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EXCITON BINDING ENERGY IN BULK AND QUANTUM WELL OF SEMICONDUCTORS WITH NON-PARABOLIC ENERGY BANDS

Payal Bhardwaj*, Nupur Das
** Department of Electronics and Telecommunication Engineering Jadavpur University, India*

Abstract: *We estimate Bohr radius and binding energy of exciton in bulk as well as quantum well for semiconductors with non-parabolic energy band structure. Kane type dispersion relation is used to incorporate such band non-parabolicity. Exciton binding energy in various III-V semiconductors are calculated for two different expressions of non-parabolicity factor α, and results are compared with those for parabolic energy bands. In presence of band non-parabolicity, exciton binding energies are found to increase in quantum wells, whereas such variation is almost insignificant in bulk semiconductors.*

Keywords: *Exciton, Binding Energy, Band non-parabolicity, III-V semiconductors*

INTRODUCTION

Exciton plays a key role in a wide range of opto-electronic devices used in optical communication systems or optical computers. Confinement of carriers leads to higher value of exciton binding energy in Quantum well (QW) or other low-dimensional systems. The energy spectrum and wave-functions of quantum confined excitons are strongly different from those of bulk excitons. The density of states changes from a smooth parabola in three dimensions to a stair case in two-dimensional (2D) system, which in turn, enhances the optical properties. Such enhancement of optical absorption and emission results in well-defined exciton lines in QWs [1] even at room temperature. Dingle et al. [2] were the first to observe enhanced excitonic effects in the quantum well structure, while Miller et al. [3] measured such increase in exciton binding energy in these structures. Bastard et al.[4] and Greene et al.[5,6] assumed confinement of the carriers in either an infinite or finite square quantum well and estimated binding energy of the exciton using variational technique. Leavitt and Little [7] presented a general method for calculating the exciton binding energies in various complex quantum confined semiconductor structures. In recent time, self-consistent approach is tried out [8], which is very effective for wide band-gap material and can be extended to asymmetric QW.

Excitonic absorption in QWs can be greatly varied by application of electric field along the direction of growth of the well and this phenomenon is termed as Quantum Confined Stark Effect (QCSE). In fact, strong modulation is obtained when absorption edge is dominated by excitonic effects. This is put to practical use in high performance semiconductor electro-optic modulators. Such devices based on zinc blende III-V semiconductors are being extensively used for data transmission, photonic switching and optical interconnects. At present, visible /ultraviolet electro-absorption modulators based on wide band gap nitride semiconductors viz. GaN films and GaN/AlGaN multiple Quantum wells [9] are being developed and characterized.

In general, the energy dispersion relation is assumed ideally to be parabolic. But the deviation of experimental results from the theoretical ones indicates the presence of non-ideal conditions. One such condition originates from band non-parabolicity. In semiconductors, the energy bands are parabolic only at the vicinity of allowed band edge. In bulk materials, higher energy states occupied by the carrier within conduction and valence bands may lie far away from the band-edge where assumption of parabolic energy band is no more valid. Such band non-parabolicity is more prominent in case of quantum structures, where carriers even in the ground states leave the band edges due to quantum size effect. Excitonic states are, therefore, expected to be profoundly influenced by the band non-parabolicity and are worth investigating.

In the present work, we calculate binding energy of the ground excitonic state in bulk semiconductor and in QW, the simplest quantum confined semiconductor structure, in presence of band non-parabolicity. In order to obtain exciton binding energy in bulk, we begin with the Schrödinger equation and use Kane dispersion relation to include non-parabolicity effect in it. The similar formulation is followed for 2D structure. From the derived results, exciton binding energies for various semiconductors are estimated using different expressions of non-parabolicity factor.

It is evident from Table II that in the case of semiconductors with parabolic energy bands, the exciton binding energy in QW is enhanced four times with respect to that in bulk. The Table further indicates that the influence of band non-parabolicity is almost insignificant on excitons in bulk materials. However, such influence is quite pronounced in case of QW. The tabulated results reveal that exciton binding energy in QW with $\alpha \neq 0$ is even greater than four times of that in bulk with $\alpha = 0$. In presence of band non-parabolicity, carrier energies are lowered, which effectively reduces the electron-hole separation and in turn, increases the exciton binding energy. It may further be noted that the original expression (4) and the approximate one (5) of non-parabolicity factor α do not make any significant change in estimated binding energies. Thus, the simple form of α can safely be used in calculating exciton binding energy.

CONCLUSIONS

In 2D systems, due to quantum size effect ground states electron and hole are lifted with respect to the allowed band edges. Such energy level lifting will increase in Quantum Wires and Quantum Dots due to higher degree of confinement. So, influence of band non-parabolicity is expected to be more and more prominent, and can be further investigated for structures with dimensionality lower than 2D.

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