Terahertz Quantum Cascade Lasers Based on Resonant-Phonon-Scattering-Assisted Depopulation

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The terahertz frequency range (1–10 THz) has long remained undeveloped, mainly due to the lack of compact, coherent radiation sources. Transitions between subbands in semiconductor quantum wells were suggested as a method to generate long wavelength radiation at customizable frequencies. However, because of difficulties in achieving population inversion between narrowly separated subbands and mode confinement at long wavelengths, lasers based on intersubband transitions were developed only very recently at THz frequencies. The first THz quantum cascade laser was developed based on a chirped superlattice structure. Recently, a bound-to-continuum transition THz laser was also developed. Both schemes rely on electron-electron scattering to depopulate the lower radiative level and achieve population inversion, and both have achieved lasing at 3.5 THz (~86 μm wavelength).

In a separate development, we have developed a 3.4-THz (~87 μm) laser that relies on resonant phonon scattering to depopulate the lower level. This depopulation scheme is similar to the original quantum cascade laser at mid-infrared frequencies, and it could offer a robust depopulation mechanism at higher temperatures in even longer wavelength lasers. Initial results were encouraging. The laser operated at temperature up to 87 K, and produced several mW output power, with still ~1 mW of power to spare at liquid nitrogen temperature. Recently, a variation of this structure has achieved lasing at a wavelength as long as 102 μm. It is clear that the field is fast evolving, and it would be interesting to contemplate several questions about further development of THz QCLs.

- What will be the highest temperature for CW operation of THz QCLs? Can we duplicate the success of room-temperature CW operation of QCLs at mid-infrared frequencies?
- Can we develop QCLs at 1 THz (300 μm) or even lower frequencies, where currently only electronic devices such as transistors function? As the subband separation approaches 1 THz (corresponding to 4 meV photon energy), both population inversion and mode confinement will be even more challenging to achieve.
- If we can develop THz QCLs at frequencies where electronic devices rule, can we use the gain medium to perform functions other than oscillators and amplifiers, for example three-terminal devices for ultrahigh-speed signal processing?

The answers to these questions and many others are the goals of our pursuit. With the collective effort by the researchers in the field, we hope these questions will be resolved positively in the near future.