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ON THE QUANTUM CONFINED STARK EFFECT IN SOME SEMICONDUCTOR NANOSTRUCTURES

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Abstract. *In this work we will introduce quantum dots, wires and wells as nanostructure objects with different dimensionality. We will demonstrate the effect of applied external static electric field on the example of semiconductor quantum wells and the appearance of Stark effect. We will briefly allude to some of the optoelectronic devices using Stark effect. The influence of quantum well concentration profile and width on Stark shifts will be examined in case of the system GaAs-AlGaAs. The applicability of the model investigations for preliminary evaluation e.g. of the optimal Al concentration profile in order to improve the Stark effect characteristics in quantum wells is considered.*

The present work is motivated by the tremendous interest in the semiconductor nanostructures [1-4]. This interest is due to their actual and potential applications in various electro-optical devices. Modern electronic and optoelectronic devices are approaching nanometric dimensions and employ semiconductor nanostructures. Nanostructures can be of three (dots), two (wire) and one (well) dimension. Here, we define the nanostructure dimensionality as the number of dimensions where the translational symmetry is broken. Devices based on one-dimensional (1D) nanostructures (superlattices and quantum wells) have already entered the marketplace. As example, electronic devices based on quantum wells (QWs), such as the high electron mobility transistor, have shown outstanding performances. Long-wavelength lasers for modern telecommunications have active regions with a sequence of QWs obtained from the heterojunction of two or more semiconductors. Physical phenomena related to semiconductor nanostructures, such as confinement of carriers in zero, one or two dimensions, are of great interest and have contributed to the definition of new concepts in modern solid-state physics. Semiconductor heterostructures and particularly, double heterostructures, including QWs, wires, and dots, are today the subject of research of two-thirds of the semiconductor physics community [1].

The purpose of this paper is to describe the quantum confined Stark effect in some semiconductor nanostructures, namely in the semiconductor QWs. QWs are very thin layered semiconductor structures [1,2,5]. Most of their special properties are due to the quantum confinement of charge carriers (electrons and holes) in thin layers of one semiconductor "well" material sandwiched between other semiconductor "barrier" layers. Quantum confinement of charge carriers forms the discrete energy levels in a QW for which the electronic and optical properties are quite different from the bulk semiconductors. Such good quality nanostructures can be made thanks to the great advances in modern epitaxial crystal growth techniques, which allow controlling the growth of thin films down to a single atomic layer. Many of the physical effects in QW structures can be seen at room temperature and can be exploited in real devices. Here we shall deal with the effects of static external electric field on the energy levels and optical properties in QWs. In semiconductor QWs, sharp excitonic absorption peaks are clearly observed even at room temperature. The electric field effects (hereafter termed Stark effects) on QW structures are very important for several reasons. They have received much attention due to the possibility of making various fast electro-optical devices. Actually, many semiconductor devices based on QWs work under an applied electric field. And also in any real transport experiment, external electric fields are applied to the system.

We will focus our attention to the absorption spectra in QWs in presence of an electric field. There are two kinds of Stark effects in QWs, depending on whether the electric field *F* is applied parallel to the growth (*z*) axis (longitudinal Stark effect) or perpendicular to it, i.e. in the plane of the well (transverse Stark effect). The transverse Stark effect problem is similar to the bulk problem and the excitonic transition essentially disappears at fairly low field (≤10 *kV/cm*). The absorption edge shifts to lower energy as in the bulk problem.

