Room-Temperature InAs-based Interband Cascade Lasers

Yuchao Jiang[a], Lu Li[a], Zhaobing Tian[a], Robert T. Hinkey[a,b], Rui Q. Yang [a], Tetsuya D. Mishima[b], Michael B. Santos[b], Matthew B. Johnson[b], and Kamjou Mansour[c]

(a) School of Electrical and Computer Engineering, University of Oklahoma, Norman, OK 73019
(b) Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK 73019
(c) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109
Rui.Q.Yang@ou.edu

Abstract: We report the demonstration of InAs-based interband cascade lasers at temperatures up to 315 K and 253 K operating in pulsed and continuous wave modes, respectively, near 5.3 microns.

Interband cascade (IC) lasers [1] are emerging as efficient semiconductor laser sources in the mid-infrared wavelength region for a variety of applications such as environmental monitoring, life sciences and planetary exploration. Unlike quantum cascade (QC) lasers based on intersubband transitions, IC lasers use interband transitions for photon emission without involving fast phonon scattering. Consequently, IC lasers have a low threshold current density and low power consumption with fewer cascade stages compared to QC lasers. Recent achievements in the development of IC lasers include continuous wave (cw) operation beyond room temperature and up to 380 K [2-5] near the 4 micron wavelength region. For longer wavelengths, these IC lasers that are grown on GaSb substrates and use InAs/AlSb superlattices (SLs) as optical cladding layers will exhibit lower cw operating temperature and output power due to the poor thermal conductivity of thick SL cladding layers. Anticipating the performance limitations of longer-wavelength lasers with this SL cladding layer, we have carried out the exploration and development of IC lasers grown on InAs substrates with the use of a highly doped n^{++}-type InAs plasmon layer as the optical cladding layer, which lowers the thermal resistance of IC lasers and extends the operation of IC lasers to longer wavelengths [6-7]. Here, we report the demonstration of InAs-based IC lasers near 5.3 microns lasing at temperatures up to 315 K and 253 K in pulsed and cw modes, respectively. In addition, we report our studies of these IC lasers with two different waveguide configurations.

Two sets of IC laser structures, comprised of 10 and 12 cascade stages, were grown in a Gen II molecular beam epitaxy (MBE) system on *n*-type InAs (001) substrates with a 1.6-μm-thick n^{++}-type InAs bottom cladding layer whose electron carrier density was 1.0×10^{19} cm^{-3} by means of Si doping. Each set consisted of two wafers that had the same cascade region, but different top cladding layers: one with a highly doped n^{++}-type InAs layer (wafer A for a 10-stage laser, wafer C for a 12-stage laser); the other without the top semiconductor plasmon cladding layer (wafer B for a 10-stage laser, wafer D for a 12-stage laser). We have made adjustments to the cascade region design used in our earlier plasmon-waveguide IC lasers. These modifications include a shortening of the AlSb/InAs SL electron injector region, and the enhancement of the hole injector (which acts as a barrier for suppressing electron leakage) by using a two quantum well configuration [4]. The cascade region is designed and grown with Al(Ga)As interfaces to achieve strain-balance.

After growth, the wafers were processed into ridge waveguide lasers, with various widths (*e.g.* 15 to 40 μm), with a SiO_2 insulation layer and metal contacts on the top layer and bottom substrate. The top metal contact window is about 2-3-μm wide near the edges (for 20, 30, 40-μm-wide ridges) or near the center (for the narrower ridges). As such, the SiO_2 insulation layer underneath the contact metal pad covers the majority of the laser ridge and serves as the cladding layer for the laser. Based on our two-dimensional waveguide simulations for transverse electric (TE) modes, the confinement factors are nearly equal for each of the waveguide configurations, regardless of whether the top semiconductor plasmon cladding layer is included or not. The calculated waveguide loss is ~ 1.0-1.5 cm^{-1} lower (depending on the ridge width) for IC lasers without the top semiconductor plasmon cladding layer.

