Thin Top-Cladding Interband Cascade Lasers Operating at Room Temperature

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Mid-IR Sb-based Interband cascade (IC) lasers [1] that combine the advantages of quantum cascade (QC) lasers [2] and type-II quantum well interband lasers were projected by simulations [3,4] to operate in cw mode up to room temperature with high output power. These lasers would enable many useful applications such as chemical sensing and environmental monitoring. Significant advances toward such a high performance level have recently been reported [5-8] in terms of large peak output power, power conversion efficiency, low threshold current density (e.g. ~9 A/cm^2 at 80 K), and high temperature operation (e.g. 325 K in pulsed and 200 K in cw modes). Here, we will report the demonstration of type-II IC lasers with a thin top-cladding layer operating at temperatures up to 310 K near 3.53 μm.

In contrast to previous IC lasers [5-8] with a thick InAs/AlSb superlattice (SL) top cladding layer (>1 μm), a thin InAs/AlSb SL layer (~0.3 μm) was grown on an 18-stage type-II IC laser structure by molecular beam epitaxy (MBE) on a GaSb substrate. The use of thin top-cladding layer can facilitate the integration distributed feedback (DFB) gratings into the laser with significant grating coupling coefficient without the need of deep etching for gratings. However, the top metal contact will be close to the active region and thus introduce a large waveguide loss. To minimize this loss, SiO_2 layers were deposited on the sidewalls of mesa stripes and metal contacts were connected to top edges of mesa stripes as employed previously for a QC laser [9]. Since the in-plane conductivity is significantly higher than the vertical one in InAs/AlSb SL, lateral current injection and distribution throughout the device are expected to be very good. A laser bar was cleaved from this sample to 1-mm-long with different mesa stripe widths and was then mounted as a single piece epi-layer-side up on Cu-blocks for testing.

Devices with mesa stripe widths of 110, 50, 30 μm on the same laser bar made from this sample lased in cw mode at temperatures up to 165, 175, 185 K, respectively. The higher cw operation temperature with the narrower mesa was due to the reduction of total heat generated with the lower threshold current when compared to wider-mesa stripe lasers. Fig. 1 shows current-voltage-light characteristics of the 30-μm-wide and 1-mm-long mesa stripe laser at a heat-sink temperature range from 80 to 185 K. Significant output power (>60 mW at 80 K; ~0.7 mW at 185 K) was obtained from the device. The high-resolution lasing spectrum (near 3.4 μm) of the device at 185 K is plotted in Fig. 2, showing constructive and destructive interference of optical modes within the Fabry-Perot cavity.

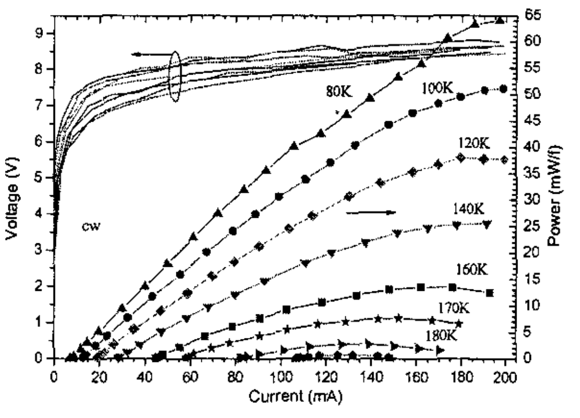

Fig. 1. Current-voltage-light (*I*-V-*L*) characteristics of a 30-μm-wide and 1-mm-long mesa-stripe laser in cw mode at several temperatures.

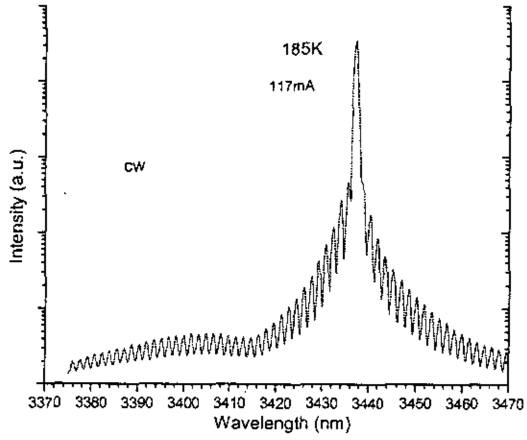

Fig. 2. The high-resolution lasing spectrum of a 30-μm-wide and 1-mm-long mesa-stripe laser in cw mode at 185 K.

The laser with a narrow mesa stripe width (e.g. 30-μm) exhibited relatively larger threshold current density compared to the wider mesa stripe (e.g. 110-μm) laser as shown in Fig. 3. This might be caused by the increased loss per volume from sidewall surfaces and top edge contacts. Nevertheless, the 30-μm-wide mesa stripe laser was able to lase in pulsed mode (with 1 μs current pulses at 1 kHz) at temperatures up to 310 K with a emission wavelength of ~3.53 μm as shown in Fig. 4, the highest among III-V diode lasers at this wavelength. This indicates sufficient optical gain available to compensate the waveguide loss from various mechanisms in the device over a wide range of temperature. Higher temperature operation is possible since it was not operated to its maximum operation temperature to avoid accident damage with circuit ringing under large current pulses.

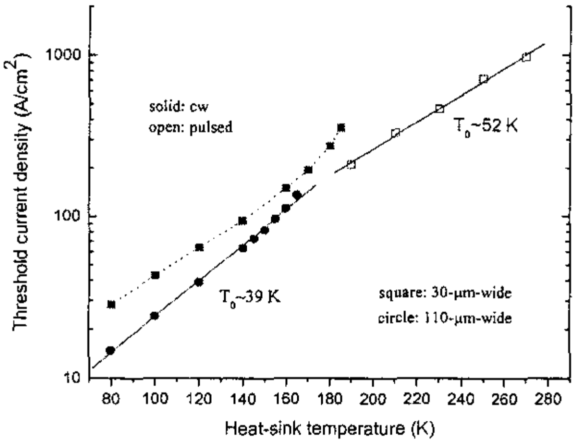

Fig. 3. Threshold current density vs. heat-sink temperature for a 110- and a 30-μm-wide mesa stripe lasers in pulsed and cw modes.

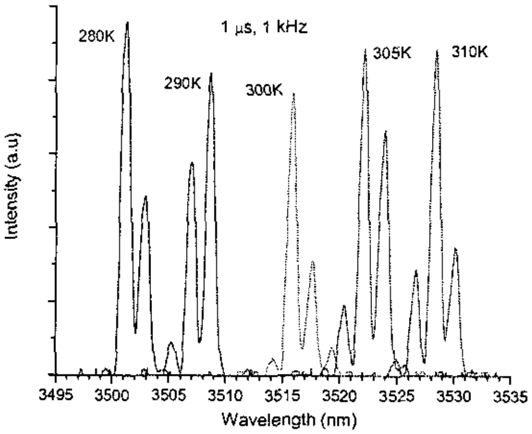

Fig. 4. Lasing spectra of a 30-μm-wide and 1-mm-long mesa-stripe laser in pulsed mode at several temperatures.

In conclusion, thin top-cladding mid-IR IC lasers have been demonstrated at temperatures up to 310 K. Our preliminary results showed that their performance is comparable to thick cladding IC lasers, which should lead to the ease of fabricating DFB lasers. The detailed characteristics of these lasers and updated results will be presented.

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