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Processing Interband Cascade Laser for High Temperature CW Operation

by Richard L. Tober, Carlos Monroy, Kimberly Olver, and John D. Bruno

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14. ABSTRACT A narrow ridge-waveguide mid-IR interband cascade laser based on Type-II InAs/GaInSb heterostructures processed with a thick gold heat spreading layer operated CW at temperatures ranging from 80 K to 214.4 K. Its differential quantum efficiency was 547% at 80 K and dropped slowly to 239% at 200 K, commensurate with a T_I of 160.2. The device had a characteristic temperature, T_0 , of 40.2 K and showed signs of significant heating at temperatures above 200 K.				
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Contents

List of Figures	iv
References	4
Distribution List	5

List of Figures

- Figure 1. L-I data for a $0.992 \text{ mm} \times 4 \text{ }\mu\text{m}$ type-II interband cascade laser. The DEQE ranges from 568% at 80 K to 239 % at 200 K, but then drops to 54% at 214.4 K.2
- Figure 2. The natural logarithm of the threshold current density plotted as a function of temperature for the $0.992 \text{ mm} \times 4 \text{ }\mu\text{m}$ laser. The straight line is a linear fit to the data below 200 K. The difference between the data points and the linear fit gives a lower bound to the temperature of the active region.3

The advent of interband cascade (IC) lasers (1) has brought new hopes for commercial and military applications that require mid-IR sources. However, in order to impact these markets, the lasers must not only emit tens-of-milliwatts, but also operate with high duty cycles at temperatures approaching 300 K. Though theoretical predictions suggest that the IC lasers could provide watts of CW power at room temperature (2), this has yet to be achieved.

Changes in design parameters, which take advantage of the unique characteristics of the type-II band alignment to enhance quantum efficiency and minimize Auger recombination, certainly have played a key role in the rapid advances in performance characteristics reported to date (3-8). But, since antimony-based materials have poor thermal conductivities, concerted efforts must be made to efficiently remove heat from the active region. Therefore, we have chosen to focus our attention in this note on the increase in operating temperature that resulted from modest changes in laser processing techniques.

The IC laser structure used for this work has 18 repeated periods of active regions separated by n-type doped InAs/AlSb injection regions structurally similar to that described earlier (3). Each period of M103 includes an active region with an asymmetric InAs/Ga_{0.7}In_{0.3}Sb/InAs “W” quantum well, followed by an AlSb barrier layer and Ga_{0.7}In_{0.3}Sb, AlSb, and GaSb layers facilitating electron transport into the neighboring InAs/AlSb injection region.

What was different about the lasers discussed in this work was the manner in which they were fabricated. In the past, the substrate side of the structure was thinned to about 100 μm before evaporating a Au/Ti contact layer onto it. Then the epi-side was wet-etched to just below the upper cladding layer (~1.5 μm), a passivation layer of SiO₂ was deposited, and this was followed by the Au/Ti contact layer. Lastly, a layer of indium was evaporated onto the substrate so that the device could be bonded to a gold plated copper mount.

For this work, the laser was prepared similar to previous samples, except for 3 differences. They were: 1) the epi-side of the wafer was etched into the upper cladding layer, 2) the Au/Ti upper contact layer was followed with 3 μm of electroplated Au, and 3) a pre-formed piece of indium foil was used to solder the device to the gold plated copper mount.

A 0.992 mm × 4 μm wide laser was fabricated, as discussed above, and mounted on the temperature-controlled cold-finger of a cryostat. Then CW spectral and L-I-V data were acquired as a function of temperature. Figure 1 shows L-I plots that were acquired in the temperature range between 80 K and 214.4 K.

