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g-Factor of Electrons in Kane Type Quantum Wells Under Crossed Electric and Magnetic Fields

Arif Babanlı[1], Deniz Türköz Altuğ[2,*]

[1] *Süleyman Demirel University, Faculty of Arts&Siences, Deprtmant of Physics, 32260, Isparta, Turkey*
[2] *Süleyman Demirel University, Hydrogen Technology Research and Application Center, 32260, Isparta, Turkey*
**corresponding author e-mail: denizturkoz@sdu.edu.tr*

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Abstract: In this paper, effective g -factors of the electronsin Kane type GaAs semiconductor in the infinite potential wellin the presence electric field and magnetic field have been calculated. The magnetic field was applied parallel to interfaces in the z direction and electric field ***F*** was applied perpendicularly to the interfaces along the *y* direction. g-factor as a function of the oscillation center was constant for ground state andparabolic for first excited in uniform magnetic field was without electric field. When the electric field was present, Lande-factor according to oscillation center decreased linearly for ground state and was non parabolic for first exited level in uniform magnetic field. We have found out that g-factor increase as the electric field increase.

Key words: Well type potential, Kane type semiconductor, g-factor

Çapraz Elektrik ve Magnetik Alan Altında Kane Tipi Kuantum Kuyusunun Elektronlarının g-Çarpanı

Özet: Bu çalışmada, Kane tipi GaAs yarıiletken sonsuz kuyu potansiyelinde elektrik ve magnetik alanın olduğu durumda elektronların etkin g çarpanı hesaplandı. Magnetik alan kuyunun sınır yüzeyleri arasına z-ekseni boyunca, elektrik alan F, y-ekseni boyunca yüzeylere dik uygulandı. Sabit elektrik alan yokken elektronun etkin g-çarpanının değeri, osilasyon merkezinin bir fonksiyonu olarak, taban durumu için sabit, uyarılmış durum için ise parabolikti. Sabit magnetik alanda, elektrik alan uygulandığında Lande çarpanının osilasyon merkezine göre değişimi, taban durumu için düzgün azalırken ilk uyarılmış durum için parabolik değildi. Ayrıca g-çarpanın elektrik alanın artmasıyla arttığını bulduk.

Anahtar kelimeler: Kuyu tipi potansiyel, Kane tipi yarıiletkenler, g-çarpan

1. Introduction

There has been considerable interest in studying the spin-dependent effect in semiconductor nanostructures, in recent years [1]. The Zeeman splitting of electron spin states of quantum well structures has been calculated by using Kane Model in Refs.[2,3]. Malinowski and Harley did an experimental measurement of the effective Lande factor in GaAs-$Al_{0.35}Ga_{0.65}As$ and strained GaAs-$In_{0.11}Ga_{0.89}As$ quantum wells under applied magnetic fields(2000) [4]. The response of the spin to an external magnetic field is determined by the g- factor (the Lande factor),which is a very important parameter for semiconductors [5].Spin-splitting and the spin resonance of spin-splitting factor to control and to interpret experimental observations is of great importance in condensed matter physics. Spin-splitting Lande factor (g)of the free electron shows interaction with the magnetic field of electron conditions. The value of the effective g-factor of electrons radically changes with the interaction of electron conditions by the crystal potential in condensed matter physics [2,6,7]. Spin-splitting factor can take very large positive values and too small negative values in various structures [8]. For instance; g = 2 in the free electron, in large the forbidden band gap semiconductor g =0.44 in GaAs, small forbidden band gap g = -50 in InSb [5,9]. Ivchenko and his friends (1997) calculated theoretically electronic g-factor in electric field. They found that g-factor was inclining as the electric fields went up [2]. Our subject was previously studied by Ivchenko and his friends but by using a different method, by using perturbation theory to calculate g-factor. Besides, they investigated g-factor according to well width, another differing point from our study [6]. Babayevby using three-band Kane's Model, energy spectrum of carriers with magnetic field, electron light hole effective g-factors in InSb quantum well calculated without the perturbation theory [10]. In this study, we used different material and conditions from Babayev's study. We calculated that g factor with electric field in GaAs.

