Quantum cascade lasers at subterahertz frequencies

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The quantum cascade laser (QCL) is a semiconductor laser based on intersubband transitions in quantum wells. It presently covers a wide spectral window ranging from 4.9 THz to 1.2 THz [1, 2]: possible applications in imaging and astronomy push the extension of the frequency range towards longer wavelengths. A control over the in-plane degree of freedom of the electron may be an essential element to obtain population inversion and optical gain at very low THz frequencies, where the broadening of the states becomes very close to the photon energy (< 5 meV).

In this work we present results obtained on low frequency THz QCL immersed in strong magnetic field. The devices, based on an intra-well transition, exhibit extremely low threshold currents (1 A/cm^2 and below) due to the reduction of the non-radiative scattering processes obtained via the magnetic field confinement [2]. A new structure relying on magnetically enhanced population inversion displays laser action at about 1 THz ($\lambda \sim 300$ μm). The structure, grown in the $Al_{0.1}Ga_{0.9}As/GaAs$ material system, is based on an intra-well excited state optical transition in a very wide (76.5 nm) quantum well. A double-metal ridge waveguide structure displays lasing action starting from an applied magnetic field of 8.2 T. The transport at constant applied bias shows extremely pronounced features attributable to magneto-intersubband resonances [3], also present in light emission. Another structure can be operated down to a frequency of 760 GHz.

Taking advantage of the tight confinement provided by the metal-metal waveguide, we also have explored microcavities and photonic crystal quantum cascade lasers based on very low frequency material. These cavities enable us to explore the coupling between transport and photon emission in the regime of very subwavelength emitters as the ratio of volume over λ^3 is far below unity. Particularly interesting are cavities presenting strong analogy with LC circuits where the Purcell factor can be much larger than unity.

1. C. Walther *et al.*, *Appl. Phys. Lett*. **89**, 231121 (2006).
2. C. Walther *et al.*, *Appl. Phys. Lett.* **91** (13), 131122 (2007).
3. G. Scalari *et al.*, *Phys. Rev. Lett.* **93**, 237403 (2004).