A Thermoelectric Effect in Quantum Cascade Lasers?

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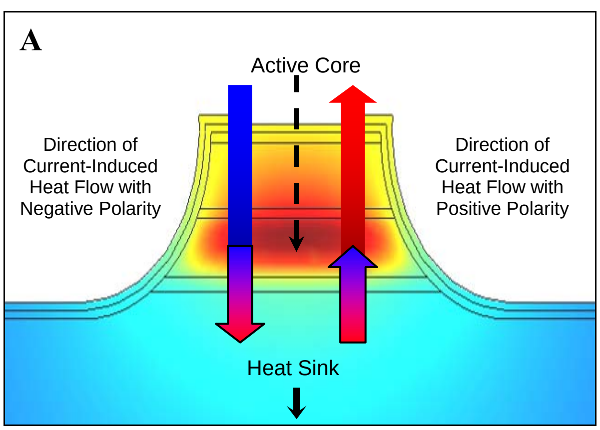
One of the chief complications confronting the widespread application of Quantum Cascade (QC) lasers is significant overheating of the semiconductor active core due to Joule heating. The overheating of the active region can prevent the emission of light and even destroy the laser. This inhibits the development of high temperature and high power QC lasers for sensor systems. Many different approaches can be used to remove some excess heating from the active core, including thick gold top contacts, InP regrowth, and epitaxial-side down mounting. A substantial amount of heat is also dissipated through the large copper block on which the QC laser is mounted. The block acts as a heat sink, allowing heat to escape from the laser and pushing the system towards thermal equilibrium. In order to enhance this thermal flow, we explore the possibility of a reversible thermoelectric (TE) cooling effect, dependent only on the direction of current. We examine whether passing negative polarity current through the electron-doped (n-type) active region into the heat sink will allow for electrons to absorb heat from the core and transport it to the heat sink due to the Peltier Effect. Conversely, positive polarity current may enable electrons to transport heat from the copper block back into the overheated active region, lessening heat dissipation (see Figure 1A).

In order to examine this potential TE effect, we simultaneously study two QC lasers, identical except for the reversing of the order of the semiconductor heterostructure layers in the active core. Hence, the two QC lasers (~5μm wavelength), mounted epitaxial-side up with thin gold coating, emit light in response to opposite current polarity. Specifically, light-current-voltage measurements are taken to determine the threshold current density ($\mathbf{J_{th}}$) of both lasers at heat sink temperatures from 80K to 300K in both pulsed and continuous wave (CW) operation. By doing so, we determine the temperature difference ($\Delta\mathbf{T}$) between the laser core and the heat sink at threshold as well as the thermal resistivity ($\boldsymbol{\rho_{th}}$), which illustrates the rate at which heat is dissipated. A higher $\Delta\mathbf{T}$ and $\boldsymbol{\rho_{th}}$ suggests lower heat dissipation. This leads to more core overheating and worse laser performance, signified by a correspondingly high $\mathbf{J_{th}}$. Preliminary data demonstrates that this method of analysis is promising in isolating a TE effect in QC lasers (see Figure 1B). Further studies will help us gain a more precise and quantitative understanding of the TE effect as well as any other effects that might contribute to heat dissipation from the laser core. This study should help both optimize QC laser design and processing as well as provide us with a better understanding of the laser's thermal properties. Ultimately, this research may contribute toward minimizing the overheating of the laser core and allowing better high temperature and high power QC lasers for various applications. This work is supported in part by MIRTHE (NSF-ERC) and DARPA-EMIL.



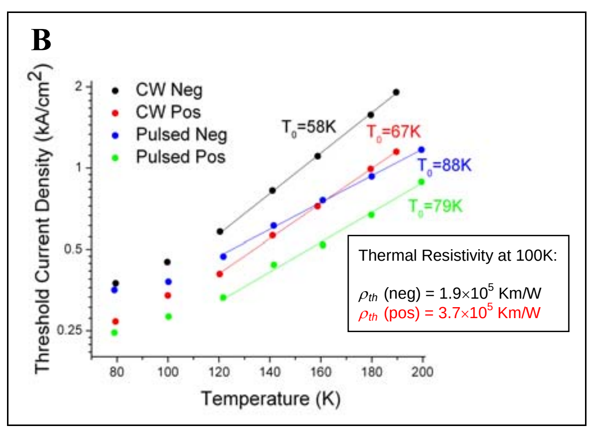


Figure 1 (**A**) A possible thermoelectric effect in the QC laser would result in electrons transporting heat from the active core to the heat sink for negative polarity current (thus cooling the core), and vice versa for positive polarity current. (**B**) Plot of $\mathbf{J_{th}}$ versus $\mathbf{T}$ for both negative polarity and positive polarity lasers; $\boldsymbol{\rho_{th}}$ values for both lasers at 100K (note the higher value for positive polarity) as well as the T_0 values are given.