Measurement of internal quantum efficiency and temperature dependence of gain and loss in interband cascade lasers near room-temperature

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Recently, type-II interband cascade (IC) lasers operating around 3.5 µm have demonstrated continuous wave (cw) operation at room temperature [1]. Even though getting room-temperature operation was an important achievement, a cw power of only 10 mW was reported. It is very important to be able to substantially increase this power in order to meet the requirements for several applications of these lasers in spectroscopy, environment monitoring, medicine and counter measures. This can be done by increasing the modal gain in these lasers, at the same time reducing the cavity losses. It is important to understand if there is any temperature dependence of the losses and internal quantum efficiency in these lasers. In contrast to previous reports [2-3], we demonstrate that the loss coefficient of 6 and 12 cascade IC lasers is temperature independent over the temperature range of 240 to 300 K. These lasers have an n-doped 200 nm symmetrical separate confinement region. A loss coefficient of 7-8 cm\(^{-1}\) is demonstrated, which compares to the best loss results obtained so far. Measurement on a 12 cascade IC laser with a p-doped separate confinement region indicates a cavity loss of 14 cm\(^{-1}\), in agreement with the expectation of higher losses for p-doped layers. An internal quantum efficiency of 80 % is measured at 240 K. A temperature dependence of the gain coefficient given by \(T_0 = 44.5\) K is measured and is in agreement with the known threshold dependence on temperature in these lasers. This suggests that Auger recombination is playing an important role in these lasers.

It is very important to determine if the internal quantum efficiency and internal losses in IC lasers is varying with temperature. To provide a more complete picture, several 6 and 12 cascade IC laser wafers were grown by MBE. Also, a p-doped 12 cascade IC laser was grown. The laser structure for the n-doped separate confinement lasers is similar to the one that was published by another group [2]. For this study, we used double trenches semiconductor ridge lasers of width varying between 7 and 13 µm. Lasers were cleaved with 3 cavity lengths: \(L_{\text{cav}} = 1, 2,\) and 3 mm. Devices with uncoated facets were mounted epi-up on copper heat sinks soldered to a TE cooler. In order to minimize thermal effects, low duty cycle (1 kHz) 200 ns current pulses were used to drive the lasers. The emission wavelength of the lasers was around 3.5 µm. The following expression describes the dependence of the threshold current density on cavity length:

\[
J_{\text{th}} = \frac{q}{\eta \tau} \left[ n_j + \frac{\alpha_j}{\Gamma} \frac{dg}{dn} + \frac{\ln(R)}{L_{\text{cav}} \Gamma} \frac{dg}{dn} \right], \quad \text{Eqn. (1)}
\]

Our experimental results measured on 12 and 6 cascade IC lasers at room-temperature, measured with ridge widths varying between 7 and 13 µm, are shown in Figs. 1 and 2. A linear fit to \(J_{\text{th}}\) vs \(1/L_{\text{cav}}\) is shown on the graph. Taking \(R = 0.38\) (as simulated from a modal calculation) for the laser facet reflectivity, we extract the gain per unit current density at threshold, \(G_j = \frac{1}{q} \eta \tau \frac{dg}{dn}\), by taking the inverse of the measured slope of \(J\) vs \(1/L_{\text{cav}}\) and by multiplying by \(\ln R\). This gives \(G_j = 0.00781\) cm/A at room-temperature, a value smaller than previously reported [2-3]. This is probably related to the lower value of \(\Gamma \frac{dg}{dn}\) in our samples. By dividing the intercept by the slope and multiplying by \(\ln(1/R)\), we obtain the internal loss \(\alpha = 8.1\) cm\(^{-1}\). Here we have
neglected the first term of Eqn (1) compared to the second term. Lasers with ridge widths of 10 µm give the lowest absorption coefficient of 7 cm⁻¹. A plot of G_J vs T was obtained for a 12 cascade p-doped separate confinement laser and is shown in Fig. 3. A similar value of G_J as the one extracted above from a measurement of the threshold current density vs 1/L_cav is again obtained for this laser at room-temperature. A T_0 of 44.5 K is extracted from a fit to the data. The internal loss coefficient is found to be independent of temperature in the temperature range studied in these measurements (T: 240 to 300 K). A measurement of the inverse of the differential efficiency \( \eta_d^{-1} \) vs L_cav at T = 240 K gives the same value for \( \alpha_c \) as previously measured and gives an internal quantum efficiency of 80 % per stage. Measurements of \( \eta_d^{-1} \) vs L_cav at higher temperatures are sensitive to temperature effects and are not reliable, even using current pulses of 200 ns at low duty cycles. This might explains why previous researchers have seen temperature dependence for \( \eta_i \) and \( \alpha_c \) [2].

Fig. 1 M869 (12 cascades) current density vs. 1/L_cav

Fig. 2 M870 (6 cascades) current density

Fig. 3 Gain per unit current density vs. Temperature for a 12 cascades IC laser.

References:

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