Under application of an electric field perpendicular to the QW layers, the energy levels are shifted from their zero-field positions which is known as the quantum confined Stark shift (QCSS). In another way, the Stark shift consists of a decrease of the energy of a given optical transition in a QW subjected to an electric field. The longitudinal electric field problem is of great interest since the exciton does not field ionized since the electron and hole states are confined because of the high barriers of the potential well. As a result, exciton transitions can persist up to electric fields of greater than 100 *kV/cm*. This effect is known as quantum confined Stark effect (QCSE) and has been used to design new optoelectronic devices, e.g., high-speed optical modulators, electro-optical bistable devices, infrared detectors, wave guides, fast switches and others. The QCSE can be understood on the basis of the same formalism as the one discussed for the exciton and band to band transitions in absence of the electric field as long as one can assume that the QW subband levels are reasonably confined states. In principle, the QW states are quasi-bound states in presence of the field with the wavefunction primarily peaked in the QW region. In the addressing exciton problem one assumes that the subband states are localized in the well and the exciton can be made up of only the confined states. There are several effects that occur in the presence of the longitudinal electric field:

1. The intersubband separations change. The field pushes the electron and hole functions to opposite sides (towards each band edge) making the ground state intersubband separation smaller. This effect is the dominant term in changing the exciton resonance energy.
2. Due to the separation of the electron and hole wavefunction, the binding energy of the exciton decreases (ground-state exciton peak energy decreases without severe line broadening of the exciton resonance).

For achieving high device performances, such as high on/off ratio and low operation voltage, it is desirable that the decrease in the exciton peak height be small and that this peak moves at a faster rate by using an applied electric field.

The study of the quantum confined Stark effect (QCSE) when a longitudinal electric field is applied to the QWs has attracted much attention both experimentally and theoretically [1-11]. Some of the experimental techniques employed in measurements of QCSE and energy level Stark shifts in QWs are: picosecond luminescence, absorption current spectroscopy, electroabsorption, photoluminescence spectroscopy, electroreflectance and time-resolved photoluminescence [7]. The experimental and theoretical investigations of the Stark effect mainly concern rectangular QWs but there are also studies for graded composition QWs and diffused QWs. For example we consider here *AlGaAs/GaAs* QWs with rectangular and graded gap *Al*-concentration profiles. QWs with a varying chemical composition are also called graded composition QWs or graded gap QWs. For practical reasons we are interested in QWs with particular optical or electro-optical properties. For instance, the so-called graded gap QW (GGQW) is more suitable for devices utilizing the Stark effect, rather than the rectangular QW (RQW) made out of homogeneous materials. The GGQWs were proposed in order to improve the Stark effect characteristics of the RQWs. The aim was to obtain a wider electric field region where the oscillator strengths are sufficiently large without any significant decrease of the Stark shifts. The *Al*–concentration profiles employed in practice were linear and parabolic profiles [10,11]. Even if the necessary preliminary data (for Stark effect in GGQWs) from experiments are available (or not), theoretical treatments of the Stark effect in QWs within realistic atomistic models [6-9] are still needed. As a result of such calculations it is possible to study the Stark shifts of the QW electronic states and their spatial distributions. With this essential and new information we can look for a potential profile that provides good Stark effect characteristics of a given QW. This will facilitate the search for new materials possessing unique electron and optical properties.

The effect of electric fields in nanostructures has been widely described in the tight binding (TB) context [3]. The flexibility of TB method in describing boundary conditions that are not periodic makes TB the best candidate for multi-band description of field-related effects in nanostructures [3,7-9]. For example, the Stark shifts of the transitions (C1-LH1) and (C1-HH1) in $Al_{0.3}Ga_{0.7}$ As/GaAs RQWs of four different well widths (18, 35, 71 and 99 monolayers) are calculated in [7] by TB approximation. The result is: the wider wells have larger shifts. In [7] one can see that the shifts depend also on the effective mass and the intensity of the electric field. The QW systems AlGaAs/GaAs are also investigated in [6,8] by TB method.

In summary, the study (experimentally and theoretically) of the QCSE when a longitudinal electric field is applied to the semiconductor QW structures is very important. This is due to the many possibilities for practical applications of this effect. It is possible to study the Stark shifts of the electronic states and their spatial distributions and to look for a potential profile that provides good Stark effect characteristics of a given quantum well.

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