A New Generation of Interband Cascade Lasers

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Abstract. We report on recent antimonide-based type-II interband cascade lasers emitting at wavelengths from 3 μm to 5.5 μm, which display pulsed threshold current densities at 300 K as low as 170 A/cm^2. Narrow ridge devices yield CW operation to 109 ^{o}C. Up to 158 mW of cw power and up to 13.5 % wallplug efficiency are observed at room temperature..

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INTRODUCTION

Semiconductor laser sources for the critical 3-5 μm spectral range are evolving and improving rapidly, with significant advances reported recently for all three of the leading approaches: the intersubband quantum cascade laser (QCL),[1] the type-I quantum well diode laser,[2] and the interband cascade laser (ICL).[3] Of these, only the antimonide-based type-II ICL appears likely to cover the entire wavelength range with high performance. Although QCLs generate larger output powers in the spectral regions for which they are best suited (typically (≥ 4 μm), ICLs may be advantageous in applications where minimizing the drive power is important (*e.g.*, in spectroscopic systems powered by batteries). Here we report results for a new generation of ICLs that appear capable of low-power cw operation at room temperature throughout the mid-IR.

RESULTS

Figure 1 illustrates the progression with time of ICL pulsed threshold current densities, as compared to some of the lowest reported results for quantum cascade lasers. All of the ICLs were standard 150-μm-wide broad-area ridges with 2 mm cavity lengths. At the end of 2010, we introduced a key design modification that improved the ICL performance to a level far beyond any reported previously. Figure 1 illustrates that when operated in pulsed mode at 27 ºC, all of the most recent lasers (labeled Gen3 in the figure) display threshold current densities in the 170-260 A/cm^2 range. The corresponding threshold power densities are as low as 360 W/cm^2, which is 20 times lower than the best values reported to date for QCLs.[4] External differential quantum efficiencies are as high as 30.8% per stage.

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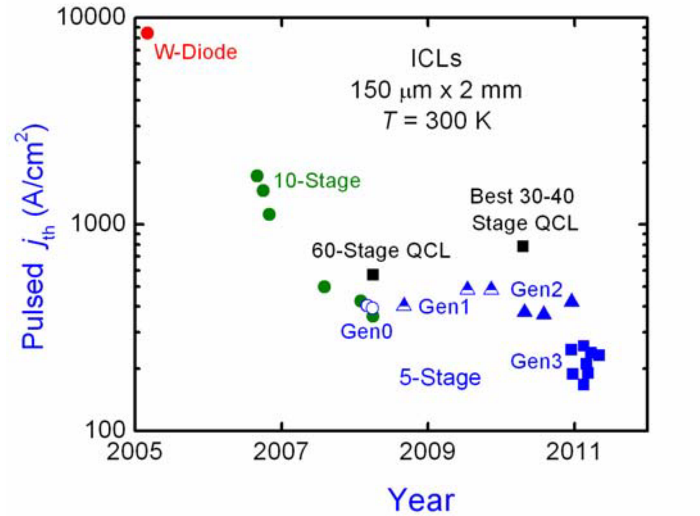

FIGURE 1. Time evolution of pulsed threshold current densities *vs.* wavelength for several generations of NRL broad-area 5-stage ICLs at 300 K. All of the ICLs emit at wavelengths between 3.0 and 4.1 μm.

Narrow ridges of width 5-11 μm and cavity length 0.5-4 mm were also fabricated using reactive ion etching with a wet clean-up etch, electro-plating with 5 μm of gold, and mounting epi-up with one high-reflection (HR) facet and the other uncoated (U) or one HR and one anti-reflection-coated (AR) facet. Figure 2 shows a series of light-current (*L-I*) curves for an 8 μm × 4 mm ridge with HR/U facets. This device operated in cw mode up to 107 ºC. At 25 ºC, an HR/AR-coated ridge of dimensions 11 μm × 4 mm emitted a maximum cw power of 158 mW. The wallplug efficiency for another ridge with dimensions 11 μm × 0.5 mm (HR/U) was as high as 13.5% at 25 ºC. The minimum operating power for the latter device was 30 mW. For 100 mW of input power, the ICL generates up to 12 mW of cw output.

