Far- and near-field study of leaky emission in oxide-confined vertical cavity lasers

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Vertical-cavity surface-emitting lasers (VCSELs) are used in data communication, sensing, illumination and other applications. Single mode (SM) VCSELs are preferable, as they allow longer distance data transmission over multimode fiber, lower noise, better coupling tolerances to waveguides and much higher brightness. To fabricate high-efficiency 600–12XX nm VCSELs, selective oxidation of AlAs aperture layers can be used with oxide-confined aperture diameters of several μm for current and optical confinement. A disadvantage of standard oxide-confined VCSELs is the difficulty of achieving SM lasing at aperture diameters needed for low-voltage, low-resistance operation. Alternative approaches, such as etched VCSEL mesas overgrown by a material with a high refractive index, can help achieve SM operation because in this case high-order modes have a higher intensity at the mesa boundary and leak into the surrounding area. At the same time, the leaky emission can be used for lateral on-chip integration of the devices. Recently, leaky emission was proposed and realized for oxide-confined VCSELs with thick oxide aperture layers [1].

In this work we study far-field (FF) and near-field (NF) electroluminescence (EL) spectra of oxide-confined VCSELs with thick oxide apertures. We show that unlike conventional thick oxide VCSELs, where high-order mode lasing is seen already at 1 mA currents and oxide aperture diameters of 4 μm, the leaky VCSEL remains SM up to 5 μm aperture diameters and currents above 4 mA.

Figure 1 compares FF and NF patterns of the leaky VCSEL at aperture sizes slightly below (a) and above (b) 5 μm. At low currents, the devices are clearly SM as revealed in the NF and FF patterns. An excited mode does appear in the larger aperture device at high current densities. Once this mode appears, an additional characteristic feature with a very low beam divergence and a large tilt angle (37°) is revealed in the FF pattern. This mode is a fingerprint of the leaky emission propagating through the oxidized VCSEL section outside the aperture in the direction parallel to the surface, with only a small fraction of light escaping from the top DBR.

We believe that this observation paves a way for better understanding of leaky SM VCSELs and for engineering of optical-field coupled VCSEL arrays and VCSEL-based on-chip integrated optoelectronic circuits.

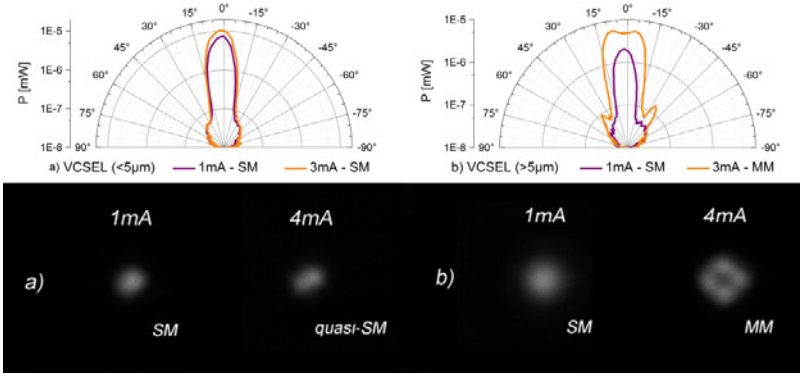

Fig. 1. Far-field and near-field profiles of two leaky VCSELs with different aperture diameters.

1. V. A. Shchukin, N. N. Ledentsov, J.-R. Kropp, *et al.*, *J. Quantum Electronics* **50** , 990 (2014).