Growth of MWIR ICLEDs on Silicon using Molecular Beam Epitaxy

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Previously, interband cascade light-emitting diodes (ICLEDs) grown on GaSb substrates have been demonstrated as useful emitters in the mid-wave infrared (MWIR) region of 3 – 5 µm for room-temperature (RT) continuous wave (CW) operation [1,2]. Transferring this technology to growth on Silicon substrates would be advantageous for applications in chemical sensing and IR scene projectors (IRSPs), providing improved manufacturability through direct integration onto these circuits. This presentation will discuss the comparison of high-performance ICLEDs grown at NRL on GaSb/Si buffers that were grown at UNM and on lattice-matched GaSb substrates, including L-I characteristics, cross-section transmission electron microscopy (XTEM) and x-ray reciprocal space mapping (RSM).

The growth of GaSb/Si involves GaSb buffer layers which were grown on Silicon (001) with a 4° offcut towards (111). The native oxide was removed using a dilute HF solution to obtain a hydrogen-passivated surface. To achieve III-V nucleation on Silicon, a ~10 nm thick AlSb layer was grown at a substrate temperature of 500°C followed by a 1 µm buffer layer and an antimony cap to prevent oxidation. The GaSb/Si wafers were then transferred to NRL where an additional 2-3 µm GaSb buffer and the ungrouped active ICLED stages were grown. This same 22-stage structure was grown on a GaSb substrate as a control sample. Accounting for differences in architecture, the ICLED structures grown on Silicon show efficiencies that are 75% of those measured in ICLEDs grown on GaSb. At 100 mA, 200-µm-diameter mesas produce 184 µW CW at 25°C and 140 µW at 85°C.

Threading dislocations were observed in GaSb buffer grown on Si from the XTEM images, showing a higher density near the Silicon substrate but reduced near the ICLED. Individual dislocations which reached the active ICLED layers exhibited a multiplying effect throughout the structure. Another growth artifact seen in these images was a slow-varying oscillation in the ICLED layers. Our presentation will provide a detailed explanation for both mechanisms and a comparison of the ICLEDs grown on Silicon to those grown on GaSb. Possible strategies for improving the epitaxial quality and device performance will also be discussed.

[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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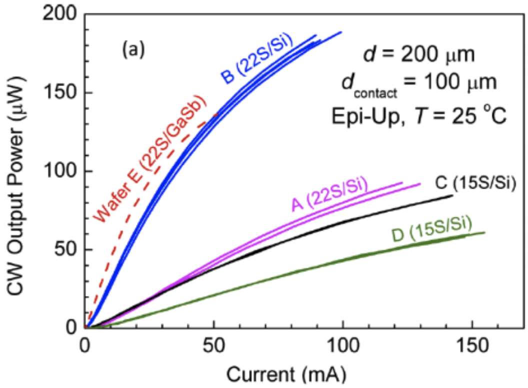

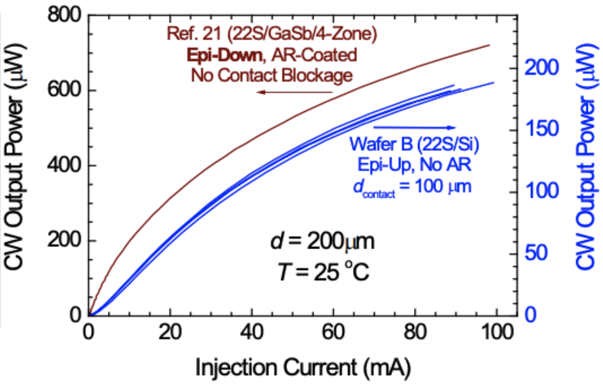

Figure 1 (left) – CW L-I characteristics at room temperature for multiple 200-μm-diameter ICLEDs from Wafers A-D on silicon and control Wafer E on GaSb. Figure 2 (right) - RT CW L-I characteristics of multiple epi-up ICLEDs on Silicon, compared to that for an epi-down and AR-coated ICLED on GaSb, all 200 μm mesa diameter. Adjustment of the right power scale by a factor of 3.3 accounts for architectural differences.

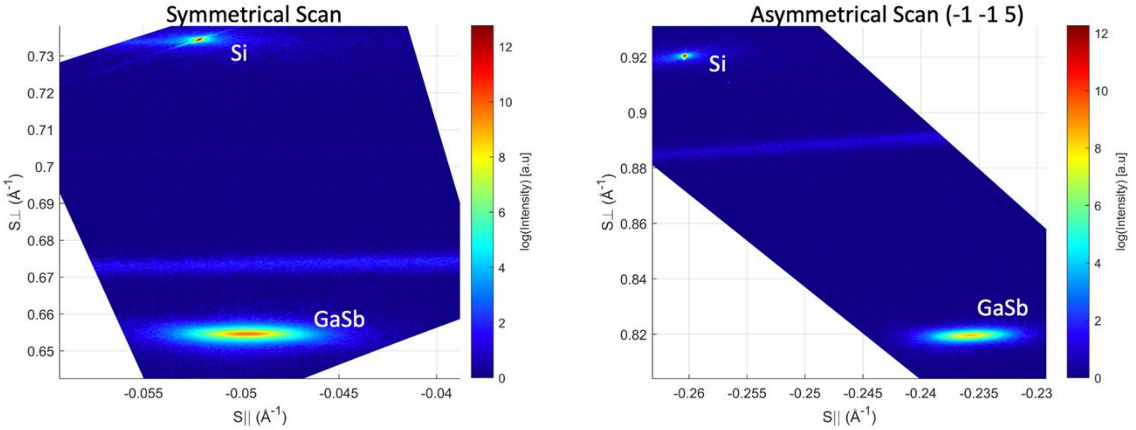

Figure 3 – XRD Reciprocal Space Map of GaSb on Silicon buffer grown at UNM. Threading dislocation density is ~ 10^8/cm^3 and the GaSb is 99.2% relaxed.

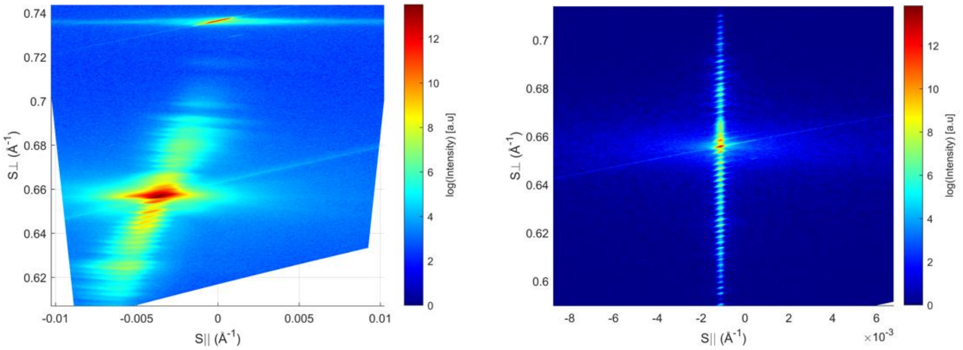

Figure 4 – (left) RSM of ICLED grown on GaSb buffer on Silicon and (right) RSM of ICLED grown lattice matched on GaSb. There is a reduction in the number of fringes in the metamorphic growth due to undulations in the ICLED structure.