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Magnetic field effects on THz quantum cascade laser: A comparative analysis of three and four quantum well based active region design

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HIGHLIGHTS

- Two QCL structures under the influence of external magnetic field are analyzed.
- LO-phonon and interface roughness scattering are taken into account.
- Numerical model for calculating upper state carrier lifetime is presented.
- Comparison of the structures and their properties are discussed.

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ABSTRACT

We consider the influence of additional carrier confinement, achieved by application of strong perpendicular magnetic field, on inter Landau levels electron relaxation rates and the optical gain, of two different GaAs quantum cascade laser structures operating in the terahertz spectral range. Breaking of the in-plane energy dispersion and the formation of discrete energy levels is an efficient mechanism for eventual quenching of optical phonon emission and obtaining very long electronic lifetime in the relevant laser state. We employ our detailed model for calculating the electron relaxation rates (due to interface roughness and electron–longitudinal optical phonon scattering), and solve a full set of rate equations to evaluate the carrier distribution over Landau levels. The numerical simulations are performed for three- and four-well (per period) based structures that operate at 3.9 THz and 1.9 THz, respectively, both implemented in GaAs/Al$_{0.15}$Ga$_{0.85}$As. Numerical results are presented for magnetic field values from 1.5 T up to 20 T, while the band nonparabolicity is accounted for.

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1. Introduction

Quantum Cascade Lasers (QCLs) have become important light sources for infrared spectroscopy within the last decade, especially when it comes to new structures operating in the terahertz (THz) region, suggesting numerous applications, such as chemical sensing, infrared imaging, non-invasive medical diagnostics and optical communications [1–13]. These devices are designed in such a manner so as to have electronic subbands defined as the upper and the lower laser level, electric pumping along the growth direction, as well as periodic repetition of active elements, which enhances the light amplification. Because of the specific properties of intersubband transitions, dynamical behavior is very different from that of inter-band lasers. The first and most important feature of intersubband transitions is very fast non-radiative scattering, proceeding on a time scale of few picoseconds [6].

THz frequencies belong to the quite under-utilized part of the electromagnetic spectrum, despite their significant application potential. This is mostly due to the lack of coherent solid-state THz sources. The so called “THz gap” falls between two frequency ranges that have been well developed, the microwave and millimeter-wave frequency range. As the conventional semiconductor photonic devices (which are based on interband transitions) are limited to frequencies higher than those corresponding to the semiconductor energy gap, the frequency range ~1–10 THz is thus inaccessible.

Terahertz QCLs are possibly the only solid-state terahertz sources that can deliver average optical power levels much greater than milliwatt that is essential for imaging applications, and also continuous wave (CW) operation for the frequency stability desired in high resolution spectroscopy techniques [5]. The realization of QCLs in the THz region was challenging because the energy

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