High Temperature Quantum Cascade Lasers

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Motivation—Quantum cascade lasers (QCLs) and the underlying physics of intersubband quantum-well transitions have been intensely investigated during the last decade. More recently, significant focus has been on the development of QCLs in the THz regime, because of important spectroscopic applications, including several involving homeland security. The present operating temperature for THz QCLs is below 150 K for continuous-wave (cw) operation. The low operating temperature is necessary to mitigate carrier thermalization effects, which are more detrimental to lasing when subband energy separations correspond roughly to that of a THz photon. Clearly, higher temperature operation is required for practical THz QCL applications.

Accomplishment—We have analyzed an optically-pumped electrically-driven quantum cascade laser (OPED) as an approach for THz generation. The scheme involves four quantum-well subbands (Fig. 1). A mid-IR laser field excites electrons from levels 1 to 2. The THz photon is created by transition 2-3, and its energy is derived from a forward electrical bias as in a conventional QCL. Lastly, the mid-IR pump field is coherently recovered via transition 3-4. Calculations based on a microscopic semiconductor laser theory show high optical conversion efficiency for temperatures up to 300 K (Fig. 2). The predicted efficiencies can exceed the Manley-Rowe quantum limit, with as much as a 1:3 mid-IR to THz photon conversion ratio. The study also uncovered interesting physics: the presence of quantum coherence which significantly reduces the threshold requirement for coherent THz generation.[1]

Significance—The OPED approach can be both a promising source for THz generation at high temperature and a practical experimental platform for studying and engineering quantum coherence effects such as electromagnetically induced transparency (EIT), lasing without inversion (LWI), and group-velocity reduction (slow light).

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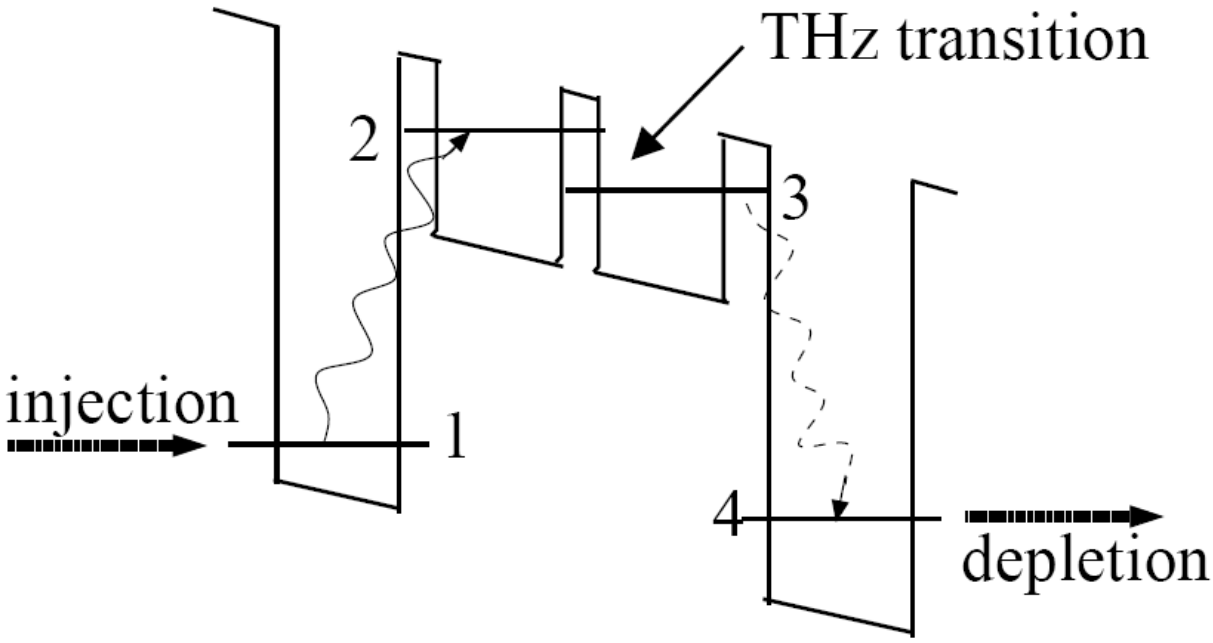

Figure 1: Single stage of proposed optically-pumped electrically-driven QCL. Without pump recovery (dashed transition), the scheme reverts to a conventional THz optical conversion configuration.