High-performance ultra-strong coupling quantum cascade lasers

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One of the greatest strengths of quantum cascade lasers (QCLs) is the design potential that is inherent in their operation and performance parameters. Through the years, many high-performance QCL designs have been developed around the globe. Here, we demonstrate that innovations in design are still – even 15 years after the QCL invention – providing significant, paradigm-shifting performance improvements.

The transport of electrons from the injecting ground level to the upper lasing level in the active region of a QCL significantly influences the laser performance [1, 2]. The stronger the coupling between these two levels, the faster electrons can be transferred into the active region. Conventionally, the optimal coupling strength was believed to be less than 10 meV, often being around 4–8 meV [3, 4]. However, if one takes into account interface roughness broadening, the effective coupling between injector ground level and upper laser level is smaller. As a result, our theoretical calculations suggest that the optimal coupling strength has been underestimated [5], and a much larger coupling strength should be employed to overcome the detuning of the resonant levels and consequently further improve QCL performance.

In this presentation, we will report on novel QCL designs with ultra-strong ~20 meV coupling. The QCL structure is grown by MOCVD on InP using strain-balanced $In_{0.66}Ga_{0.34}As/Al_{0.69}In_{0.31}As$ and consists of a low-loss InP-based waveguide surrounding 43 repeats of the injector–active region sequence. The injector has a sheet doping density of 1×10^{11} cm^{-2}. Conventional ridge waveguide lasers are fabricated.

Pulsed light-current-voltage measurements are performed at several heat sink temperatures. The lasers show high wall-plug efficiency and peak power. Most tested lasers with lengths ranging from 2.3–3.0 mm have peak wall-plug efficiencies of more than 40% at 80 K. The best-performing laser (an as-cleaved 13.6 ⌈m wide × 2.9 mm long device) shows an 80 K threshold current density of 0.42 kA/cm^2, a peak wall-plug efficiency of 46.7%, and an output peak power of at least 10 W from both facets. At 9 K, the peak wall-plug efficiency increases slightly to 48.2%. This is a significant improvement on previously reported results [6, 7]. At 300 K, the threshold current density is 2.07 kA/cm^2 and the peak wall-plug efficiency is ~14.2%.

In summary, we report on a new QCL design approach that employs much larger coupling strength and thus effectively overcomes the interface-roughness-introduced detuning of the tunneling process between the two levels. Our lasers show significant improvement in both peak output power and wall-plug efficiency.

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