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Progress of Sb-based Type-II Mid-IR Interband Cascade Lasers

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Interband cascade (IC) lasers that utilize optical transitions between the conduction and valence bands in a staircase of Sb-based type-II quantum wells (QWs) [1] represent a new class of mid-IR diode lasers. By combining the advantages of quantum cascade (QC) lasers [2] and type-II quantum well interband lasers, type-II IC lasers were projected by simulations [3,4] to operate in cw mode up to room temperature with high output power. Although significant advances toward such a high performance level have been reported [5] in terms of high peak output power and power conversion efficiency, the amount of effort expended in developing Sb-based IC lasers is very limited in contrast to other semiconductor lasers such as InP- and GaAs-based QC lasers, and their performance is still far from the theoretical projections. Here, we will report the progress of Sb-based type-II mid-IR IC lasers made at the Jet Propulsion Laboratory.

We have recently grown type-II IC laser structures using molecular beam epitaxy (MBE) on GaSb and GaAs substrates. The laser samples have been examined by x-ray diffractometry and exhibited many sharp satellite peaks, indicating good crystal structural quality. Broad area stripe lasers were made from the IC laser samples and mounted on Cu-blocks for testing. Lasers made from those samples lased in a wavelength range from ~2.8 to 4.1 μm in a wide temperature range up to 325 K, the highest reported operation temperature to date for electrically pumped interband III-V mid-IR lasers. Fig. 1 shows the pulsed lasing spectra of a 15-stage laser in the wavelength (λ) range from ~3.21 to 3.27 μm, red shifting when the temperature was raised from 260 to 325 K with a rate (dλ/dT) of ~0.9 nm/K. This laser was also operated in cw mode at heat-sink temperatures up to 165 K, higher than previous records (~150 K) for early type-II IC lasers [5]. Fig. 2 shows current-voltage-light characteristics of a 150-μm-wide and 1-mm-long mesa stripe laser at a heat-sink temperature range from 80 to 160 K. The inset of Fig. 2 is the high-resolution lasing spectrum at 160 K, showing constructive and destructive interference of optical modes within the Fabry-Perot cavity. The separation between adjacent longitudinal modes is ~14 Å, in good agreement with the calculated value for a 1-mm-long cavity. The output power exceeded 100 mW/f at 80 K.

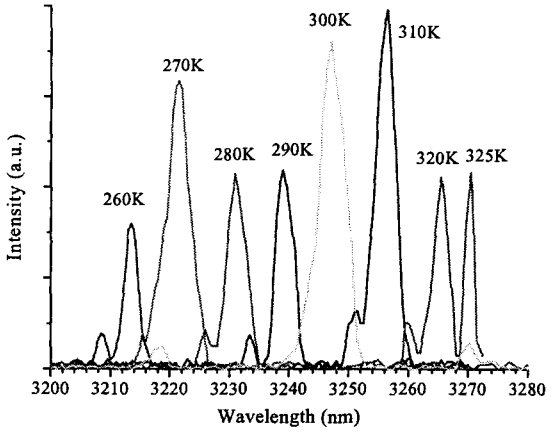

Fig. 1. Lasing spectra from a 150-μm-wide and 0.8-mm-long mesa-stripe laser in pulsed mode (1 μs, 1 kHz).

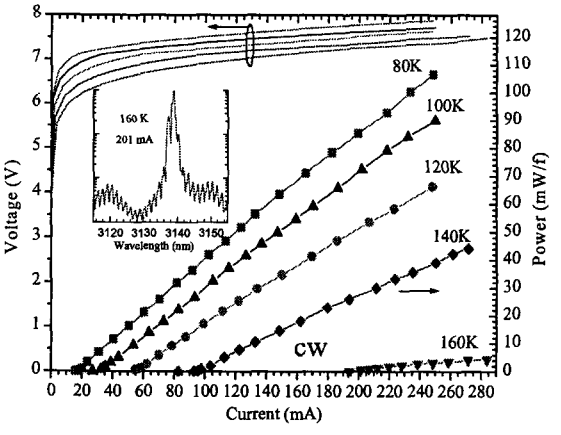

Fig. 2. Current-voltage-light (*I*-V-*L*) characteristics of a 150-μm-wide and 1-mm-long mesa-stripe laser in cw mode at several temperatures and its high-resolution lasing spectrum (inset) at 160 K.