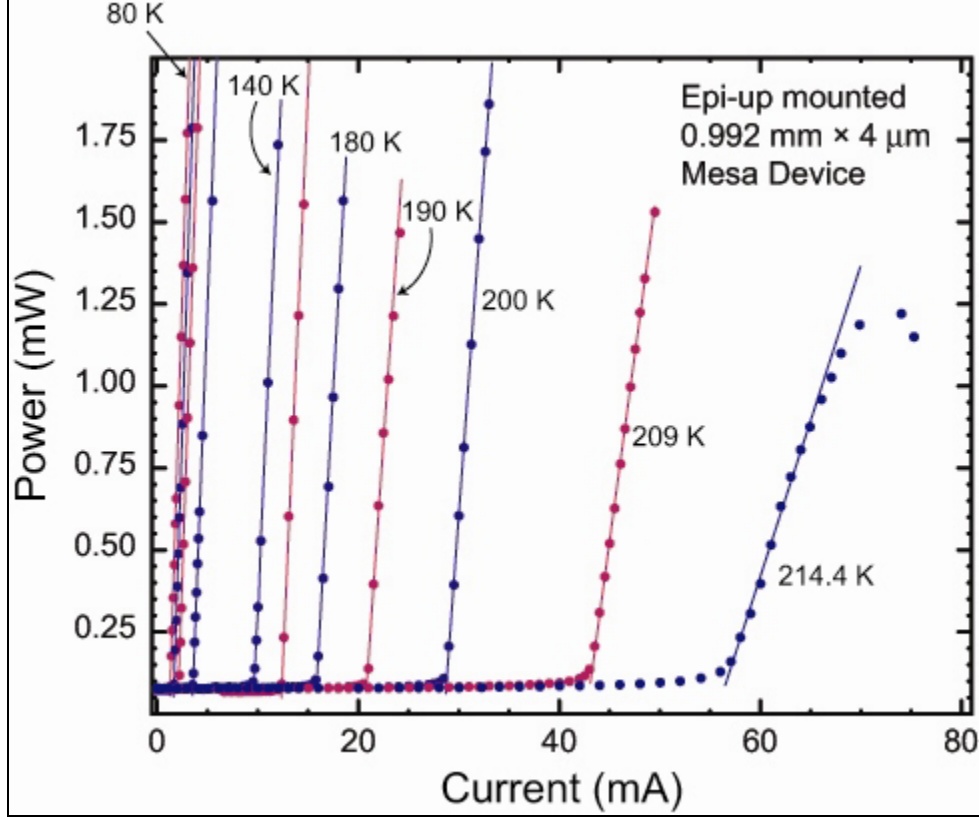


Figure 1. L-I data for a 0.992 mm × 4 μm type-II interband cascade laser. The DEQE ranges from 568% at 80 K to 239 % at 200 K, but then drops to 54% at 214.4 K.

The curves are quite linear above threshold and correspond to differential external quantum efficiency (DEQE, S) values that decrease slowly from 568% at 80 K to 239% at 200 K according to

$$\ln(S) = \ln(S_0) + \frac{T}{T_1}.$$

Above 200 K the DEQE drops rapidly to 54% at 214.4 K. The temperature dependence of the DEQE (below 200 K) yields a T_1 of 160.2 K. Figure 2 shows a plot of the natural logarithm of the threshold current density, J_{th} , as a function of temperature

$$\ln(J_{th}) = \ln(J_0) + \frac{T}{T_0},$$

where J_{th} is the threshold current density, J_0 is the threshold current density at 0 K, and T_0 is the device characteristic temperature. The data below 200 K results is linear and yields a value of 40.2 K for T_0 . Above 200 K, the data diverges from linearity because there is a finite thermal resistance, R_{th} , between the active region and the silicon diode temperature sensor on the cold finger. This temperature difference, ΔT , can be written as:

$$\Delta T = T_H - T_A = VIR_{th},$$

where T_H and T_A are the heat sink and active region temperatures, V and I are the bias and injected currents at threshold. The active region temperature extrapolated from the linear portion of the data shown in figure 2 is 232.5 K. This yields a value of 43.5 W/K for the thermal resistance between the active region and the heat sink.

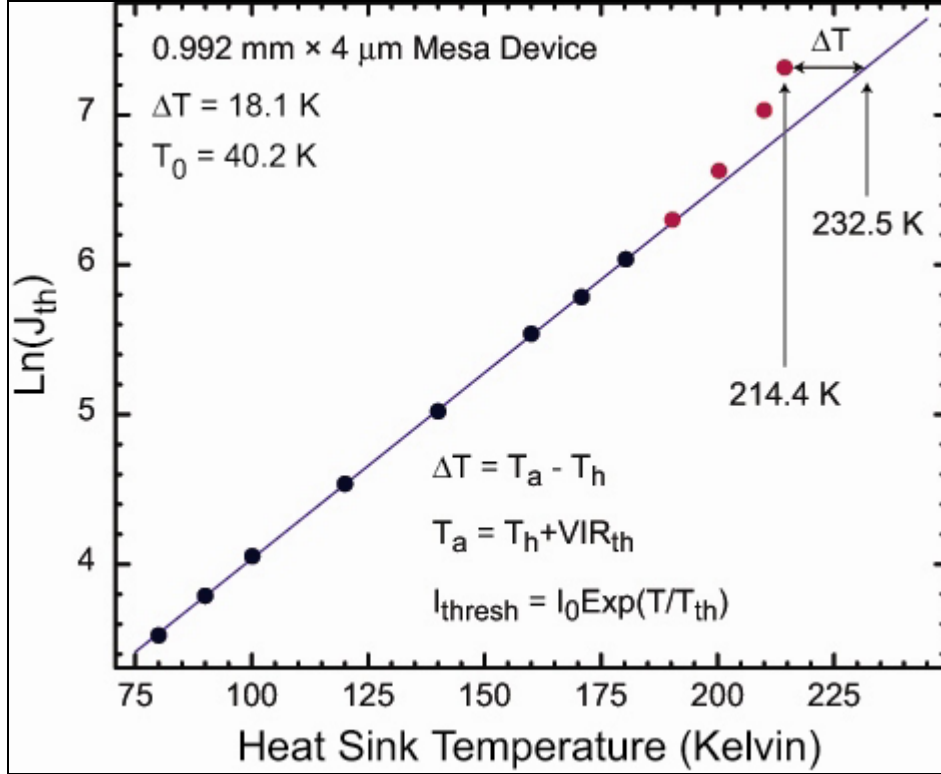


Figure 2. The natural logarithm of the threshold current density plotted as a function of temperature for the 0.992 mm × 4 μm laser. The straight line is a linear fit to the data below 200 K. The difference between the data points and the linear fit gives a lower bound to the temperature of the active region.

The maximum CW operating temperature of 214.4 K is, to the best of our knowledge, the highest published to date for an electrically mid-IR pumped laser. It is almost 70 K greater than our previous result of 150 K from a similar laser structure (8). We attribute the increase in operating temperature to modest improvements in the processing and packaging techniques. Specifically, the electroplated gold deposited on the epi-up side of the laser significantly increases thermal spreading, calculations corroborate this posit. The indium preformed foil improved the integrity of the bond between the laser and the Au plated copper heat sink. This latter point is evidenced by TEM images of the interface between the laser structure and the gold plated copper mount.

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