Doping engineering in THz QCLs

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Abstract

In THz quantum cascade lasers (QCLs), the position and the concentration of dopants have a strong influence on their performances. We show that an accurate modeling of charge impurity scattering within non-equilibrium Green's functions (NEGF) allows for a comprehensive understanding of the influence of the doping profile on the QCL performances. We show that engineering of the doping profile can be used for optimizing existing THz QCLs but also to design novel geometries.

Introduction

The doping profile in THz QCLs has a strong influence on their performances. Migration of dopants in THz QCLs have been shown to strongly influence the current threshold and the output power [1]. The optimal doping densities have been shown to be very different for optimizing the output power or the operating temperature [2]. Indeed the location of the dopants strongly influences the QCL properties since the ionized dopants create not only a mean-field electrostatic potential but also induce Coulomb scattering processes.

Results

Using an accurate modeling of impurity scattering within a non-equilibrium Green's functions (NEGF) calculation, we show that impurity scattering is an esssential ingredient to understand the operation and the limitations of THz QCL. We show that impurity scattering is responsible for contrasting and counterintuitive effects on the gain and transport properties [1] (see Fig. 1), in agreement with experimental observations (eg..[2]). We show that impurity scattering not only limits the lifetime of the lasing transition, but is also a major source of dephasing in THz QCLs. As a consequence, impurity scattering is shown to strongly limits the efficiency of resonant tunneling processes, even for low doping concentrations.

Using this understanding, we show that various THz QCL geometries can be optimized by changing the dopant location. The optimal location of dopants is shown to be a trade-off between the reduction of the upper laser lifetime and the efficiency of resonant tunneling processes.

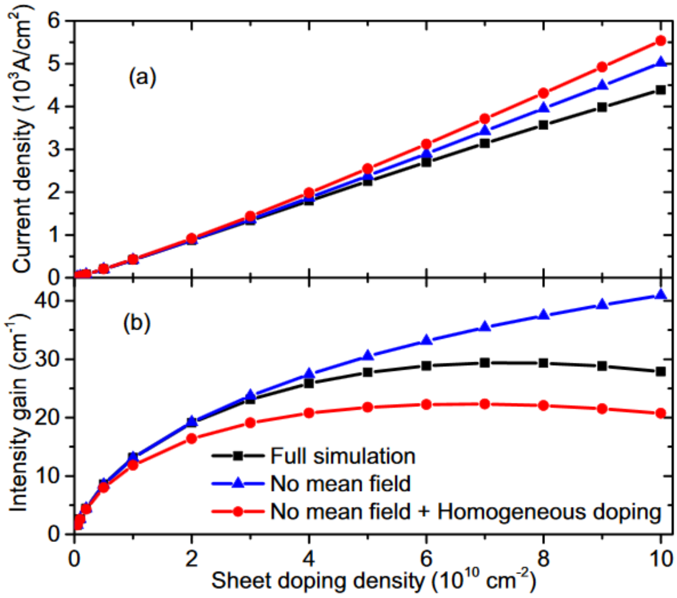

Fig. 1: (a) Current density and (b) intensity gain as the function of the sheet doping density for a THz GaAs/AlGaAs QCL (see [3]). The full calculations are indicated by black squares, calculations without considering mean field by blue triangles, and calculations without mean field and assuming a homogeneous doping density by red circles.

References

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[3] T. Grange, "Contrasting influence of charged impurities on transport and gain in terahertz quantum cascade lasers", Phys. Rev. B 92, 241306 (2015).