Novel Quantum Cascade Laser Characterization: A Study on Thresholds and the Effects of Core Heating

Phillip X. Braun[1], Anthony J. Hoffman[1], Xiaojun Wang[2], Jen-Yu Fan[2], Mary Fong[2], and Claire Gmachl[1]
[1] Department of Electrical Engineering, Princeton University, Princeton, NJ 08544, U.S.A.
[2] Adtech Optics, Inc., City of Industry, CA 91748, U.S.A.
email: pbraun@princeton.edu

Since its invention, the Quantum Cascade laser (QCL) has demonstrated enormous potential for mid-infrared gas-sensing applications. For this potential to be fully realized, however, improvements need to be made in laser performance, particularly in continuous wave (CW) operation and at room temperature. This in turn requires improvements in laser design. Our research, which provides a comprehensive understanding and characterization of QCLs, takes necessary steps toward such improvements. Specifically, this work focused on laser thresholds, or the point at which a laser begins to emit coherent light. Because thresholds are dependent on input power and laser temperature, threshold data can be interpreted to describe a number of significant QCL parameters and effects. Importantly, our measurements allowed us to characterize the core temperature and threshold current of a QCL in CW operation. From these data we were able to isolate and solve for the current efficiency term in the wall-plug efficiency (WPE) equation, devise a method for approximating thermal resistivity even when a laser is not in CW operation, and experimentally measure WPE as a cooling (i.e., heat-reductive) effect.

Standard QCL characterization has included measuring input current, input voltage, and optical power output. Our novel characterization technique instead focuses on the effects of core heating by applying a DC (direct current) baseline to regulate laser temperature. As DC power and thus laser temperature is increased, more current is required to reach threshold. Fig. 1A shows a threshold increase from 302 to 647 mA for one of the lasers tested. Data analysis and simulations produced a number of significant results: the threshold current density data provide a solution to the current efficiency component of the WPE equation, $(J-J_{th})/J$, where J is the known input current density and J_{th} is the measured threshold current density. The thermal resistivity, R_{th}, of the laser, or the amount of core heating for a given amount of power, can be recovered from the data points below CW threshold. We demonstrated that the temperature-dependence of R_{th}, underestimated or presumed negligible in previous QCL calculations, has a dominating effect on laser performance, as shown in Fig. 1B, where for one set of curves R_{th} remains constant at 32 K/W and for the other set R_{th} is allowed to vary with temperature. In addition, we demonstrated that core temperature in relation to input power can be determined by examining pulsed thresholds at different heat sink temperatures. Our research, in determining these effects and parameters, should enable improved QCL design and a consequent enhancement in QCL performance. This work is supported in part by MIRTHE and DARPA-EMIL.

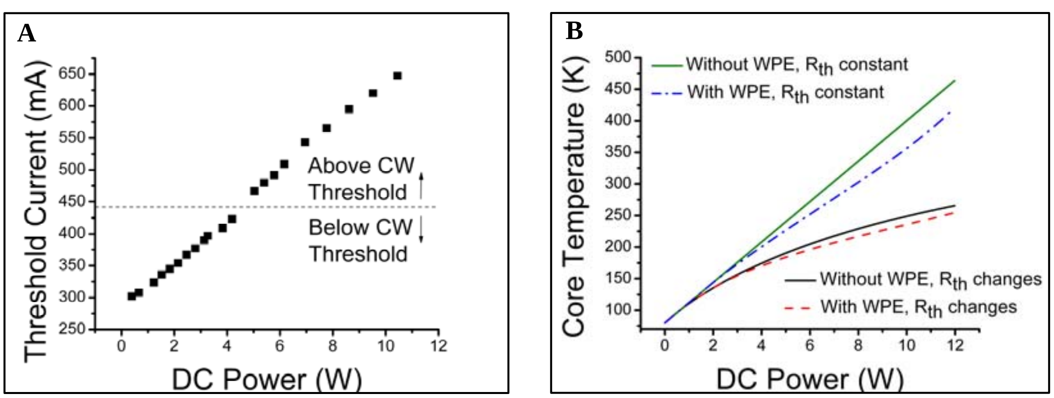

Fig. 1 **(A)** Plot of threshold current versus DC input produced by superimposing current pulses on a DC baseline. **(B)** Calculations of core temperature versus DC input which take thermal resistivity and WPE into account. The solid lines represent non-lasing (0% WPE) curves whereas the dashed lines incorporate experimentally recovered WPE with a peak at approximately 24%. Note the dramatic effect of a thermal resistivity which changes with temperature.