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# Improved oxide VCSEL aperture inspection using hyperspectral imaging

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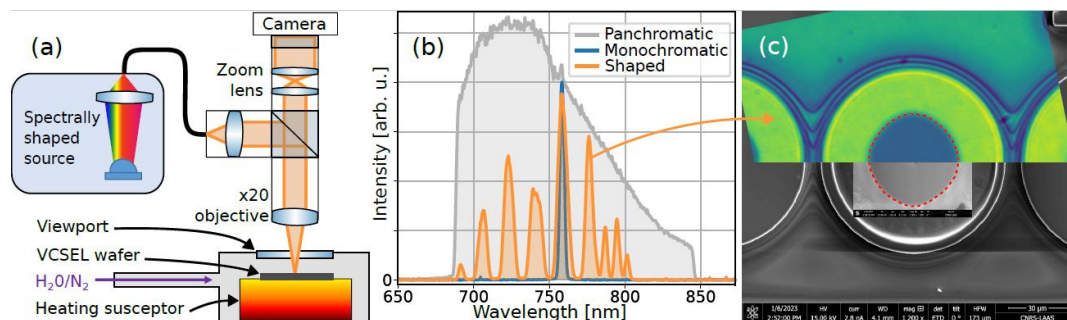
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Oxide-aperture Vertical-cavity Surface-Emitting Lasers (VCSELs) are the prime light sources used in data centres, and are becoming increasingly embedded in optical sensors such as for Light Detection And Ranging (LIDAR) or 3D (facial) recognition [1]. Central to their fabrication and to their electrical and optical characteristics is the tight control over the oxide aperture, the latter being created by the selective lateral thermal oxidation of a thin layer of semiconducting AlGaAs buried in the middle of the VCSEL vertical stack into an insulating oxide (AlOx) material [2]. If real-time in-situ monitoring systems using either a white-light or a single narrow-band illumination and a near infrared camera [3], [4] have been implemented to address this issue, there are still particular combinations of VCSEL stacks and process conditions that make the oxide aperture detection difficult.

In this submission, we report the improvement in the oxide aperture measurement brought by using hyperspectral imaging techniques. Practically, we have built an illumination source, based on a supercontinuum laser source and a digital micromirror device (DMD), whose spectrum can be shaped at will. Top-view images of the aperture of an already-oxidized VCSEL sample were acquired under static in-situ inspection conditions at room temperature (see Fig. 1a) and subsequently compared. Three types of illuminations were used, respectively, panchromatic lighting, which corresponds to the white-light broadband case, monochromatic illumination for which the spectrum is restricted to the narrow (~5 nm) spectral band giving maximum contrast between the AlOx and AlGaAs areas, and the shaped illumination, where the spectrum is proportional to the positive intensity contrast distribution between these two regions (see Fig. 1b). The most precise oxide aperture edge-detection was achieved using shaped spectrum illumination. Indeed, this illumination enables to make the most between the high-contrast but speckle-altered images of monochromatically-lit scenes and the high-fluence (hence high-speed) recordings usually obtained using panchromatic illumination. The accuracy of the VCSEL oxide aperture measurement was confirmed by Scanning Electron Microscopy (SEM) imaging enabled by a destructive Focus Ion Beam Etching (FIBE) of the top half of the VCSEL stack (Fig. 1c).

Future work will be devoted to moving away from the above-described improvement in the static inspection of lateral oxidation to report an adjusted system enabling real-time monitoring.



**Fig. 1** (a) Schematic of the oxidation furnace and in-situ optical monitoring system.

(b) The three illumination shapes generated with the spectrally-shaped source used for the VCSEL oxide aperture imaging.

(c) Composite image with the overlap of the optical in-situ inspection view obtained with shaped spectrum illumination (upper part), the zoomed FIBE SEM image (bottom center), and a wider-view FIBE SEM image (bottom part).

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