Importance of localization for scattering rates in heterostructures

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ABSTRACT

We developed a numerical model for the exact calculation of the electronic scattering rates in disordered heterostructures allowing a better description of the non radiative inter-subband transitions. It appears that the disorder-induced localization effects and the location of the scatterers inside the structure play an important role.

INTRODUCTION

One of the most detrimental effects to lasing action in Quantum Cascade Lasers (QCLs) is the non radiative inter-subband scattering which consists in the elastic or inelastic scattering of a carrier that are initially placed in the upper laser subband. Among the many sources of inter-subband scattering, the most efficient elastic scatterers are the interface defects and the ionized impurities, while the LO phonon absorption/emission dominates the inelastic scattering.

MODEL AND RESULTS

The simplest way to handle inter-subband scattering is to use the Born approximation and to compute the scattering rate by the Fermi Golden rule [1]. What is unsatisfactory with this approach is that before undergoing an inter-subband scattering, an electron performs a number of intra-subband transitions, or, stated differently, because the low lying states of the intra-subband Hamiltonian of the system are scattered/localized in the layer plane by the disorder [2].

To account for this effect, we have numerically calculated the eigenstates of a QCL based on an asymmetrical double quantum well (DQW) design, in the presence of ionized (screened) impurities and interface defects [3]. As expected and as shown in Fig. 1, the results of the calculation show an energy spectrum that contains low lying states which have very little similarity with the unperturbed plane wave states. From these exact eigenstates, we have computed the inter-subband impurity and interface roughness scattering rates and we have found that it is significantly larger for the localized states than for the eingenstates far enough away from the subband edge (i.e that much ressemble plane waves).

The result is shown in Fig. 2 which displays the calculated scattering rate for ionized impurities (blue dashed line) and for interface defects (red dotted-dashed line). For comparison, the result of the calculation of the scattering rate at the Born approximation has been added (dotted and continuous lines) and displays a good agreement with the exact calculation for higher energy/delocalized states.

CONCLUSION

Our work points out the crucial importance of the existence and the location of the scatterers in the structure. In particular, we found that the scattering rates from the bound states differ significantly from the one obtained at the Born approximation for free states. It appears that the trapping of carriers on the impurity states is an important phenomenon when there are few free carriers in the structure, a typical situation in QCL.

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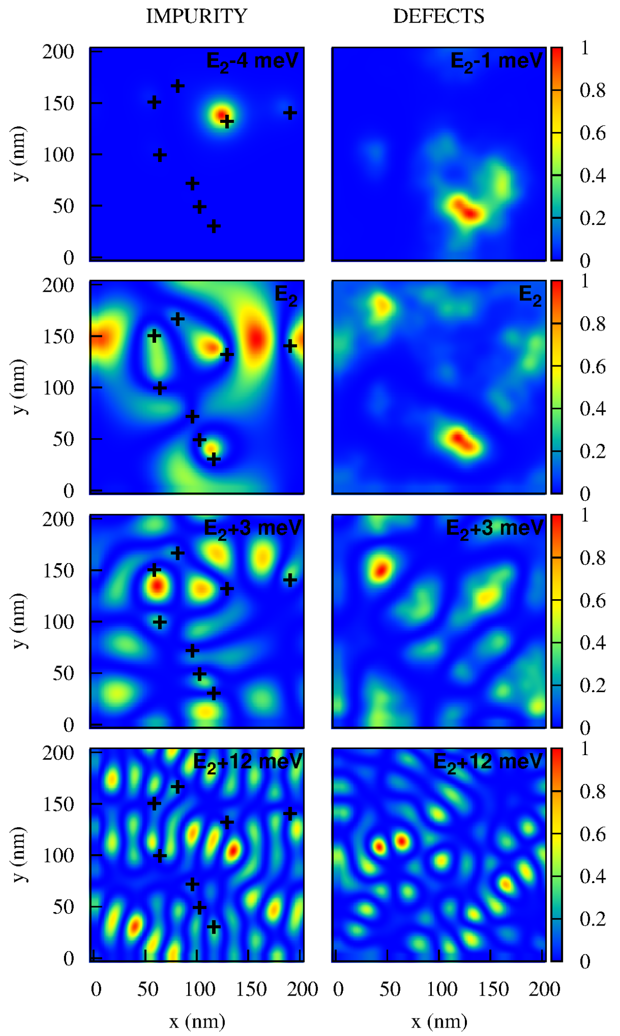

Fig. 1. Color plots of the normalized probability density for several eigenstates of intra-subband Hamiltonian in presence of the in-plane disorder. Left panel: the energies are $E_2 - 4$ meV, E_2, $E_2 + 3$ meV, $E_2 + 12$ meV, respectively. The in-plane scattering potential corresponds to the potential energy created by 8 impurities placed on a plane located in the wide well of the DQW structure. Right panel: the energies are $E_2 - 1$ meV, E_2, $E_2 + 3$ meV, $E_2 + 12$ meV, respectively. The in-plane scattering potential corresponds to the potential energy associated with interface defects.

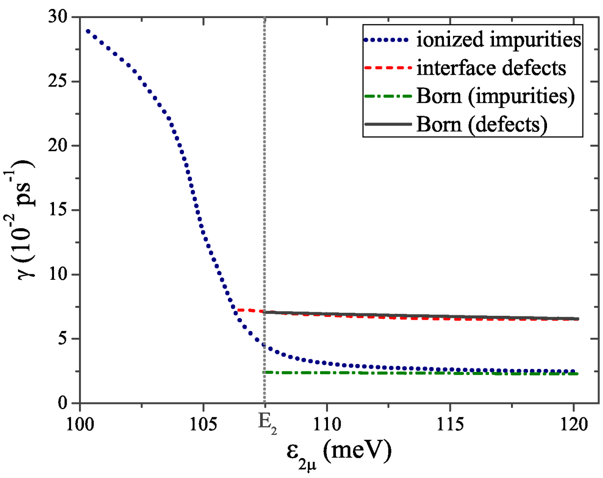

Fig. 2. Inter-subband scattering rate versus the Hamiltonian eigenvalues of the DQW structure for screened ionized impurities (red dotted line), interface roughness (blue dotted-dashed line) and at the Born approximation for each type of scatterer (green and orange solid line). The inter-subband transition $|2\rangle \rightarrow |1\rangle$ is considered. The unperturbed energy level is E_2=107.46 meV.