Photon Absorption in Regimented Quantum Dot Arrays

A. Luque Rodríguez*, S. Rodríguez-Bolívar, and F.M. Gómez-Campos
Departamento de Electrónica y Tecnología de los Computadores. Facultad de Ciencias. Universidad de Granada, 18071 Granada, Spain. +34 958 241 577
e-mail: abrahamluque@ugr.es

ABSTRACT

A study of the intraband absorption coefficient in cuboid InAs quantum dot periodic nanostructures embedded in GaAs is presented. The miniband structure of electron states in the conduction band is related to the size and shape of the quantum dots. The effect of strain is also taken into account in the simulations.

INTRODUCTION

Quantum dots (QDs) represent an interesting topic in the controlled modification of optical, electronic and thermoelectric properties of semiconductor materials [1]. Applications in optoelectronic and other devices have been theoretically proposed [1-4] due to its easy tuning properties by means of controlling size, shape, and density of QDs. However, an important requirement needed for avoiding an undesirable degradation of these properties is to achieve a good ordered structure in the system. Thus, although Stranski-Krastanov method is the most used technique to grow quantum dots, this is not the most appropriate technique for achieving regimentation because of their random nature. A few papers have been published where ordered nanostructures are developed and characterized, showing excellent agreement between experimental results and theoretical predictions [5-6].

SIMULATION OF ARRAYS OF QUANTUM DOTS

We have studied energy quantization from states belonging to conduction bands in ordered arrangements of GaAs/InAs quantum dots with cuboid geometries (Fig.1). The supercell (the spatial period of the structure), is repeated along the X, Y and Z axis. We solve the Schrödinger equation [4] of the system within the Effective Mass Aproach (EMA), considering different masses for the QD and the barrier materials and including strain by means of the 8×8 $k \cdot p$ Pikus-Bir Hamiltonian.

RESULTS

Figure 2 shows the four lowest minibands belonging to the conduction band for 250 nm^3 QDs having different shapes. The considered shapes and a sketch of the corresponding points in the Q-space are depicted in Fig. 1. The separation between neighbouring dots has been kept 3 nm in the X, Y and Z direction for every case. This value provides a noticeable interaction between dots, and therefore the states form a miniband.

It is clear that a band gap between first and second miniband appears in Fig. 2 for all the cases. Whereas the location of the first miniband is practically the same for the three samples, the upper minibands are strongly influenced by the shape of the QD.

Figure 3 shows the computed absorption coefficient for the three previous samples for light polarization in (1,0,0) direction. Well-defined threshold values are found for each shape: about 0.1 eV for flattened cuboids, about 0.2 eV for regular cubes, and about 0.25 eV for elongated cuboids. This behaviour could be analyzed in terms of the transitions between the shown minibands: from X to K points in the Q-space the minibands are almost parallel, favouring a particular photon energy that could be related with that threshold.

CONCLUSION

We have calculated the absorption coefficient in arrays of InAs quantum dots embedded in GaAs and found thresholds at about 0.1 eV, 0.2 eV and 0.25 eV, depending mainly on the dot shape and slightly on the quantum dot volume. These thresholds are in the far infrared region and

could be used for detectors in that region of the electromagnetic spectrum.

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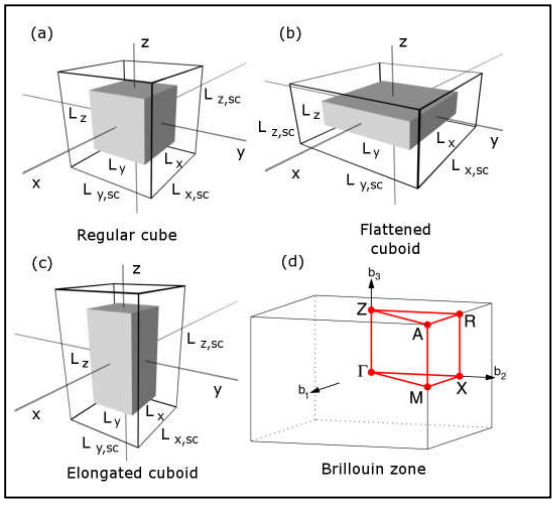

Fig 1. (a), (b) and (c): Supercells for the three studied cases. (d) Q-space of the system and points of interest.

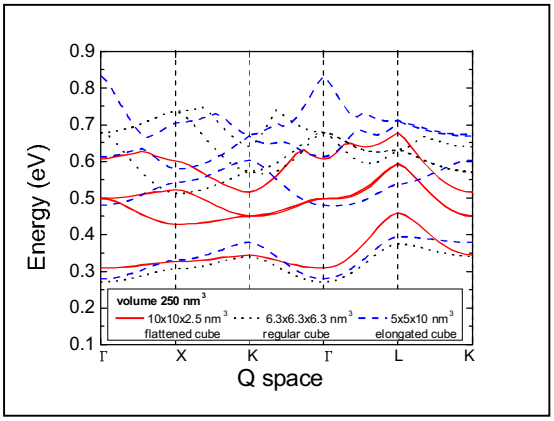

Fig. 2. Minibands for the three analyzed samples: flattened cuboids (solid lines), regular cubes (dotted lines) and elongated cuboids (dashed lines)

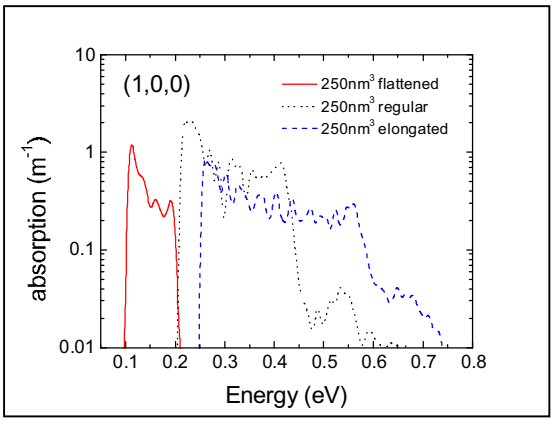

Fig. 3. Absorption coefficient for three different samples for light polarization in the (1,0,0) direction. Fermi energy was placed at the midgap of the quantum dot. Samples with 250 nm^3 and three different shapes were used to analyze the effect of changes in the shape.