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LASER FIELD EFFECT ON THE ANOMALOUS POLARIZATION IN SQUARE QUANTUM WELL UNDER HYDROSTATIC PRESSURE

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Lucrarea îşi propune un studiu al efectelor combinate ale unei radiaţii laser liniar polarizate, presiunii hidrostatice şi câmpului electrostatic asupra unei gropi cuantice dreptunghiulare din $GaAs/Al_xGa_{1-x}As$ *. Rezultatele arată că polarizarea anomală a primului nivel excitat este parţial compensată de prezenţa radiaţiei laser. Energia de tranziţie între nivelele de subbandă poate fi modificată prin variaţia intensităţii câmpului laser şi a presiunii hidrostatice.*

The polarization of the carriers in an electric field in GaAs/AlGaAs quantum well under the simultaneous action of the high-frequency laser filed and the hydrostatic pressure is investigated. The results show that the anomalous polarization of the first excited level is partially compensated by the presence of the laser radiation. The intersubband transition energy can be tuned by changing laser field intensity and hydrostatic pressure.

Keywords: Square quantum well, anomalous polarization, laser field radiation

1. Introduction

In the last decades the study of semiconductor heterostructures, particularly under the action of external fields, has attracted the interest of many researchers. The effect of an applied electric field on the electronic levels in quantum wells was presented in earlier studies [1-3]. In recent years, these studies have been extended to low-dimensional systems under intense laser fields. This is due to the possibility to develop novel devices based on the intersubband transitions such as far-infrared photo-detectors [4-8], electro-optical modulators [9-11], and infrared lasers [12, 13].

In this study, we have investigated the effects of the electric and high-frequency laser fields on the energy states in a GaAs/AlGaAs quantum well under a hydrostatic pressure.

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2. Theory

We assume an electron subjected to a time-independent potential $V(\vec{r})$ and under the simultaneous action of a laser radiation field represented by a monochromatic plane wave of frequency ω, a hydrostatic pressure and a static electric field. For a linear polarization, the vector potential associated with the radiation field is given by $\vec{A}(t)=\vec{e}A_0\cos(\omega t)$, where $\vec{e}$ is the unit vector of the polarization. The motion of the electron in the laser field is described by

$$\vec{\alpha}(t)=\vec{e}\alpha_0\sin(\omega t), \qquad \alpha_0=\frac{qA_0}{m^*\omega} \tag{1}$$

where q and m^* are the charge and the effective mass of the electron, respectively, and α_0 is the laser-dressing parameter.

In the high-frequency limit [14] the laser-dressed potential is given by

$$V_d(\vec{r},\vec{\alpha}_0)=\frac{\omega}{2\pi}\int_0^{2\pi/\omega}V(\vec{r}+\vec{\alpha}(t))dt \tag{2}$$

For an electron in a square quantum well (SQW) under a laser field with the vector of the polarization along the growth direction, and under the hydrostatic pressure p the Hamiltonian $H_z(\alpha_0,p)$ can be written

$$H_z(\alpha_0,p)=-\frac{\hbar^2}{2m^*_{w,b}(p)}\frac{d^2}{dz^2}+V_d(z,\alpha_0,p)+qFz \tag{3}$$

Here $m^*_{w,b}(p)$ is the effective mass in the well (barrier) material and $V_d(z,\alpha_0,p)$ is the laser-dressed confinement potential, both modified by pressure, and F is the electric applied field. The hydrostatic pressure dependence of the electron effective mass and the potential barrier is considered, for example, in the work of Raigoza et al. [15].

For SQW the dressed confinement potential is given [16] by the expression

$$V_d(z,\alpha_0,p)=\begin{cases}0, & |z|\in[0,b-\alpha_0) \\ \dfrac{V_0(p)}{\pi}\arccos\dfrac{b-|z|}{\alpha_0}, & |z|\in[b-\alpha_0,b+\alpha_0] \\ V_0(p), & |z|\in(b+\alpha_0,+\infty)\end{cases} \tag{4}$$

where $b=L/2$ is the half-width of the QW and $V_0(p)$ is the height of the barrier.

In absence of the electric field, we calculate an effective width $L_{eff}(\alpha_0,p)$ for infinite well, which gives the same energy levels of a “dressed” finite quantum well.

For a charged particle in this effective infinite well under a uniform electric field F, the Schrödinger equation can be written as

$$-\frac{\hbar^2}{2m^*}\frac{\mathrm{d}^2}{\mathrm{d}z^2}\zeta(z)-(E+qFz)\zeta(z)=0 \tag{5}$$

