

First Demonstration of High Performance 940 nm VCSELs Grown on 200 mm Diameter Substrates

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ABSTRACT

We report the first growths of advanced 940 nm VCSEL structures on 200 mm (8") diameter substrates. IQE has extended its IQGeVCSEL™, previously demonstrated on 150 mm diameter Germanium substrates, to 200 mm diameter wafers. Growths were carried out on volume production ready Aixtron G4 MOVPE reactors, and all of the benefits previously demonstrated at 150 mm still apply on the larger diameter Germanium substrates: zero EPD substrates, more mechanically robust substrates, significantly lower wafer bow, and elimination of slip lines.

The large wafer bow/warp seen in conventional VCSEL structures on GaAs substrates is an inherent consequence of the lattice mismatch between the GaAs substrate and the AlGaAs constituents of the VCSEL DBR layers. As the DBR layers are quite thick, the total compressive strain in the full structure on GaAs deforms the final wafer, typically in excess of 200µm. By growing 940 nm VCSELs on Ge substrates we have eliminated this problem because the lattice parameter of Ge sits between those of GaAs and AlAs and creates a largely strain balanced structure. For comparison, VCSEL growths have also been carried out on 200 mm GaAs substrates, which have recently become commercially available. The extreme bow and warp typically exhibited by VCSEL epiwafers on GaAs translate to higher chip cost due to increased yield loss and additional processing steps required to flatten the wafer. Comparison of identical epitaxial VCSEL structures on both Ge and GaAs is presented.

INTRODUCTION

IQE has previously reported the introduction of Germanium substrates as a drop-in replacement for GaAs for the manufacture of Vertical Cavity Surface Emitting Lasers (VCSELs) on large area 150 mm substrates [1]. As VCSELs have become more and more commoditized for advanced 3D sensing applications, more focus has been applied to

improving manufacturing yields and understanding yield loss mechanisms across the supply chain, in order to reduce overall production costs. A significant consequence of this focus is that epitaxial growth of VCSEL wafers on 150 mm GaAs substrates is characterized by significant wafer bow/warp, a direct consequence of the residual compressive strain in the epitaxial stack. This strain is due to the small amount of lattice mismatch between the GaAs and AlGaAs constituents of the Distributed Bragg Reflector (DBR) mirror layers that make up the VCSEL, and the relatively large thickness of these epilayer structures. These wafers can exhibit bow and warp values of well in excess of 200µm on 150 mm GaAs, making subsequent wafer characterization and processing extremely challenging, and also leading to yield losses and increases in manufacturing costs. It can also lead directly to formation of crystallographic dislocations and defects that also have a deleterious effect on device performance, yield and reliability.

Ge overcomes this problem as it has a bulk lattice parameter that is nearly midway between GaAs and AlAs, permitting the epitaxial growth of strain balanced structures, significantly reducing the residual strain in the system, thereby significantly reducing wafer bow and warp. Ge has additional advantages over GaAs which are pertinent for this application, most notably that Germanium is available dislocation free (zero EPD) and mechanically more robust than GaAs.

A further advantage of Germanium is that it is already available in larger diameters, notably 200 mm [2], which offers an immediate route to larger VCSEL epiwafers with the same advantages over GaAs, as previously demonstrated. We therefore now report a comparative study of 940 nm VCSEL epiwafers grown on 200 mm GaAs and Germanium substrates, as a route to lower manufacturing costs.

EXPERIMENTAL DETAILS

VCSEL epiwafers were grown by Metalorganic Vapor Phase Epitaxy (MOVPE) on Aixtron 2800G4 production

reactors [3] at IQE's Cardiff manufacturing facility in the UK. This reactor had been reconfigured for 5x200 mm wafers/ run, see figure 1, specifically for this purpose.

The 940 nm VCSEL structure used for these growths is an IQE generic high power layer design, the same as has previously been reported for 150 mm Ge and GaAs growths. In this way a direct comparison between the GaAs and epiwafers can be made. The Ge substrates were supplied by Umicore Electro-Optical Materials, doped n-type and with a surface miscut of 6° from the (001) surface plane. The substrate miscut on Ge is utilized to overcome anti-phase issues related to the growth of a polar material on a non-polar surface [4,5]. The 200 mm GaAs wafers were supplied by AXT and were doped n-type, also with a 6° miscut from the (001) surface plane.