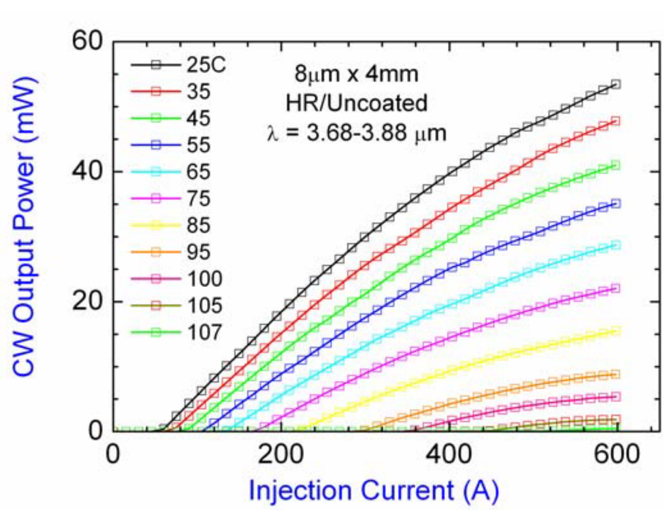

FIGURE 2. Cw output *vs.* current for an 8 μm x 4 mm ridge (HR/U) at a series of temperatures.

While thus far most of the new generation of ICLs have emitted in the spectral range 3.27-3.90 μm at 300 K, two other structures have been designed and grown for emission at 4.6 μm and 5.5 μm (5.8 μm at 340 K). Although the threshold current densities for those devices are somewhat higher (*e.g.*, 650 A/cm^2 for the longest wavelength), that value nonetheless compares favorably with the best ICLs operating at *any* wavelength only three years ago. The threshold power of 1380 W/cm^2 is low enough that room temperature cw operation may be feasible once narrow ridges are processed. Figure 3 illustrates the dramatic reduction of threshold power density *vs.* λ for Gen3 devices compared to earlier ICL generations.

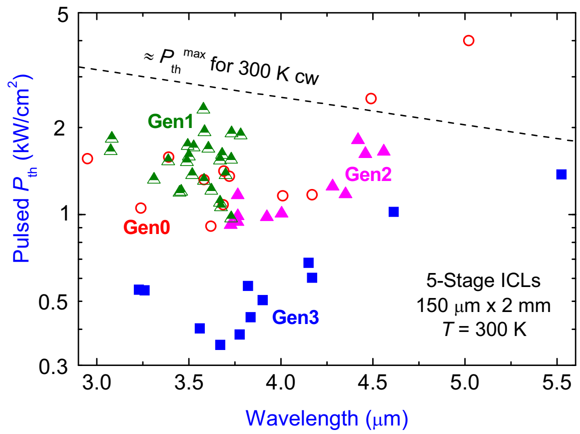

FIGURE 3. Pulsed threshold power density vs. λ for various generations of ICLs wafers.

DISCUSSION

Probably the most significant finding of this work is that cw lasing can be achieved at a remarkably low input power of < 30 mW when a short cavity (0.5 mm) is employed. This is more than 25 times lower than the best QCL value reported to date (830 mW).[4] The ICL advantage comes not only from its lower threshold current density (see Fig. 1), but also its much lower threshold voltage of < 2.5 V as compared to 10-15 V for most QCLs. Far less voltage is required because ICLs typically employ only 5 stages, whereas QCLs need 30-40 stages to achieve best results. The low input power signifies an extension of the battery lifetime for fielded chemical sensing systems by 1-2 orders of magnitude. Although output into a narrow spectral line is also required for laser spectroscopy, in earlier work we demonstrated cw output powers of up to 45 mw into a single spectral mode from Gen1 DFB devices operating at thermoelectric cooler temperatures and above.[5]

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