Quantum Cascade Lasers: What Is Still in Store?

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Quantum cascade laser are semiconductor lasers based on intersubband transitions in quantum wells. Two important milestones have been achieved recently. The first is the demonstration of room temperature continuous wave operation at $\lambda = 9$ µm. Single longitudinal mode powers of 10mW at 20C were achieved in a structure based on a two-phonon resonance. An other important milestone is the demonstration of the first terahertz quantum cascade laser at 4.5 THz by the group of INFN in Pisa.

These two results are very encouraging, as they demonstrate that quantum cascade lasers have indeed the potential to cover the entire mid- to far-infrared wavelength range with sources suitable for spectroscopy and telecommunication applications.

A number of significant challenges remain, however. Room temperature continuous wave operation has yet to be demonstrated across a larger portion of the mid-infrared spectrum, specifically in the 3–5 µm band and with long device lifetime. In the THz regime, an important question will be the possibility of achieving operation with temperatures within range of Peltier coolers. The issue of the maximum operation temperature of THz QC laser might lie in the understanding of temperature-dependent dephasing processes, since no intersubband luminescence has yet been demonstrated at temperatures larger than about 140 K. Another crucial challenge will be to maintain population inversion at high temperature between the closely spaced intersubband levels.

A possibility to improve QC laser performances is to include an additional in-plane confinement potential. When designed correctly, the latter might provide new resonances that can simultaneously enhance the upper state lifetime and decrease the lower state lifetime. Recent experiments using this concept, where the confinement was provided by a perpendicular magnetic field, achieved extremely low threshold current densities, as low as 18 A/cm^2 for a device operating at 3.5 THz. Another approach is to use the gain predicted in Bloch oscillators. Recent work by our group demonstrated, using a density matrix approach, that gain might still arise between subbands, even with a marginal population inversion, due to in-plane scattering. Experiments aiming a demonstrating the experimental evidence of this gain in mid-infrared quantum cascade lasers will be described.

Finally, the quantum cascade laser is one approach that would enable Si-based device to achieve laser action. In collaboration with the Paul Scherrer Institute in Villigen, electroluminescence in strain-compensated Si/SiGe structures has been demonstrated.