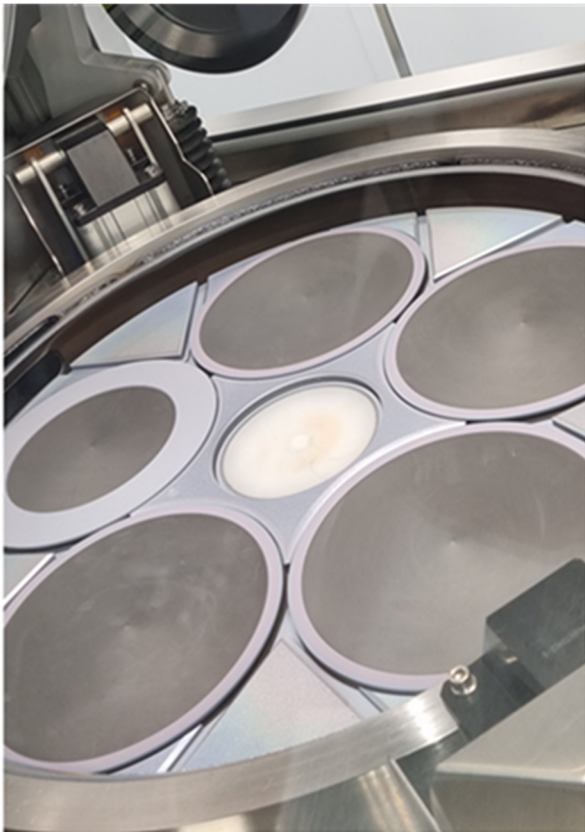


Fig. 1. Image of the growth cell of the 2800G4 MOVPE tool used for this work, showing the 5x200 mm wafer configuration. The satellite seen on the left hand side of the image has a 150 mm recess, enabling the growth on 150 mm wafers in this configuration and/or the growth of 150 mm and 200 mm substrates in the same epitaxial growth run.

Nominally identical 940 nm VCSEL epitaxial structures were grown on both types of substrate in consecutive growth runs.

There were some minor adjustments made for the nucleation onto Ge substrates [4,5], but otherwise the processes and structures are the same for both substrates. By structuring the growths in this manner it was possible to eliminate or reduce as much process variability from the growths as possible, to enable a true like-for-like comparison of the structures on the different substrates.

The reconfiguration of the MOVPE reactor to 5x200 mm/run involves moving the wafer centre positions closer to the centre of the platen. In order for a realistic comparison to be made with the same VCSEL structure grown on 150 mm diameter substrates previously, a set of 200 mm graphite satellites was procured with 150 mm recesses, as seen in figure 1. This permits epitaxial growth on 150 mm substrates in this 5x200 mm configuration, and the ability to mix 150 mm and 200 mm substrates in the same run if required.

RESULTS

Epitaxial VCSEL growths were setup using IQE's standard proprietary calibration processes. Figures 2 and 3 are room temperature PL spectra for VCSEL active region calibration samples on 200 mm Ge and GaAs respectively. In each case the calibration is typically set at ~15 nm below intended lasing wavelength, and it can be seen that both spectra are largely identical, with the Ge sample having slightly narrower FWHM. These results are typically what would be expected for similar structures grown on 150 mm diameter substrates, either Ge or GaAs.

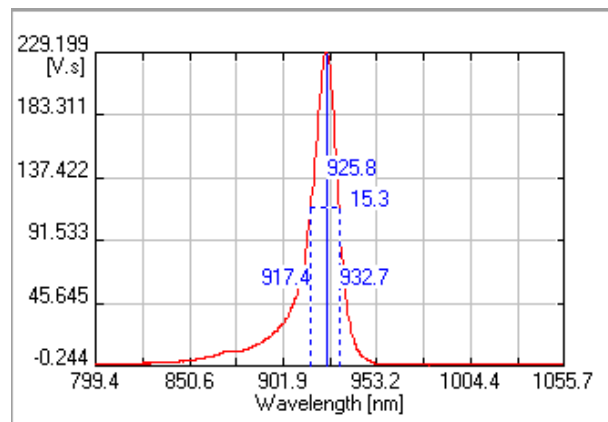


Fig. 2 PL spectrum from VCSEL active region calibration sample on 200 mm Ge substrate

Calibration and doping of the DBRs was carried out using conventional IQE process, without encountering any major problems. Some process adjustments were then made to optimize cross wafer uniformity in each case, utilizing

reflectivity wafer maps for this purpose, then allowing the growth of the full VCSEL structures on both types of 200 mm wafer.

