Metamorphic growth of MWIR ICLED on Silicon

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Interband cascade light emitting diodes (ICLEDs) grown on GaSb substrates have emerged as an effective continuous wave (CW) room temperature emitter technology in the 3 – 5 µm wavelength range [1,2]. The integration of ICLEDs directly on a silicon substrate can lead to significant benefits in manufacturability for applications including chemical sensing and IR scene projectors (IRSPs).

This presentation will discuss the growth at NRL of high performance ICLEDs on GaSb/Si buffers that were grown at UNM. The growths on GaSb *vs*. GaSb/Si are compared for crystallographic quality using cross section transmission electron microscopy (XTEM) and X-Ray reciprocal space maps (RSM). XTEM images show the presence of threading dislocations in the GaSb buffer grown on Si, with a higher density near the silicon substrate and reduced closer to the ICLED. We measure a range from 5×10^7 to 2×10^8 cm^2 in different samples. Individual threading dislocations in the GaSb buffer can reach the ICLED and multiply once they reach the active stages (figure 1). Another artifact of growth on silicon is an undulation in the ICLED layers. Our presentation will provide a detailed mechanism for both of these observations, and we will compare the results to those for an ICLED grown lattice-matched to a GaSb substrate (figure 2). We will also discuss possible strategies for improving the epitaxial quality and device performance.

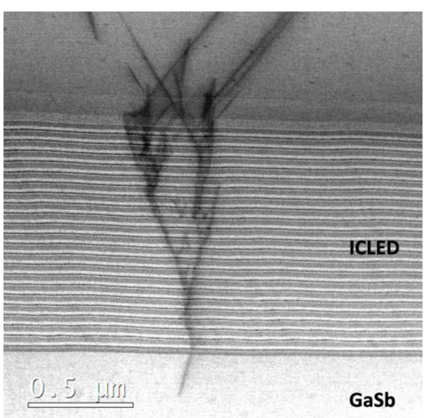

Figure 1 - Threading dislocation multiplication seen in an ICLED grown on GaSb/Silicon.

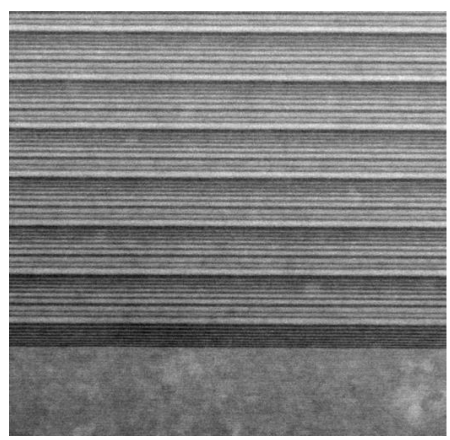
Figure 2 - Highly planar and defect free layers in an ICLED grown lattice-matched on GaSb.

[1] C. S. Kim et al., Opt. Engr. 57, 011002 (2018).
[2] N. Schäfer et al., Opt. Engr. 58, 117106 (2019).
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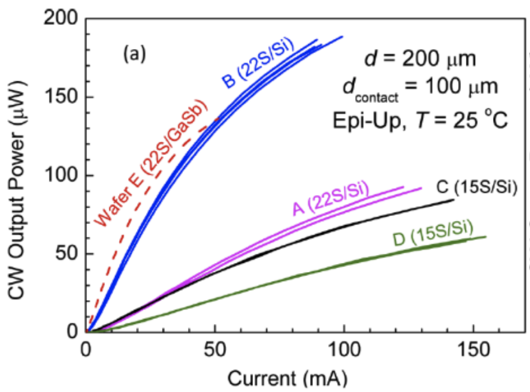
Supplementary Pages

Epitaxial process for growth of ICLED on GaSb/Silicon: The first step in the process involves GaSb buffer layers that are grown on (001) silicon with an offcut of 4° towards (111). The native oxide on the silicon is removed using a dilute HF etch resulting in a hydrogen passivated surface. The III-V nucleation on the Silicon is achieved by growing a ≈ 10 nm thick AlSb layer at a substrate temperature of 500 °C, followed by the growth of a 1µm thick GaSb buffer layer. The GaSb/Si wafers are then transferred to NRL with an antimony cap to prevent oxidation. An additional GaSb buffer 2-3 µm thick is now grown followed by the ungrouped active ICLED stages. A control structure is also grown to the same 22-stage design on a GaSb substrate. The epi-up ICLED grown on silicon exhibits efficiencies 75% of those for epi-down ICLEDs grown on GaSb when differences in architecture are accounted for. At 100 mA, 200-µm-diameter mesas produce 184 µW CW at 25°C and 140 µW at 85°C.



