Continuous-wave operation of InAs-based interband cascade lasers above room temperature

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Abstract: Pulsed and continuous wave operations of InAs-based interband cascade lasers were demonstrated at temperatures up to 377 and 308K, respectively, with low threshold current densities (278 A/cm^2) at 300K at wavelengths around 4.7 µm.

With multiple type-II active regions connected in series, interband cascade (IC) lasers [1] have been developed as efficient semiconductor mid-infrared laser sources for a variety of applications such as environmental monitoring, life science and planetary exploration [2]. In the last decade, the threshold current densities of GaSb-based IC lasers at room temperature (RT, 300 K) had been reduced to 630 A/cm^2 [3], 400 A/cm^2 [4], 170 A/cm^2 [5] and ~100 A/cm^2 [6], all at wavelengths below 4 µm. Such a low threshold has significant benefits to lowering power consumption and to achieving high continuous wave (cw) operating temperature (e.g. 388 K [7]), high wall plug efficiency (e.g. 15% at RT [7]) and high output power (e.g. 592 mW at RT [8]). Extending the wavelength beyond 4 µm becomes difficult for GaSb-based IC lasers because the thick InAs/AlSb superlattices (SLs) required as optical cladding layers have low thermal conductivity and are challenging to grow by molecular beam epitaxy (MBE). Alternatively, InAs-based IC lasers with highly doped InAs as the optical cladding layer have been demonstrated in the wavelength range from 3.3 µm to 11 µm [9-10]. RT operation in pulsed mode has been achieved beyond 5 µm [11], 6 µm [12] and 7 µm [13]. In this work, we report the first demonstration of InAs-based IC lasers operating above room temperature in cw mode. This marks an important milestone for InAs-based IC lasers.

Two sets of IC laser structures, comprised of 12 (R142, R143) and 10 (R144, R145) cascade stages, were grown in a Gen II MBE system on *n*-type InAs (001) substrates, with an n$^+$-type InAs bottom cladding layer (1.6 µm and 1.2 µm thick for the 10-stage and 12-stage sets, respectively) that was doped with Si to 1.5×10^{19} cm^{-3}. The thicknesses of the separate confinement layers (SCLs) were adjusted to obtain appropriate optical confinement for each set of IC lasers. In each set, the central three InAs quantum wells (QWs) in the electron injector of every cascade stage were doped with Si to 3.3×10^{18} or 1.6×10^{18} cm^{-3} for examining carrier rebalancing [5] in InAs-based IC lasers. After growth, the wafers were processed into deep-etched broad-area (150- and 100-µm-wide) mesa stripes and narrow-ridge (10-, 12-, 15-, 20-µm-wide) lasers by contact photolithography and wet chemical etching. The processed wafers were cleaved into laser bars with cavity lengths of 1.5 to 3.5 mm, uncoated facets and epi-side-up mounting on copper heat-sinks for measurements.

In pulsed operation, 100-µm-wide and 2-mm-long devices made from each set of wafers had threshold current densities J_{th} as low as 290 A/cm^2 near 4.7 µm at 300 K. A 150-µm-wide device exhibited a RT threshold current density of 278 A/cm^2, the lowest ever reported among mid-infrared semiconductor lasers at similar wavelengths. One device from R144 lased at temperatures up to 377 K near 5.1 µm, the highest operating temperature reported for electrically-pumped interband lasers at this wavelength. In Fig. 1, threshold current densities for several representative devices are plotted as a function of heat-sink temperature T. Their characteristic temperature (T_0) (in the neighborhood of 300 K) was in the range of 46-57 K, comparable to that of state-of-the-art GaSb-based IC lasers in the 3-4 µm wavelength region [14].

Narrow-ridge devices with a top layer of ~4-µm-thick electroplated gold were able to lase in cw mode at RT in a wavelength range from 4.6 to 4.9 µm. As shown in Fig. 1, the cw operating temperatures achieved from the 10-stage lasers were higher than those from the 12-stage lasers. Figure 2 shows the cw current-voltage-light (*I-V-L*) characteristics of a 10-µm-wide and 3.5-mm-long device (from wafer R144) at several heat-sink temperatures. The inset shows its cw lasing spectra at temperatures up to 308 K near 4.85 µm. By comparing threshold current densities in cw and pulsed modes, the specific thermal resistances were deduced to be in the range of 6.5 to 11.5 Kcm^2/kW for the laser characteristics shown in Fig. 2. This is higher than for GaSb-based IC lasers in the 3-4 µm wavelength region with a similar size and thicker SL claddings, which suggests further room for improvement. More details and the latest results will be reported at the conference.

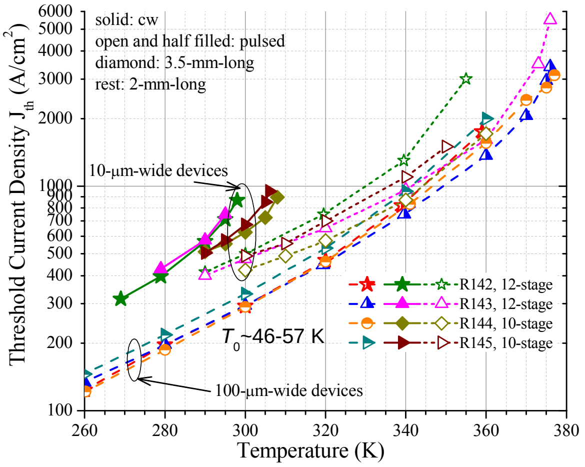

Fig. 1. Threshold current density vs heat-sink temperature for both broad-area and narrow-ridge lasers.

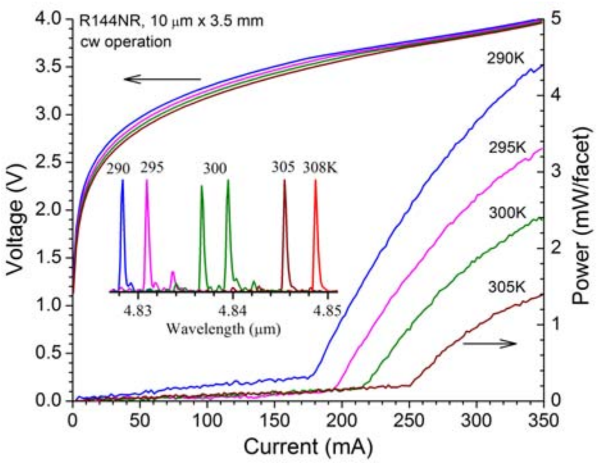

Fig. 2. Current-voltage-light characteristics for a 10-µm-wide and 3.5-mm-long device (from wafer R144) in cw operation. Inset: cw lasing spectra near threshold.

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