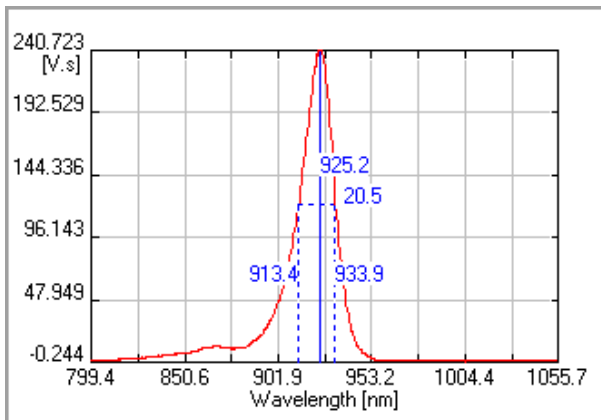


Fig. 3 PL spectrum from VCSEL active region calibration sample on 200 mm GaAs substrate

Figures 4 and 5 demonstrate typical wafer maps of FP-dip distribution across Ge (Figure 4) and GaAs (Figure 5) 200 mm wafers. This is a standard metric used to evaluate wafers in standard 150 mm VCSEL production and the uniformity achieved is excellent, at least matching the values that would be expected for this parameter on production on 150 mm wafers, which is extremely encouraging

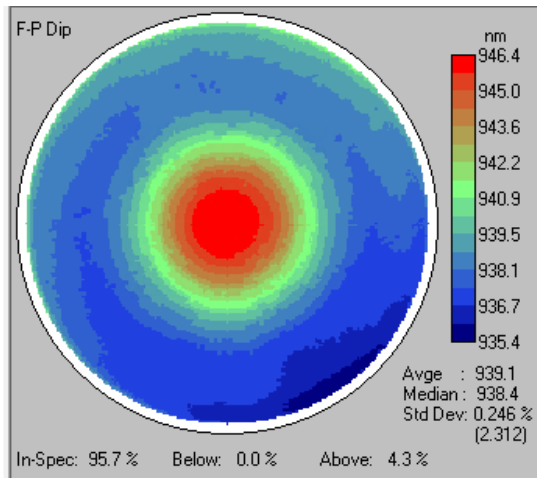


Fig. 4 Wafer reflectivity map, indicating distribution of FP-dip across 200 mm Ge wafer, with 5 mm edge exclusion. The standard deviation of ~0.25% is an excellent result

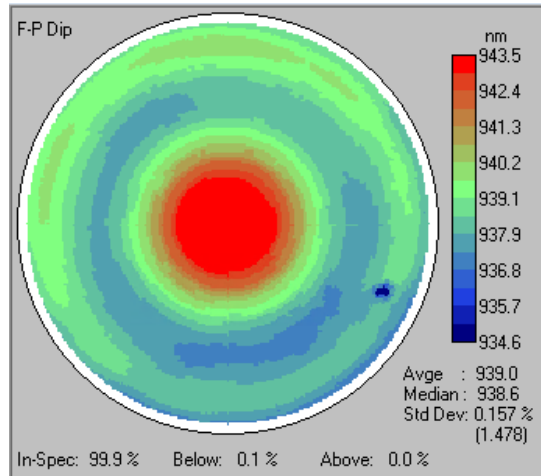


Fig. 5 Wafer reflectivity map, indicating distribution of FP-dip across 200 mm GaAs wafer, with 5 mm edge exclusion. The standard deviation of only ~0.16% is an excellent result

Whilst the FP-dip uniformity is excellent on both wafers, the lower figure on the GaAs wafer is indicative of slightly better cross wafer uniformity of the constituent epilayers. Both wafers used the same growth process and the difference is attributed to slight differences in the substrate specifications, which will be addressed in future growths.