The lasers made from a 23-stage IC laser sample grown on a GaAs substrate also exhibited good performance. Our preliminary testing has demonstrated that these IC lasers on GaAs substrates can be operated at temperatures up to at least 250 K at wavelengths near 4 μm in pulsed mode as shown in Fig. 3. These suggest the possibility of integrating type-II IC lasers with GaAs- and InP-based electronic circuits. At present, these IC lasers on GaAs substrates have relatively higher threshold voltages (>11 V) and currents compared to similar IC lasers grown on GaSb substrates. The IC lasers with the same nominal cascade structure grown on a GaSb substrate can lase at temperatures up to 300 K at a wavelength near 4.1 μm. Also, the 23-stage IC lasers on GaSb substrates were operated in cw mode at temperatures up to 140 K at a wavelength near 3.8 μm. Fig. 4 shows current-voltage-light characteristics of a 150-μm-wide and 1-mm-long mesa stripe laser (on GaSb substrate) at a heat-sink temperature range from 80 to 130 K. A very low threshold current density (e.g. ~10 A/cm^2 at 80 K) was achieved with large output power (> 80 mW at 80 K). The output power can be further increased since the device was operating far from saturation. The threshold voltage was less than 9 V, only about 1 V higher than the minimum voltage required in an ideal case (23 stages multiplied by the photon energy in eV), indicating an efficient use of applied bias.

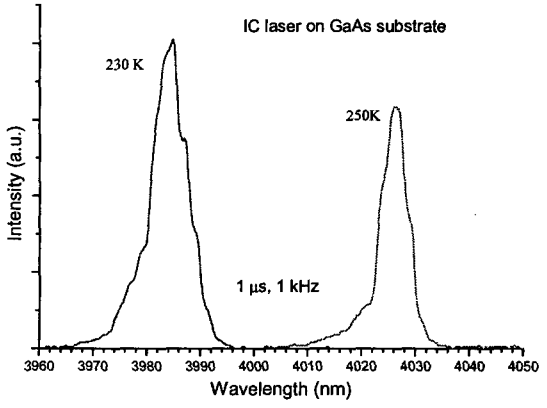

Fig. 3. Lasing spectra of a 150-μm-wide and 1-mm-long mesa-stripe laser (on GaAs substrate) in pulsed mode at 230 and 250 K.

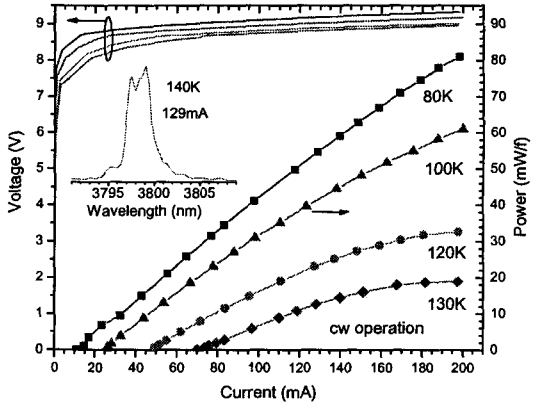

Fig. 4. Current-voltage -light characteristics of a 150-μm-wide and 1-mm-long mesa-stripe laser (on GaSb substrate) in cw mode at several temperatures and its lasing spectrum at 140 K (inset).

In conclusion, significant progress has been made in Sb-based type-II IC lasers in terms of both high operation temperatures and low threshold current density. The maximum cw operation temperature can readily be raised with the fabrication of narrow-stripe lasers. Our preliminary result showed that a 30 μm-wide mesa stripe laser was able to lase in cw mode at heat-sink temperatures up to 200 K. The detailed characteristics of these lasers and updated results will be presented.

1. R. Q. Yang, at *7th Inter. Conf. on Superlattices, Microstructures and Microdevices*, Banff, Canada, August, 1994; Superlattices and Microstructures **17**, 77 (1995).
2. J. Faist, F. Capasso, D. L. Sivco, C. Sirtori, A. L. Hutchinson, and A. Y. Cho, Science **264**, 553 (1994).
3. J. R. Meyer, I. Vurgaftman, R. Q. Yang, and L. R. Ram-Mohan, Electron. Lett. **32**, 45 (1996).
4. I. Vurgaftman, J. R. Meyer, and L. R. Ram-Mohan, IEEE Phot. Tech. Lett. **9**, 170 (1997).
5. R. Q. Yang, J. L. Bradshaw, J. D. Bruno, J. T. Pham, D. E. Wortman, IEEE J. Quantum Electron. **38**, 559 (2002); and references therein.