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Terahertz Quantum-Cascade Lasers: Carrier Transport and Photonic Crystal Cavities

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ABSTRACT

The focus of this work is the electron transport in the active region of terahertz (THz) quantumcascade lasers (QCLs) and the realization of photonic crystal (PhC) resonators for these lasers. The active region of our THz-QCLs is based on the longitudinal optical (LO) phonon depopulation mechanism. This scheme utilizes a LO phonon scattering process for the depopulation of the lower laser. Thereby, an extremely short life time in the lower laser state is achieved. The active region is designed to show the gain maximum around 2.8 THz, corresponding to a wavelength of 110 mm or a transition energy of 10 meV.

Due to the small subband spacing in the active region, it is necessary to understand the transport processes precisely. The performed doping study shows clearly that the crucial parameter for a lasing THz-QCL is the alignment field. The threshold current can be controlled linearly by the doping concentration up to a sheet density of 1.9e10 cm-2. The doping changes the electrical conductivity of the structure, the optical properties are almost unaffected.

The electron-electron scattering, which normally is problem for systems with a small sub-band spacing, is negligible due to the low concentration in THz-QCLs.
Photonic crystals are an excellent system for laser resonators as their dispersion relation is defined purely by design. We present two different concepts for resonators based on isolated pillars. The PhCs for both concepts are fabricated directly from the active region and embedded into the double-metal waveguide. The first type of devices consists of a bulk gain region which is surrounded by a PhC mirror.

These lasers are designed to lase in the bandgap of the PhC. The second type of devices consists of only the PhC, the bulk gain region is removed. These devices rely on so-called flat-band regions at high symmetry points of the PhC. Both PhC concepts offer a lithographic tuning of the emission frequency within almost the entire gain bandwidth of the active region of more than 400 GHz.