In order to transform this equation into the Airy differential equation it is convenient to use the new variable Z:

$$Z=-\left[\frac{2m^*}{(q\hbar F)^2}\right]^{1/3}(E+qFz) \tag{6}$$

So, the new form of the Schrödinger equation is

$$\frac{\mathrm{d}^2}{\mathrm{d}Z^2}\zeta(Z)-Z\zeta(Z)=0 \tag{7}$$

whose solutions are of the form

$$\zeta(Z)=a\mathrm{Ai}(Z)+b\mathrm{Bi}(Z) \tag{8}$$

where a and b are two constants and Ai(Z) and Bi(Z) are the Airy functions [2]. The boundary conditions are

$$\zeta(Z_+)=\zeta(Z_-)=0 \tag{9}$$

where $Z_\pm=Z\left(\pm\frac{1}{2}L_{eff}\right)$. The eigen-energies are determined as the solutions of the equation

$$\mathrm{Ai}(Z_+)\mathrm{Bi}(Z_-)-\mathrm{Ai}(Z_-)\mathrm{Bi}(Z_+)=0 \tag{10}$$

3. Results and conclusions

For our calculations we consider a GaAs/$Al_{0.3}Ga_{0.7}As$ SQW with L=100Å and $m_w=0.0665m_0$.

When the barrier height of the quantum well is finite, it is well known that the wave functions of the electrons leak into the barrier region. Thus the effective well width L_{eff} is usually larger than the true well width. Fig.1 shows the dependence of the obtained L_{eff} on the laser field parameter for the ground state energy (E_1) and the first excited state energy (E_2) and for two pressure values. We observe a reduction of the effective well width as the laser parameter increasing for both energy states. This is due to the decreases of the effective well width (lower part of the confinement potential) with the laser field [17]. Also L_{eff} decreases with pressure increasing [18].

The dependence of E_1 and E_2 energy levels on the electric field for different laser parameters and for two pressure values is presented in Fig.2. We observe that in zero laser field (α_0 = 0) the ground state energy E_1 lowers and the first excited state E_2 raises slightly with F, in accord with previous calculations for square quantum wells [19]. One notes that by increasing the laser parameter the quantum-confined Stark effect behavior is still parabolic with the electric field for both levels.

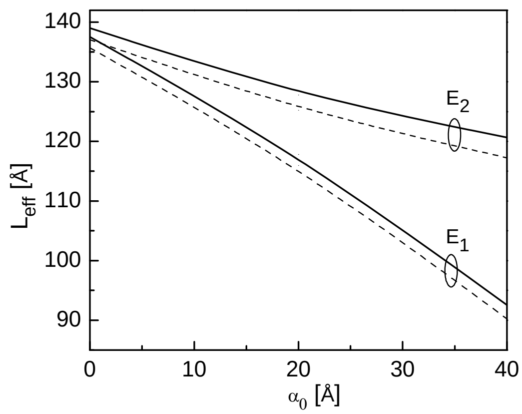

Fig.1. Effective well width versus the laser field parameter for the ground (E_1) and first excited (E_2) levels and for p = 0 (solid line) and p = 13.5 kbar (dashed line).

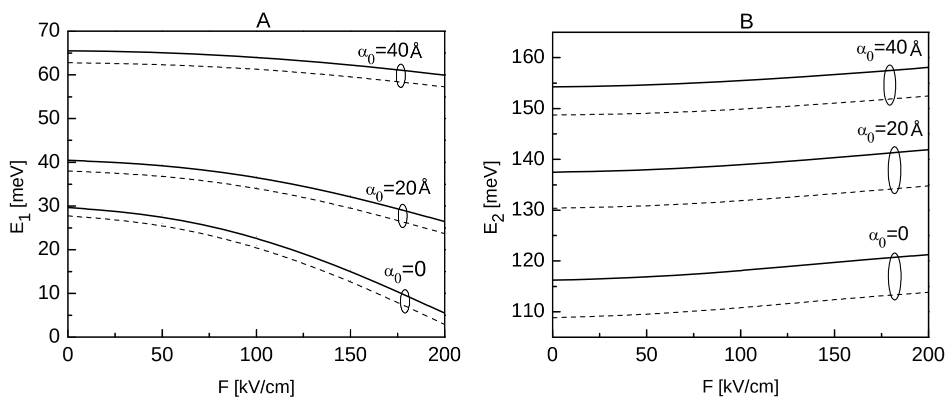

Fig.2. The ground energy level (A) and the first excited energy level (B) versus the electric field for different α_0 values and for p = 0 (solid line) and p = 13.5 kbar (dashed line).

We have also calculated the two-level transition energy; the results are shown in Fig.3 as a function of the electric field for different α_0 and pressure values.

In Fig.4 the effects of the electric and laser fields on the ratio of the probability of finding an electron on the right-hand side to the left-hand side of the well for the ground and the excited states are presented. The electron distribution becomes asymmetric due to the electric field polarization for the both electronic states. For the ground state the ratio decreases with the electric field as expected. On the contrary, our calculations show an anomalous response of the excited state to the electric field. A negative polarization (the maximum of the probability distribution is moved in the field direction) is obtained, which leads to a ratio increases with the strength of the electric field *F*.

