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First Demonstration of 940-nm VCSELs Fabricated over 200-mm GaAs- and Ge-Substrates

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***Abstract*—We report on the first fabricated and characterized full 200 mm VCSEL wafers. We investigate performance of nominally identical VCSEs, across 200 mm, grown on both GaAs- and Ge-substrates. Germanium offers a reduction in bow compared to standard GaAs substrates typically used in AlGaAs-based VCSELs, providing a route to larger diameter wafers and longer emission wavelengths in this material system.**

Keywords—VCSEL, Germanium, 200 mm, wafer bow, manufacturing

I. INTRODUCTION

Emerging applications such as autonomous things, augmented/virtual reality and automotive LiDAR demand larger arrays, higher performance, and improved reliability from vertical cavity surface emitting lasers (VCSELs). These new applications are the driving force for lower cost and increased manufacturability of VCSELs with the production of the world's first 200 mm VCSEL epi-wafer announced in 2022 [1].

Germanium has garnered a lot of interest in recent years due to its suitability as an alternative substrate for GaAs/AlGaAs based VCSELs [2, 3]. It offers advantages such as zero etch pit density, simpler recycling, and is already commercially available in diameters up to 300 mm. However, the biggest advantage is the reduced lattice mismatch between Ge and AlAs, reducing the overall compressive strain in a thick-DBR structure, typically seen with GaAs-substrate wafers. This has further advantages such as a reduction in the wafer bow which has been shown to be beneficial for 150 mm substrates [4]. This study also first demonstrated comparable VCSEL performance from GaAs- and Ge-substrate devices across full 150 mm wafers.

As wafer sizes continue to increase, initially VCSEL growth studies on 200 mm wafer were fabricated and characterized as small coupons only [5]. We, therefore, now report on the fabrication and characterization of 940-nm VCSEL device performance over 200 mm for the first time, comparing those grown on GaAs- and Ge-substrates.

II. MATERIALS & METHODS

The epitaxial structure of the VCSELs used in this study is a proprietary generic p-i-n layout, designed for 940-nm emission wavelength, and is nominally identical on both n-doped GaAs- and Ge-substrates. It consists of a multiple quantum-well gain medium sandwiched between upper p-doped AlGaAs/AlGaAs and lower n-doped AlAs/AlGaAs DBR mirrors. The lower DBR also contains a small number of repeats of AlGaAs/AlGaAs, between the active and start of the AlAs layers. One $Al_{0.98}GaAs$ layer is included just above the active region in the upper DBR which acts as an electrical and optical confinement layer, following selective oxidation. Due to the difference in substrate materials, the wafers were produced in two separate growth runs by IQE plc, but with the same growth process used for each.

This study uses planarization-free oxide confined VCSELs, following a VCSEL quick fabrication process that was previously designed, and reported in detail in [6]. The fabrication for both GaAs- and Ge-substrate wafers is identical except for the choice of metal contact deposited directly to the substrate side of the wafer, to create a global n-contact. More details about the fabrication process flow can be found in [4]. To note, the 200 mm GaAs VCSEL wafer has been processed without backside silicon nitride (SiN_x) compensation, which if one method to partially mitigate wafer bow.

Following completion of the fabrication, continuous wave power-current-voltage-wavelength measurements were performed on a semi-automated wafer-prober equipped with calibrated integrating sphere for light collection.

Fig. 1: A completed 200-mm VCSEL wafer. Each wafer contains 250,000 VCSEL devices.

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III. RESULTS

A. *Wafer Bow*

Surface height measurements were carried out over a 200 mm GaAs and Ge substrate VCSEL wafer to measure the magnitude of the wafer bow/warp in each case. The 3D results can be seen in Fig. 2. The Ge-substrate wafer shows a 3 times reduction in the magnitude of the peak-to valley surface height. The increased amount of compressive strain in the GaAs-substrate wafer can cause problems in fabrication such as photolithography and oxidation processes, as well as unintended wafer breakages.

