Record lifetimes of GaAs based lasers epitaxially grown on silicon

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Early GaAs based quantum well lasers epitaxially grown on silicon rapidly degraded within a few seconds [1]. Since then, significant improvements in device characteristics such as threshold, output power, and slope efficiency have been made due to improved material growth and fabrication. However, the short lifetimes of such lasers remain an outstanding issue, with the longest reported operating lifetime in continuous wave operation being around 80 hours near room temperature prior to total device failure [2].

To meet commercial reliability standards, operating lifetimes upwards of thousands of hours in rigorous testing conditions are required to insure low field failure rates. InAs/GaAs quantum dot lasers have shown remarkably long lifetimes in spite of defect densities deemed too high for quantum well lasers [3]. Consequently, we postulate that the lifetimes of GaAs based lasers on silicon may be enhanced using quantum dot active regions in place of quantum wells. Here we report the first study on the reliability of quantum dot lasers epitaxially grown on silicon.

Ridge waveguide lasers were fabricated from 1.3 μm InAs quantum dot laser material grown on Ge/Si substrates by molecular beam epitaxy. These devices have demonstrated high output powers (>170 mW) and high temperature lasing (up to 120 C) while maintaining low thresholds; the former two are records among lasers on silicon [4]. These characteristics were obtained despite the high density (>10^8 cm^{-2}) of threading dislocations present in the active region observed in cross sectional transmission electron microscope images. 15 devices were randomly selected for aging in continuous wave operation, five of which are quantum dot lasers grown on GaAs substrates for comparison. All devices are aged at 30^{o}C under 100 mA of constant applied current (1-2.5 kA/cm^2 depending on device size). The initial output powers at these conditions varied from 3-24 mW. Degradation is monitored by periodic LIV sweeps at 30^{o}C. We define failure as a maximum output power <1 mW).

At the moment of this writing, the longest aged device has surpassed 1,500 operating hours, nearly 20 times improvement over the previously reported longest lifetime [2]. We have not yet observed any catastrophic failures corresponding to a sharp decrease (increase) in output power (threshold)[2,5]. Failed devices are instead due to gradual degradation occurring over a much longer time scale (~300 hours for the shortest lived device). So far three devices on silicon have failed, while the others have all surpassed 1000 hours of testing. For comparison, a GaAs/AlGaAs quantum well laser grown on Ge/GeSi/Si substrates similar to ours and also aged at constant current (~2 mW initial output power at RT) reported a lifetime of 4 hours prior to catastrophic failure, indicating a huge advantage to quantum dot lasers. Detailed aging data and device performance will be presented along with an analysis of the device degradation.

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