**Terahertz Quantum-Cascade Lasers: Physics of the Electrons Transport, Design Review and Temperature Performance Optimization**

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The paradigm of exploiting intra-band electron transport and maintaining population inversion via resonant tunnelling, combined with semiconductor band structure engineering has yielded state of the art sources in far-infrared spectrum: Terahertz-frequency quantum cascade lasers (THz QCLs).

Since their first demonstration [1], a variety of designs provided devices lasing in the range 1.2 – 5.6 THz, with high output power and operating temperature up to 250 K in pulsed regime [2-4].

There is a great interest of achieving room temperature performance and this possibility seems exhausted after 20 years of research and development with GaAs/AlGaAs material system.

In this work we present a detail review of THz QCL designs and discuss temperature degradation mechanisms which outline their strengths and weaknesses.

Our density matrix transport model [5] has demonstrated very high quality and reliability in predicting the cut-off temperature across various designs and we have recently employed it in temperature optimization procedure [6].

The current record structure employs a three level system where lower lasing level is efficiently extracted via interaction between electrons and longitudinal optical (LO) phonons. This design has proven its temperature performance robustness over the years, however latest record device [4] employed extraction transition of 51 meV which is much higher from the LO phonon resonant energy (36 meV. We attribute this behaviour to a known disadvantage of using LO phonon scattering mechanism for assistance in lasing process at THz frequencies. This scattering process is most efficient at resonant energy of 36 meV, however it may persist up to 60 meV and as THz lasing energy is typically 12-16 meV it is clear that in a three level system, this process may inadvertently extract the upper lasing level (the LO phonon scattering leakage).

In [5,6] we presented a novel design which does not suffer from LO phonon scattering leakage and simulated over 4 million devices in a search for optimal structure. Our focus in [6] was to generate a structure with lower threshold and in this work we present novel designs which in contrast have higher thresholds, however exploit extraction transition in 46 – 51 meV range offering better temperature degradation efficiency.

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