Monolithic Integration of InGaAs/GaAs/AlGaAs Lasers on Si Substrates

Personnel

M. E. Groenert (E. A. Fitzgerald)

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The fiber optic revolution of the last 25 years has been enabled in part by the development of inexpensive and highly reliable solid-state semiconductor lasers. Unfortunately the large difference in lattice constants between direct-gap III-V compounds and silicon has prevented the monolithic integration of semiconductor lasers with Si-based logic circuits. The promise of complete single-chip optoelectronic integration of high-speed Si and SiGe processors with high-bandwidth III-V lasers remains obstructed by the basic lattice constant mismatch between these two materials systems.

Continuing research in our group has investigated the use of GeSi alloys as buffer layers for accommodating III-V/Si lattice mismatch strain. Using relaxed graded Ge/GeSi buffer layers on a Si substrate, AlGaAs/GaAs quantum well lasers have been demonstrated on Si for the first time. Despite un-optimized laser structures demonstrating high series resistance and large threshold current densities, measured surface threading dislocation densities on the order of 2x106 cm-2 have enabled cw room-temperature lasing at a wavelength of 858nm.

The laser structures are oxide-stripe gain-guided devices with differential quantum efficiencies of 0.13 and threshold current densities of 577 A/cm2. Identical devices grown on commercial GaAs substrates showed differential quantum efficiencies of 0.19 and threshold current densities of 529 A/cm2. GaAs/Ge/Si integration issues including thermal expansion mismatch, facet mirror cleaving on offcut Si substrates and Ge autododping behavior in GaAs have been overcome. Improved devices with lower series resistance have been fabricated demonstrating differential quantum efficiencies of 0.20 and threshold current densities of 269 A/cm2. Lower series resistance has also enabled an order of magnitude improvement in device lifetime, which appears to be limited by dark-line-defect (DLD) formation in the active regions. Compressively strained InGaAs/GaAs/AlGaAs quantum well lasers have been demonstrated as well, with cw threshold current densities of 700 A/cm2 and differential quantum efficiencies of 0.13 at a wavelength of 890nm. Preliminary lifetime results indicate that InGaAs laser performance and lifetime may be limited by misfit dislocation formation in the quantum well active regions.

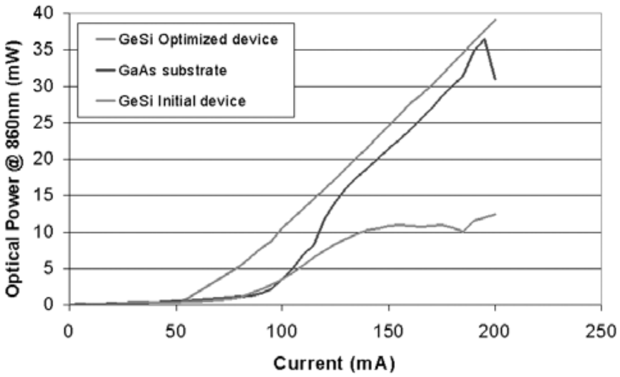

Fig. 48: L-I curves for devices grown on GaAs and Ge/GeSi/Si substrates. Optimized devices on Ge/GeSi/Si show reduced series resistance, increased efficiency, and a dramatic improvement in cw device lifetime.