constructed for measuring M^2 values of on-wafer VCSELs and report the resulting M^2 values for various oxide-confined VCSELs and photonic crystal (PhC) VCSELs as fabricated in [2]. These initial measurements were taken from an on-hand sampling of oxide-confined and PhC VCSELs and are not meant to infer a meaningful comparison between the two optical confinement techniques but to demonstrate the viability of the measurement setup to measure and calculate the M^2 values for each type of VCSEL. Future systematic studies are planned to examine parameters that lead to a near single Gaussian mode as defined by $M^2 < 1.5$ [3].

2. Experimental Setup and Method

A Thorlabs BP109-VIS Slit Scanning Beam Profiler in conjunction with the BP1M2-150 Profiler Extension Set is used to calculate the M^2 values for different aperture sizes and injection currents IAW ISO Standard 11146. A Mitutoyo 50x infinity-corrected long working distance objective collimates the beam from the VCSEL which is followed by a 75 mm plano-convex lens to focus the beam within the measurement region and utilize the available measurement area of the optical detector as shown in Fig. 1. The practical challenge with this setup is the need to mount the instruments vertically while placing and maintaining electrical contact on the on-wafer devices.

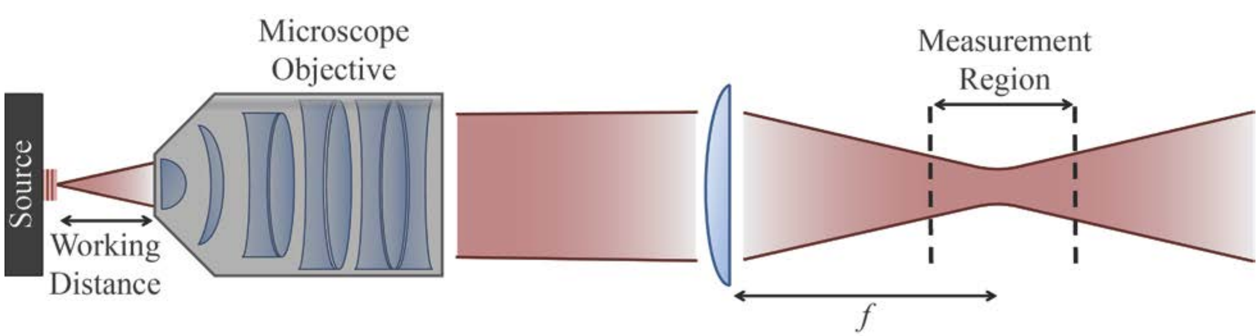

Fig 1. Illustration of experimental setup. The VCSEL beam is collimated through the microscope objective and then focused using a 75mm plano-convex lens to place the beam waist within the travel range of the profiler extension set.

We characterized oxide-confined VCSELs with aperture sizes of 2.5, 5.0, 7.5, and 10.0 μm and the M^2 value was measured on at least five different devices of each aperture size. We characterized PhC VCSELs fabricated at two different etch depths with lasing aperture sizes of 5 and 10 μm and the M^2 value was measured on at least three different devices of each aperture size and each of the two hole depths. The 5 µm PhC VCSELs have a *b/a* ratio of 0.7 and an *a* value of 4 µm, where *a* is the hole spacing and *b* is the hole diameter. The 10 µm PhC VCSELs have a *b/a* ratio of 0.7 with 3.5 < *a* < 5.0 µm. All devices reported here were characterized over an injection current range of 1 to 15 mA.

3. Results and Discussion

We present the measured M^2 values for the oxide-confined VCSELs with aperture sizes described above as a function of injection current in Fig. 2a. The beam propagation factor of the VCSELs reduces as the aperture size decreases with the 2.5 µm aperture devices exhibiting near single mode operation across their range of operating currents. Despite the single mode operation at lower aperture sizes, the M^2 values monotonically increase with increasing injection current.

We also measured the M^2 values for PhC VCSELs with aperture sizes of 5 and 10 µm. We show these values alongside M^2 values of VCSELs of like aperture size in Fig. 2b, where both the 5 and 10 µm aperture PhC VCSELs showed an M^2 value < 1.5. Unlike the oxide-confined VCSELs, the PhC VCSEL beam propagation factor demonstrated little to no dependence on injection current. Finally, the M^2 measurements for the PhC VCSELs appear to be independent of etch depth.

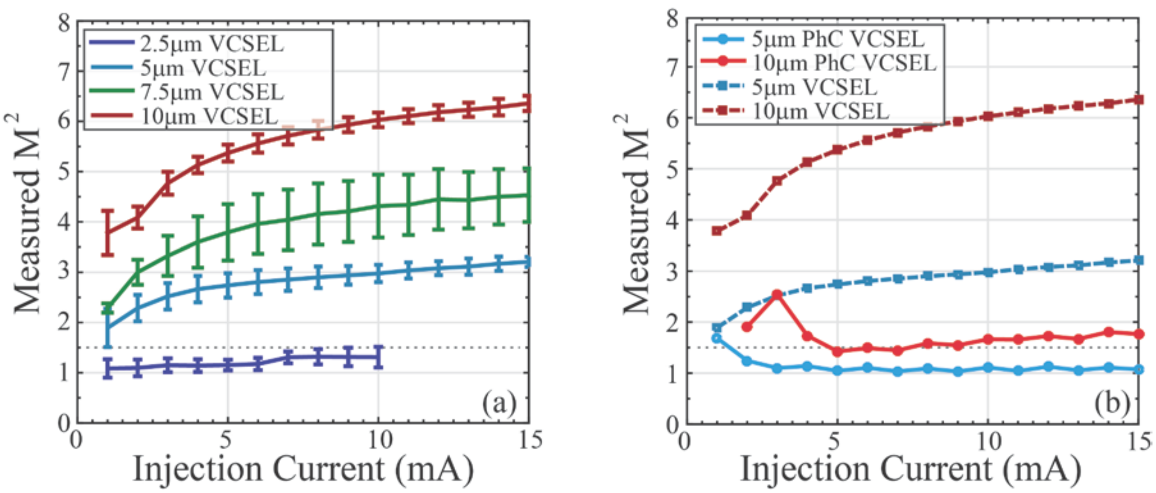

Fig 2. (a) Measured M^2 values and standard deviation for oxide-confined VCSELs with apertures sizes of 2.5, 5, 7.5, and 10 µm. (b) M^2 values for aperture sizes of 5 and 10 µm for both VCSELs and PhC VCSELs with a *b/a* ratio of 0.7 and *a* values of 3.5 to 5.0 µm.

4. Conclusion and Future Work

The constructed setup successfully determined M^2 for both on-wafer oxide-confined and PhC VCSELs. Our limited testing suggests that the beam propagation parameter for VCSELs can be dependent on its fabrication method and applied injection current. We observed that smaller optical aperture sizes achieve M^2 values closer to one for the oxide-confined VCSELs (as expected due to the relatively smaller number of lasing modes) and, regardless of aperture size, the M^2 value increases as the injection current increased (again indicative of additional modes). Alternatively, 5 and 10 µm PhC VCSELs demonstrate M^2 values < 1.5 that are less dependent on injection current. Future systematic studies are planned to investigate device parameters that lead to optimal beam quality.

5. References

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