Absorption in disordered heterostructures: contributions from intra- and inter-subband scattering and impact of localised states

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ABSTRACT

We developed a model for the exact calculation of the absorption spectrum in disordered heterostructures allowing the understanding of the lineshape in terms of the contributions from intra-subband and inter-subband scatterings. A dopant engineering of the inter-subband lineshape is proposed.

INTRODUCTION

Quantum cascade lasers are unipolar devices where the lasing action takes place between two conduction subbands of a biased multi-quantum well structure. The absorption/emission spectrum in multi-well structures strongly depends on the presence of static scatterers or phonons that can activate a variety of intra-subband and inter-subband oblique transitions (the free carrier absorption, FCA).

MODEL

We have solved numerically the Schrödinger equation by an exact diagonalization for a double quantum well (DQW) structure in presence of interface defects and ionized impurities. In Fig.1 we show the numerically calculated absorption spectrum and we compare it with the results of the perturbative model described in [1]. The respective contribution of intra- and inter-subband scattering are also shown. An important issue is to understand how the results of the exact diagonalization compare to the results of the model based on Non Equilibrium Green Function (NEGF) methods [2] used to describe working QCL. We will discuss the domain of applicability of currently used models [3](see Fig. 2).

APPLICATION: DOPANT ENGINEERING

We study a DQW where the impurities are randomly placed on a plane. The results of the calculation show that ionized impurities change dramatically the nature of the energy spectrum by creating bound states below the subband edges. Nevertheless we have found that the effect of the impurity potential on the absorption spectrum can be tailored by adjusting the position of the impurity plane with respect to the heterostructure wave functions, thus allowing a dopant engineering. The absorption spectrum was also calculated by the NEGF approach, which takes into account scattering within the self-consistent Born approximation (dotted lines). While this approximation does not provide the effects of bound states, the general trend regarding the position dependence of the linewidth is reproduced. These results are shown in Fig.3.

CONCLUSION

We show that currently used models fail in describing the absorption spectrum in heterostructures far from resonance while our model allows a quantitative estimation of losses due to FCA. We also point out how tailoring the impurity plane position allows to control the absorption lineshape thus leading to a dopant engineering.

REFERENCES

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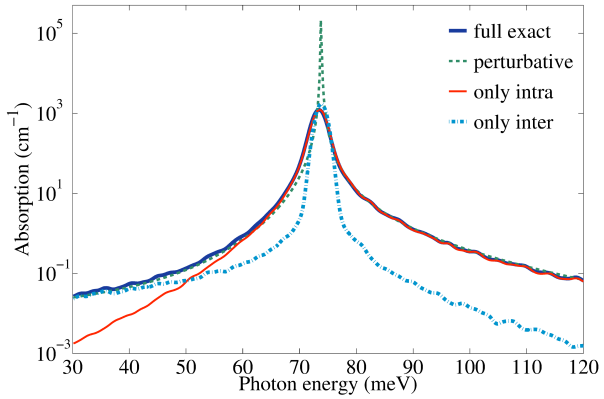

Fig. **1**. Absorption spectrum for the E_1-E_2 transition in a GaAs/$Al_{0.25}Ga_{0.75}$As DQW (9/2/3 nm) in presence of interface defects: full exact calculation (blue full line), keeping only intra-subband scattering (red full line), keeping only inter-subband scattering (blue dash dotted line), perturbative model (green dotted line). T = 100 K.

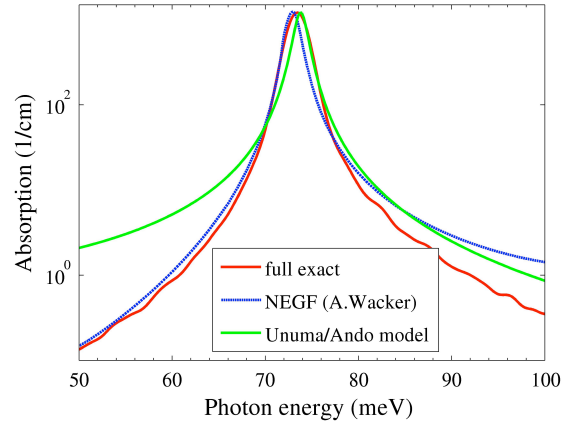

Fig. **2**. Absorption spectrum for the E_1-E_2 transition in a GaAs/$Al_{0.25}Ga_{0.75}$As DQW (9/2/3 nm) in presence of interface defects: calculation done by full exact diagonalization including two subband mixing (red line), by NEGF methods (blue line) and with the Unuma/ Ando model (green line) [3].

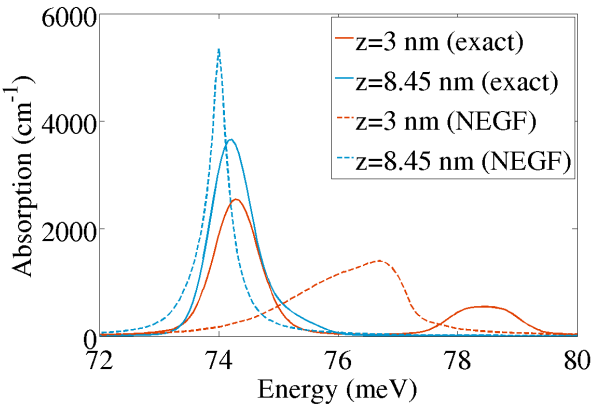

Fig. **3**. Absorption spectrum for a GaAs/$Al_{0.25}Ga_{0.75}$As DQW (9/2/3 nm) in presence of ionized impurities (n_s = 2.17x10^{10} cm^{-2}) calculated by exact diagonalization (continuous line) and NEGF methods (dotted lines) using Born approximation. The impurity plane is placed in the left hand side well of the DQW at z = 3 nm and z = 8.45 nm. T=100K.