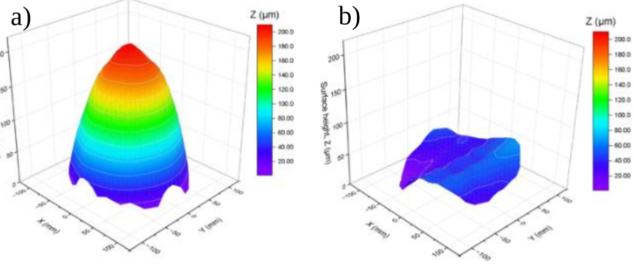

Fig. 2: 3D surface height profiles for nominally identical VCSEL structures grown on a 200 mm diameter (a) GaAs and (b) Ge substrate.

B. *Device Characterstics*

Fig. 3 shows the peak wavelength of nominally 9 µm aperture VCSELs, at 3 mA, on both substrate types. Both wafers have a typcal radial peak wavelength variation, with emission around 940 nm. However, it is noticed that the peak wavelength at the very center of the Ge-substrate wafer (Fig.3(b)) is ~3 nm longer and has an increased standard deviation over the GaAs-substrate devices.

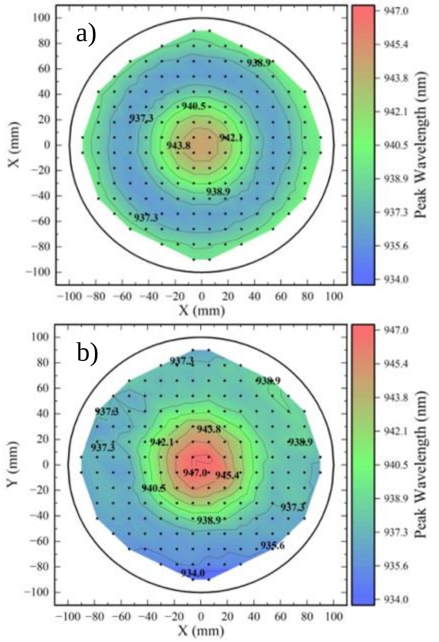

Fig. 3: Wavelength contour map of, nominally 9 µm aperture, VCSEL devices at 3 mA on a) GaAs and b) Ge-substrate

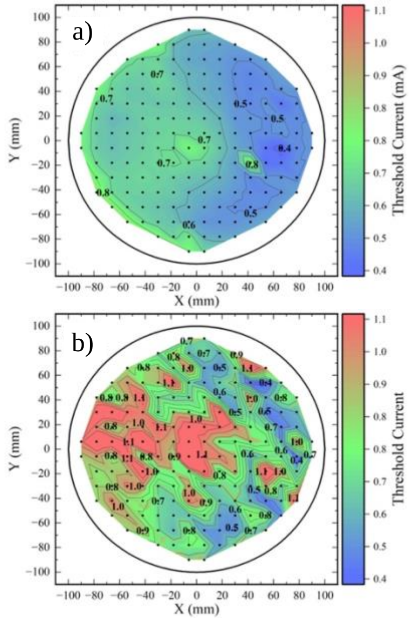

Fig. 4: Threshold current contour map of, nominally 9 um aperture, VCSEL devices on a) GaAs- and b) Ge-substrates

The threshold current for nominally 9 µm aperture devices is also measured across each 200 mm wafer and presented in Fig.4. The GaAs-substrate devices show a variation of 0.4 mA across the wafer, whereas on Ge there is a variation of 0.7 mA, with the mean threshold current being marginally lower for the GaAs-substrate VCSELs. The small differences in both wavelength and threshold current between GaAs- and Ge-substrate devices, are likely a result of the same growth process being used for both substrate materials, /which could be optimized in future growth runs. Irrespective of this, there is promising comparable performance on both GaAs and Ge when moving to 200 mm substrates, with fabrication of either being a nonlimiting factor with regards to performance uniformity.

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