The processed wafers were cleaved into laser bars with cavity lengths of 1-3 mm with facets left uncoated and mounted epi-side-up on copper heat-sinks for measurements. A 16-µm-wide device from wafer D lased in pulsed mode at temperatures up to 315 K near 5.34 µm (Fig. 1), which is higher than the maximum pulsed operating temperature of 295 K for an earlier IC laser at the similar wavelengths of 5.2 µm [8]. A 15-µm-wide laser from wafer C lased in pulsed mode at temperatures up to 310 K near 5.4 µm, comparable to the device from wafer D. A 20-µm-wide device (without a thick top gold layer) from wafer C lased in cw mode at temperatures up to 253 K near 5.27 µm (Fig. 2), which is higher than the earlier records of 229 and 165 K for IC lasers at the similar wavelengths of 5.1 and 5.4 µm, respectively [8-9]. Also, devices (with 10 cascade stages) from wafers A and B lased at temperatures up to 295 K and 248 K (247 K for wafer B) near 5.3 µm in pulsed and cw modes, respectively. These results indicate that the maximum operating temperature for both waveguide configurations is similar regardless of whether there is the top semiconductor plasmon cladding layer or not. However, the threshold current densities are not necessarily comparable and vary from device to device due to non-uniformities in the wafers (*i.e.*, different defect densities) and processing variations. These defects are *not* expected to have much influence on the obtainable modal gain and waveguide loss, which are what ultimately determine the maximum pulsed-mode operating temperature of a laser (when heating effects can be neglected). Devices from wafer C exhibited the lowest threshold current density (*e.g.* 3.8 A/cm^2 at 80 K and 643 A/cm^2 at 300 K). More details and the latest results will be reported at the conference.

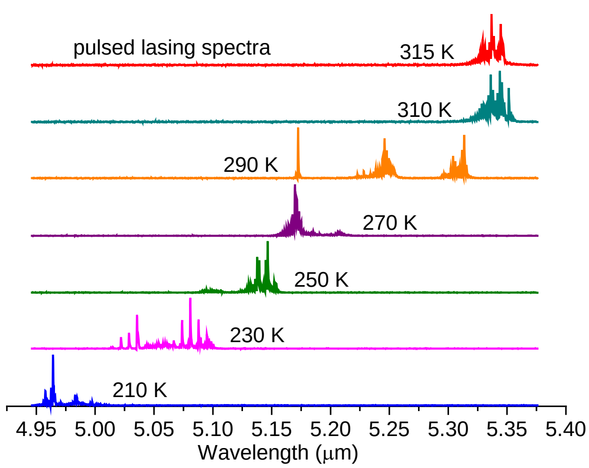

Fig. 1. Lasing spectra for a 16-µm-wide IC laser from wafer D in pulsed mode and at several temperatures.

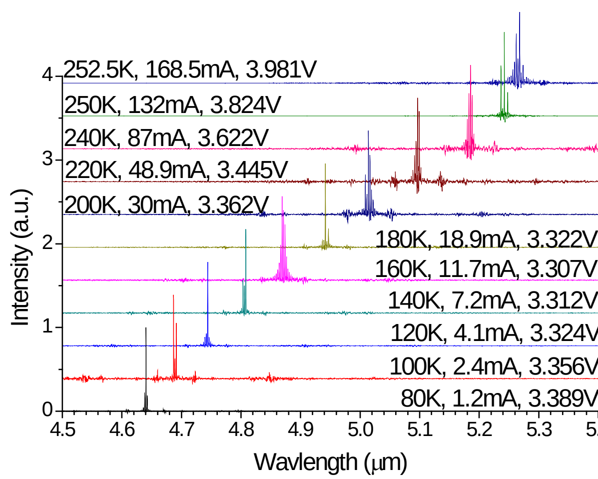

Fig. 2. Lasing spectra of a 20-µm-wide IC laser from wafer C in cw mode at different temperatures.

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