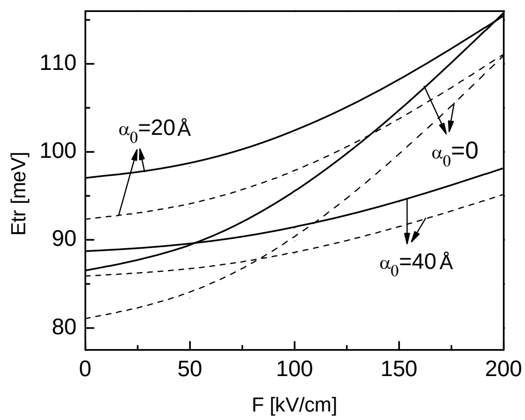

Fig.3. Transition energy as a function of the electric field for different α_0 values and for p = 0 (solid line) and p = 13.5 kbar (dashed line).

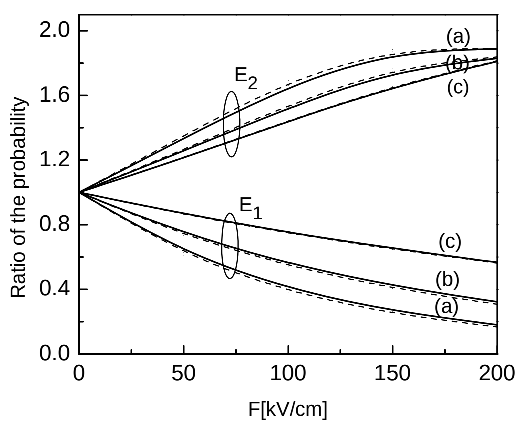

Fig.4. Ratio of the probability versus the electric field for different values of the laser parameter and for p = 0 (solid line) and p = 13.5 kbar (dashed line). Notations (a), (b) and (c) are associated with α_0= 0, α_0= 20Å, and α_0= 40Å, respectively.

We observe that the laser radiation, which reduces the well height, partially compensates the electric field induced asymmetry and reduces the ratio values for the both levels.

It has be pointed out that the anomalous behavior of the excited states in the electric field can be obtained only by the use of Airy functions or advanced numerical techniques [19].

In conclusion, the results obtained show that the polarization effect due to electric field in a finite quantum well exhibits different physical phenomena for the ground and the excited states. In the excited states a displacement of the maximum of the probability of finding an electron along the field is obtained and this anomalous polarization is reduced in the presence of a high-frequency laser field.

R E F E R E N C E S

[1]. *S.L. Chuang and D. Ahn*, J. Appl. Phys. 65, 1989, p. 2822.
[2]. *D.A.B. Miller, D.S. Chemla, T.C. Damen, A.C. Gossard, W. Wiegmann, T.H. Wood and C.A. Burrus*, Phys. Rev. B 32(2), 1985, p. 1043.
[3]. *E. Niculescu, A. Radu, A. Iorga*, U.P.B. Sci. Bull., Series A **70** (3), 2008, p. 51.
[4]. *L.C. West and S.J. Eglash,* Appl. Phys. Lett. 46, 1985, p. 1156.
[5]. *R.J. Turton and M. Jaros*, Appl. Phys. Lett. 47, 1989, p. 1986.
[6]. *F. Capasso, K. Mohammed and A.Y. Cho*, Appl. Phys. Lett. 48, 1986, p.478.
[7]. *K.W. Gossen, and S.A. Lyon*, Appl. Phys. Lett. 47, 1985, p.289.
[8]. *K.K. Choi, B.F. Levine, C.G. Bethea, J. Walker,and R.J. Malik*, Appl. Phys. Lett. 50, 1987, p.1814.
[9]. *D. Ahn and S.L. Chuang*, Phys. Rev. B 35, 1987, p. 4149.
[10]. *D. Ahn and S.L. Chuang*, Phys. Rev. B 33, 1986, p. 9034.
[11]. *R.P.G. Karunasiri, Y. J. Mii, and K.L. Wang*, IEEE Electr. Device L 11, 1990, p. 227.
[12]. *R.F. Kazarinov, and R.A. Suris*, Sov. Phys. Semicond. 5, 1971, p. 707.
[13]. *J. Faist, F. Capasso, D.L. Sivco, C. Sirtori, A.L. Hutchinson, and A.Y. Cho*, Science 264, 1994, p. 553.
[14]. *M. Gavrila and J.Z. Kaminski*, Phys. Rev. Lett. 52, 1984, p. 613.
M. Marinescu, and M. Gavrila, Phys. Rev. A **53**, 2513 (1995).
[15]. *N. Raigoza, C.A. Duque, E. Reyes-Gomez, L.E. Oliveira*, Phys.Stat.Sol. (b) 243, 2006, p. 635.
[16]. *O.O.D. Neto and Q. Fanyao*, Superlatt. Microstruct. 35, 2004, p.1.
[17]. *E. Ozturk, H. Sari, and I. Sokmen*, Solid State Commun. 132, 2004, p. 497.
[18]. *A. John Peter, and K. Navaneethakrishnan*, Superlatt. Microstruct. 43, 2008, p. 63.
[19]. *S.E. Okan, I. Erdogan and H. Akbas*, Physica E 21, 2004, p. 91.