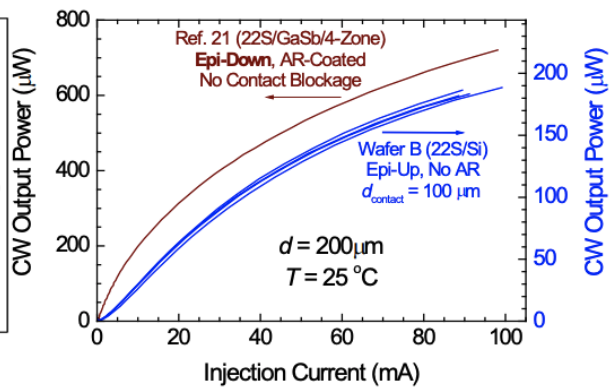


Figure 1 (Left) – Cw L-I characteristics at room temperature for multiple 200-µm-diameter ICLEDs from Wafers A-D on silicon and control Wafer E on GaSb; Figure 2 (Right) - RT cw L-I characteristics of multiple epi-up ICLEDs on silicon, compared to that for an epi-down and AR-coated ICLED on GaSb with active stages divided into 4 groups positioned at antinodes of the optical field, all with 200 µm mesa diameter. Adjustment of the right power scale by a factor of 3.3 accounts for architectural differences.

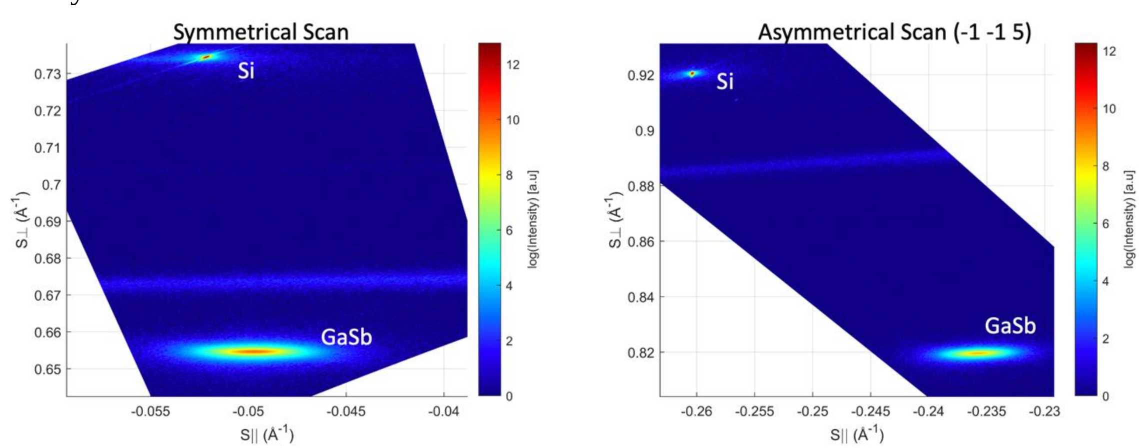
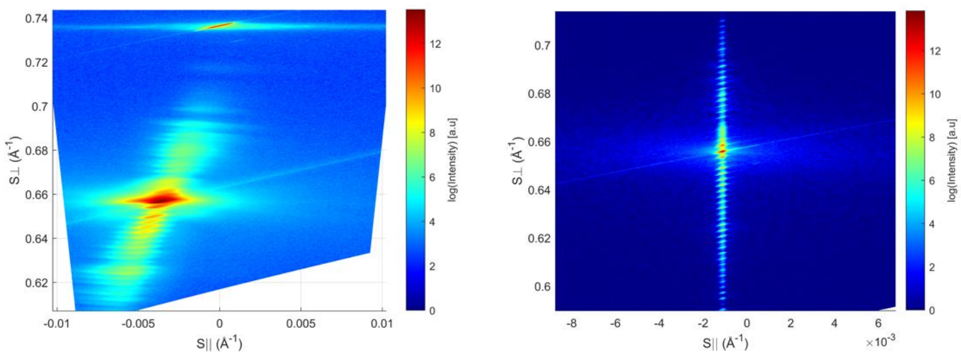


Figure 3 – XRD Reciprocal Space Map of GaSb on Silicon buffer grown at UNM. Threading dislocation density is ~ $10^8/cm^3$ and the GaSb is 99.2% relaxed.



Fgure 4 – (left) RSM of ICLED grown on GaSb buffer on Silicon and (right) RSM of ICLED grown lattice matched on GaSb. There is a reduction in the number of fringes in the metamorphic growth due to undulations in the ICLED structure.