

Simulation of Quantum Cascade Lasers: A Popular summary

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Lasers, short for "Light Amplification by Stimulated Emission of Radiation," are devices that generate and emit an intense beam of coherent light. The concept of lasers was first proposed in the mid-20th century, and since then have revolutionized numerous industries within scientific research, manufacturing, telecommunications, etc. thus becoming an integral part of our modern lives.

Quantum Cascade Lasers (QCLs) represent a paradigm shift in laser technology, capitalizing on the principles of quantum mechanics. These lasers operate in the mid-infrared to terahertz frequency range, spanning wavelengths from approximately 3 to 300 micrometers. This spectral range, often referred to as the "molecular fingerprint region," is crucial for numerous applications in scientific research, industry, and defense. QCLs enable high-resolution spectroscopic analysis, sensitive gas detection, long-range communication, non-destructive imaging, and scientific investigations, revolutionizing fields such as environmental monitoring, industrial process control, medical diagnostics, free-space communication, security screening, and fundamental scientific research.

Unlike traditional lasers, which rely on energy level transitions within a single material, QCLs exploit an innovative design, known as the quantum well, to generate laser action. A Quantum well is formed by layering different semiconductor materials to create what is called a heterostructure. This heterostructure consists of alternating layers, with each layer acting as a barrier or a well for electrons. The barriers prevent the electrons from freely moving across the structure, confining them within the quantum wells.

The confinement of electrons within the quantum wells is crucial for the operation of QCLs. It creates discrete energy levels or states for the electrons, similar to the energy levels in an atom. When an electric current is applied to a QCL, electrons

are injected into the quantum wells. As they move through the structure, electrons at higher energy states deexcite in order to occupy lower energy states, subsequently releasing energy in the form of light. This light directly corresponds to the energy difference between the states. After deexcitation, the electrons at lower states undergo what is known as resonant tunneling. This quantum mechanical effect allows the electrons to transition from one quantum to the other, and QCLs are designed such that the lower energy states of one well coincide with higher energy state in its adjacent well, and so the whole process repeats.

This thesis aims to model this process which holds significant importance in understanding, optimizing, and advancing QCL performance. Simulations and modeling play a pivotal role in the development and understanding of new technologies by allowing researchers to gain insights that are otherwise costly to obtain experimentally.