LO-phonon emission by hot electrons in terahertz quantum cascade lasers

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***Abstract*— We present experimental data on one particular Quantum Cascade Laser (QCL) structure under a strong magnetic field applied parallel to the growth axis. The emitted power shows strong oscillations as a function of B. The analysis of these oscillations exhibits two mechanisms of non-radiative relaxation, an elastic scattering mechanism (interface roughness) and an inelastic one (LO-phonon). Due to electron thermal distribution in Landau Levels (LLs) of the upper laser state, LO-phonon emission can break population inversion in a THz QCL under magnetic field.**

***Index Terms*— Quantum Cascade Laser, Terahertz, quantum well structures, magnetic field.**

Recently, a new design of Quantum Cascade Lasers (QCL) operating in the terahertz (THz) domain that combines the advantages of the bound-to-continuum approach together with the use of a LO-phonon resonance was proposed [1]. The latter presents a large energy separation used to significantly reduce the laser lower state lifetime by allowing optical phonon scattering of the electrons and also to reduce the thermal backfilling of the lower state.

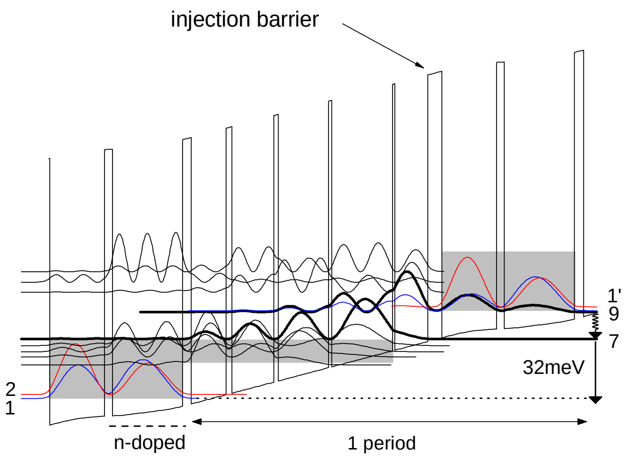

Fig 1: Self-consistent solution of coupled Schrödinger and Poisson's equations for one period of the structure.

We present measurements performed on that particular structure under a strong magnetic field applied parallel to the growth axis. Each level of the QCL is split into a series of Landau levels (LLs). As previously reported, the lifetime of the upper state of the laser transition, and thus the output power, can be modulated by varying the magnetic field. A strong increase of the scattering rate, and therefore an output power minimum, is observed when two LLs are brought into resonance, since in that case electrons can scatter elastically, essentially as a result of the interface

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roughness. This leads to dramatic oscillations of the emission power which vary as B^{-1}. (Figure 2, solid arrows) Besides these features, a second series of oscillations is also clearly observed in this structure. (Figure 2, dashed arrows)

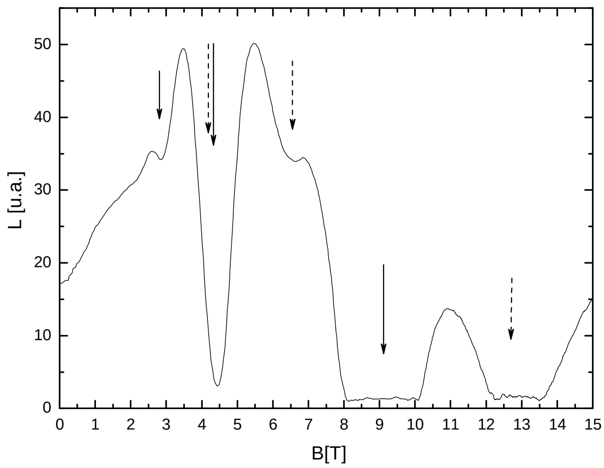

Fig 2: Emitted power as a function of the magnetic field under constant current density J = 225A.cm^{-2}

Such minima cannot be accounted by inter-LL resonances or by resonant electron-electron scattering (Auger like effect) as previously observed in different structures. We show that they can be explained by LO-phonon emission from hot electrons injected in the LLs of the upper level. For critical values of the magnetic field, these electrons can resonantly emit one LO-phonon and relax directly to the fundamental LL of the laser transition, leading to a minimum in the output power. We are developing a simple model to show how both extraction of lower laser state and non-radiative relaxation can lead to a switch off of the laser.

References

[1] G. Scalari, N. Hoyler, M. Giovannini, and J. Faist, Appl. Phys. Lett. 86, 181101 (2005).