

Monolithic III-V/Si Photonics

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Integration of III-V devices on Si substrates has been pursued for over two decades through a variety of methods including monolithic growth and conventional wafer bonding. While wafer bonding techniques allow independent optimization of both device and circuitry, monolithic growth offers better utilization of the integrating platform, lack of complex assembly and better heat dissipation. The monolithic approach utilizing GaAs/AlGaAs has resulted in room-temperature (RT) edge emitting lasers and even vertical cavity lasers (VCSELs) on Si (100). While these early results were encouraging, the device characteristics are marginal due to micro-cracks that result from the large GaAs/Si thermal mismatch and high dislocation density in the GaAs buffer.

Our approach to monolithic III-V growth on Si is fundamentally different from the previously reported work due to the unique growth mode of AlSb on Si compared to GaAs on Si. We utilize a very thin AlSb layer nucleated on Si, which relieves almost the entire strain caused by the 13% lattice mismatch via a 2-D array of 90° misfit dislocations. These dislocations form at the III-V epi/Si interface and propagate within that plane. They do not thread vertically into the material. We have fully characterized this growth mode, which extends to GaSb on GaAs and other highly mismatched systems, and we have developed a theoretical model to support our experimental data. In contrast, GaAs on Si predominantly forms 60° misfits and results in extensive threading dislocations. Apart from an optimized growth mode, the growth of AlSb on Si has another advantage over growth of GaAs on Si in that it has a significantly better thermal expansion coefficient agreement.

We will discuss modeling and epitaxy along with recent device demonstrations including monolithic VCSELs on a Si substrate operating under room-temperature optically-pumped conditions. The 13% lattice mismatch is accommodated by a spontaneously formed 2-D array of 90° misfit dislocations at the AlSb/Si interface. This growth mode produces relaxed (98%), very low defect-density ($\sim 8 \times 10^5/\text{cm}^2$) material indicated in x-ray diffraction, transmission electron microscopy and etch-pitch density measurements. The VCSEL characterization includes lasing spectra and light-in versus light-out curves. A peak threshold excitation density of $I_{\text{th}} = 0.1 \text{ mJ}/\text{cm}^2$ and a multimode lasing spectrum peaked at 1.62 μm , results from a 3 mm pump-spot size.