Figures 6 and 7 show typical reflectivity spectra for these epitaxial wafers, with Figure 6 showing the result for the 200 mm Ge wafer, and Figure 7 that for the 200 mm GaAs wafer. These spectra are both taken from close to the wafer centres and are largely identical for FP dip, intensity and stop band position and width.

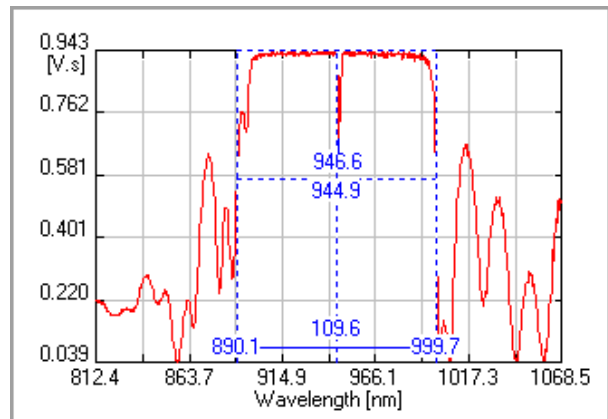


Fig. 6 Typical Reflectivity spectrum for 200 mm Ge VCSEL wafer

Finally, both types of VCSEL wafer were tested for bow/warp using a Flatscan Optical Surface Profiler. The use of Germanium has already been demonstrated to be advantageous for VCSEL growth on 150 mm wafers, due to the Ge lattice parameter permitting strain balanced epitaxy, thereby significantly reducing the net compressive strain in the epitaxial stack [1]. This data is summarized in Table 1, comparing both 200 mm wafers with those previously measured on 150 mm.

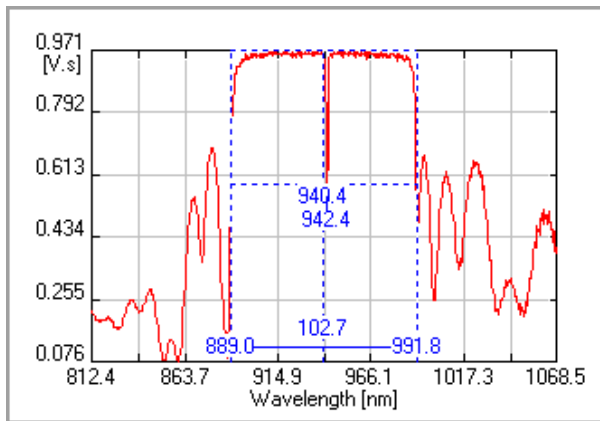


Fig. 7 Typical Reflectivity spectrum for 200 mm GaAs VCSEL wafer

TABLE I

PEAK TO VALLEY WAFER DISTORTION OF VARIOUS VCSEL EPITAXIAL WAFERS FROM THIS WORK. 150 MM WAFER DATA IS FROM REF [1]

Wafer Structure	Peak to Valley Flatness Measurement (μm)
200 mm GaAs VCSEL	309.6
200 mm Ge VCSEL	83.9
150 mm GaAs	227.7
150 mm Ge	24.9

It can clearly be seen that the benefits of Ge, already established on 150 mm VCSEL wafers, are also established on 200 mm diameter wafers. The use of Ge significantly reduces the degree of wafer bow, offering simpler VCSEL fabrication processes and improved manufacturing yields and chip reliability.

CONCLUSIONS

We report the very first growths of 940 nm VCSEL structures on 200 mm substrates, offering a clear route to larger manufacturing volumes at lower manufacturing costs/wafer.

IQE will be at the forefront of this development. As for 150 mm wafers, the Ge and GaAs wafers yield largely similar results, highlighting that these substrates are interchangeable for this application. The significantly lower wafer bow demonstrated on Ge, along with zero dislocations and better mechanical strength, compared with GaAs, make Ge the ideal substrate for VCSEL applications, especially at these larger wafer diameters.

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ACRONYMS

VCSEL:	Vertical Cavity Surface Emitting Laser
DBR:	Distributed Bragg Reflector
MOVPE:	Metalorganic Vapour Phase Epitaxy
PL:	Photoluminescence
FWHM:	Full Width Half Maximum
FP:	Fabry-Perot