Continuous-wave operation of extremely low-threshold GaAs/AlGaAs broad-area injection lasers on (100) Si substrates at room temperature

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Room-temperature continuous-wave operation of large-area (120 μm × 980 μm) GaAs/AlGaAs graded-refractive-index separate-confinement heterostructure lasers on (100) Si substrates has been obtained. Minimum threshold-current densities of 214 A/cm² (1900-μm cavity length), maximum slope efficiencies of about 0.8 W/A (600-μm cavity length), and optical power in excess of 270 mW/facet (900-μm cavity length) have been observed under pulsed conditions.

Semiconductor optoelectronics, particularly for optical interconnects, can be made compatible with Si technology, provided that high-quality light emitters such as GaAs/AlGaAs lasers are achieved on Si substrates. To this end, various researchers have focused on GaAs/AlGaAs lasers as the potential device as well as a test of material quality.[1–4] Dislocations, strain, and other defects present in the material, however, have kept the threshold-current densities high and limited the measurements to pulsed conditions. In this Letter we present results on extremely low-threshold current lasers and the first report to our knowledge of continuous wave (cw) operation of a GaAs/AlGaAs/Si injection laser at room temperature.

The epitaxial structures were grown by molecular-beam epitaxy (MBE) on (100) Si tilted by 4° toward (110). The substrate cleaning procedure and growth conditions used were similar to those of Ref. 5. The graded-refractive-index separate-confinement heterostructure laser consisted of a 7-nm quantum-well, 350-nm parabolic graded region and a 1.5-μm cladding AlGaAs layer on each side of the confining structure. The thickness of the GaAs buffer layer ranged between 2 and 2.5 μm. Broad-area devices having a width of 120 μm and a cavity length that varied between 500 and 1900 μm were fabricated by a standard fabrication and cleaving procedure. Virtually all the 10 or so wafers grown with different MBE deposition conditions exhibited threshold-current densities below 1000 A/cm². In the best wafer, threshold-current densities as low as 214 A/cm² were obtained, as determined from the sudden onset of laser spectral lines atop the spontaneous recombination background. The light-current characteristic of this particular laser, measured under pulsed conditions, is shown in Fig. 1. The peak power and the average power (within the electrical pulse) are plotted against the injection currents with thresholds of 263 and 323 A/cm², respectively.

At low duty cycles (≤0.1%) and pulse widths of about 200 nsec, the lasing action started at the trailing edge of the current pulse and spread into a square response when the current intensity was increased, indicating that the leading edge of the pulse was used to saturate the absorption caused by defects. When the pulse width was increased, this effect obviously was not so relevant. Near and at cw operation, the saturable absorber does not affect the results noticeably.

The thermal properties of lasers taken from this wafer were such that broad-area lasers with varying cavity lengths can be run at room temperature (300 K) under 30%-duty-cycle pulsed conditions on the probe station without any apparent degradation of lasing threshold and output power.

A 120 μm × 980 μm broad-area laser was operated cw at room temperature after being mounted upside down on a diamond heat sink with In. The laser survived a number of repeat performances. Figure 2 shows the cw laser spectrum obtained by a spectrometer with an optical multichannel analyzer. The horizontal scale is 10 nm in total. The laser was biased at

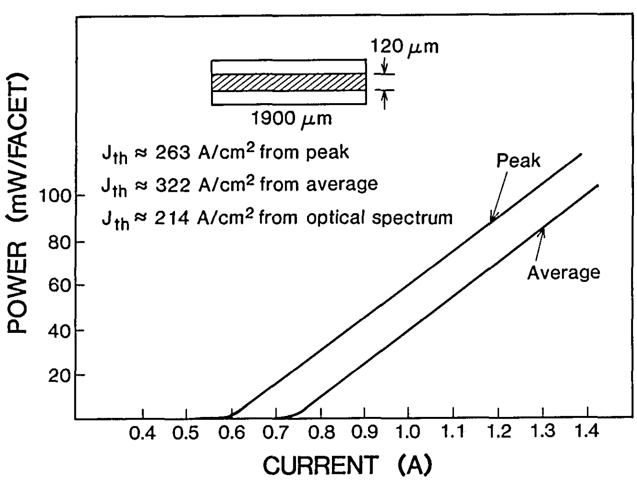

Fig. 1. Light-current characteristics of a long-cavity broad-area laser.

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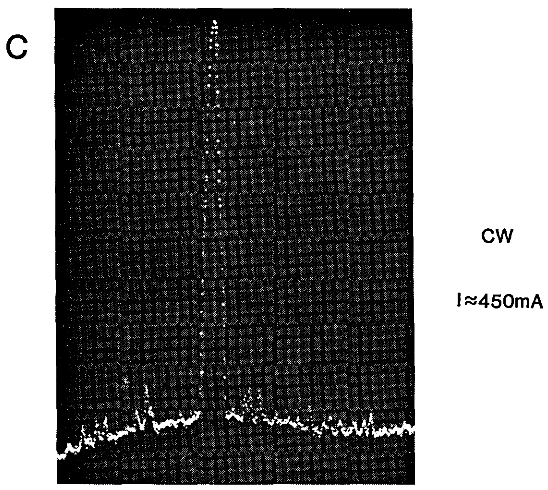

Fig. 2. Laser spectrum under cw operation. The center of the wavelength is at 840.4 nm.

150% of I_{th} at room temperature and operated on four different occasions for a total of 4 min with little measurable degradation of performance. The cw threshold current of this particular laser was 350 mA.

For comparison, identical lasers were also grown and fabricated on GaAs substrates. Threshold-current densities as low as 140 A/cm^2 were obtained in devices with cavity lengths of about 1000 μm, and densities of 85 A/cm^2 were obtained in an extremely long cavity of 8 mm.

Comparisons of lasers on Si and GaAs substrates indicate that those on GaAs have lower threshold characteristics. Threshold currents of devices on GaAs substrates under pulsed and cw conditions were identical. However, devices on Si substrates suffered a one-time increase as determined by the spectrum method in the pulsed threshold current of 3% after the cw operations. The origins for this increase are not understood. The difference between the pulsed and cw threshold currents in our devices indicates that the thermal contact in our lasers is still a problem. We are currently concentrating our attention on improved bonding and various schemes for reducing and arresting defect propagation. In shorter broad-area lasers, total slope efficiencies of as high as 0.8 W/A (quantum efficiency $\approx$ 57%) and output powers of 270 mW (900-μm cavity length) were also obtained under pulsed conditions.

In conclusion, we have demonstrated threshold-current densities of GaAs/AlGaAs on Si lasers that are comparable with those on GaAs substrates. We have also achieved cw operation of broad-area (120 μm $\times$ 980 μm) lasers on Si substrates at room temperature. The lasers are still alive.

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