Bipolar cascade lasers at emitting wavelengths near 2 μm

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Near-IR bipolar cascade lasers have recently been investigated [1-5] for some potential advantages such as high output power and increased quantum efficiency compared to conventional diode lasers. A quantum efficiency that may be greater than unity was explicitly pointed out by van der Ziel and Tsang two decades ago [6] when they studied monolithic integrated GaAs diode lasers with tunnel junctions. In this work, we investigate a bipolar cascade laser in the wavelength region of near 2 μm. This wavelength region is important for chemical sensing and wind profile lidar.

The bipolar cascade laser structure was grown by metalorganic vapor phase epitaxy (MOVPE) on S doped n-type InP (001) substrate. The laser consists of two identical separate-confinement quantum well (QW) laser structures coupled by a 100-nm-thick tunnel junction that is composed of 50-nm Zn-doped ($1x10^{18}$) InP and 50-nm Si-doped ($4x10^{18}$) InP layers. After the growth, the sample was processed into 150-μm-wide and ~1.1-mm-long mesa-stripe devices with both facets left uncoated. The laser was operated in cw mode at heat-sink temperatures up to 205 K. Fig. 1 shows current-voltage-light characteristics of a laser at a heat-sink temperature range from 120 to 200 K. Its differential external quantum efficiency (DEQE) exceeded 70% at 150-170 K, suggesting possible internal quantum efficiency greater than unity. The threshold voltage was ~6.4-7.3 V in this temperature range, which is several times higher than the minimum voltage (~1.33-1.28 *V*) required in the ideal case (number of cascade stages multiplied by the photon energy in *eV*). This large excess voltage resulted from large resistance of the tunnel junction where the doping concentrations were not high enough to have efficient carrier transport between the two serially stacked laser regions at a low bias. The combined effects of large voltage and current for this broad-area laser limited its maximum cw operation temperature to 205 K.

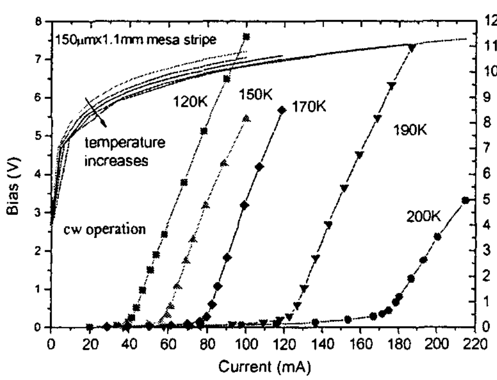

Fig. 1. Current-voltage-light (*I*-V-*L*) characteristics of a 150-μm-wide and 1.1-mm-long mesa-stripe laser in cw mode at several temperatures.

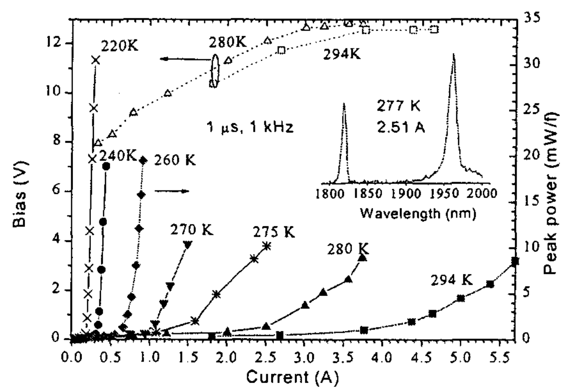

Fig. 2. Current-voltage-light (*I*-V-*L*) characteristics of a 150-μm-wide and 1.1-mm-long mesa-stripe laser in pulsed mode at several temperatures. The inset is its lasing spectrum at 277 K and with a current of 2.51 A.

When the laser was operated under pulsed conditions (1-μs-long current pulses at 1 kHz), it could lase at significantly higher temperatures. Fig. 2 shows its current-voltage-light characteristics at a temperature range from 220 to 294 K. Its DEQE was greater than 90% at 220 K and is better than the value in cw mode. However, the DEQE decreased significantly when the temperature was raised above 270 K. In addition, at 277 K as shown in the inset of Fig. 2, a lasing peak emerged at a short wavelength (~1.82 μm) with comparable emission intensity in respect to the main lasing peak (~1.96 μm). When the temperature was raised to 280 K and above, the emission peak at the short wavelength became dominant as shown in Fig. 3 and the emission peak at the long wavelength disappeared. The emission intensity at the short wavelength became stronger when the temperature was raised from 294 to 300 K. This suggested that the transitions involving an excited state in QW active regions might be responsible for the emission peak at the short wavelength since the excited state is populated with more carriers at the higher temperature. This is consistent with our observation of that the emission peak at the short wavelength was much (~an order magnitude) smaller than the fundamental emission peak at temperatures of 275 K and below (Fig. 4). Also, high currents with large bias were required for the emission at the short wavelength. This resulted in a strong electric field in QW active regions, which broke its symmetry and significantly changed the selection rules of optical transitions in symmetric QWs.

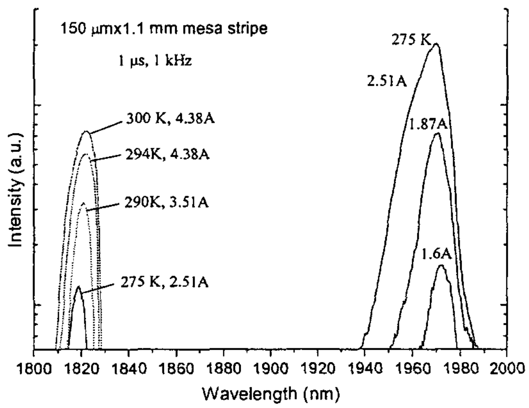

Fig. 3. The pulsed lasing spectra in temperature range from 275 to 300 K. Notice that the vertical axis is logarithmic.

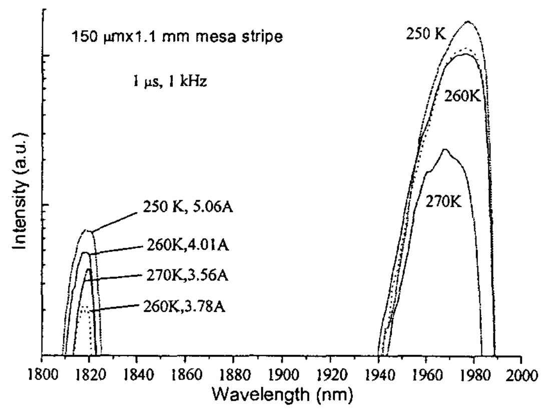

Fig. 4. The pulsed lasing spectra in temperature range from 250 to 270 K. Notice that the vertical axis is logarithmic.

In conclusion, broad-area InGaAs/InP based bipolar cascade lasers at emitting wavelength near 2 μm have been investigated, which exhibited dual wavelength lasing depending on temperature and injection current. We hope that the rich features exhibited by this bipolar cascade laser would stimulate further theoretical and experimental efforts, leading to better understanding and improved laser devices.

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