2. Materials and Methods

Figure 1 shows the structure that was used in this study. Magnetic field B is applied parallel to the interfaces along the *z*-direction. Electric field *F* is applied perpendicularly to the interface along the y-direction [11].

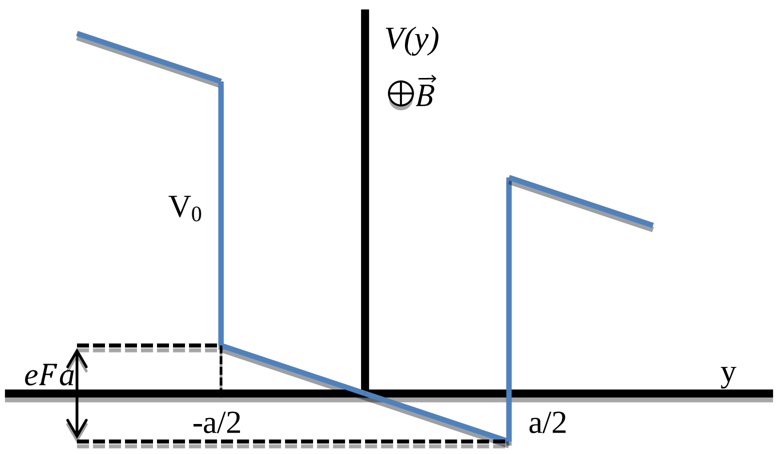

Figure 1. An infinite quantum well of depth $V_0=\infty$and width a in external, mutually perpendicular electric fieldand magnetic field, ***F***=F***y=U/a*** and***B***=B***z*** [11]

A single effective-mass approximation Schrödinger equation is as follow for the considered quantum well;

$$\{\frac{1}{2m(E)}[p+eA]^2+V(y)+\frac{1}{2}g\mu_B B\sigma_z-E\}\psi(x,y,z)=0 \tag{1}$$

Where *m (E)* is effective mass in Kane's model, *e* is absolute value of electron charge, μ_B-Bohr magnetone, A vector potential; A=(-*B*y, 0,0), V (y) is potential of the well.

Relationship between effective g-factor and effective mass is as follow in Kane type semiconductors [12].

$$\frac{1}{m(E)}=\frac{1}{m_n}\frac{\mathrm{E_g}(\mathrm{E_g}+\Delta)}{3\mathrm{E_g}+2\Delta}\frac{3E+3\mathrm{Eg}+2\Delta}{(E+\mathrm{Eg})(E+\mathrm{Eg}+\Delta)} \tag{2}$$

$$g(E)=g_0-\frac{2m_0}{m_n}\frac{\Delta}{(E+\mathrm{E_g})(E+\mathrm{E_g}+\Delta)}\frac{\mathrm{E_g}(\mathrm{E_g}+\Delta)}{3\mathrm{E_g}+2\Delta} \tag{3}$$

HereE_g-forbidden band gap, Δ-spin-orbital splitting, m_0-free electron mass, m_n- effective mass at the conduction band bottom.V (y) is the potential of the infinite well. For the value of infinite well electric potential energy given by

$$V(y) = \begin{Bmatrix} \infty & , & |y| > a/2 \\ -\frac{eU}{a}\left(y - \frac{a}{2}\right) & , & |y| \leq a/2 \end{Bmatrix} \quad (4)$$

Here U; electric field, a; width of quantum well. The electron wave function may be written as

$$\psi(x, y, z) = e^{i(k_x x + k_z z)}\chi\,(y) \quad (5)$$

$$\{\frac{d^2}{dy^2} - \frac{{m_0}^2\Omega^2}{\hbar^2}(y - y_0)^2 - \frac{p_z^2}{\hbar^2} - \frac{2m(E)}{\hbar^2}V(y) - \frac{2m(E)}{\hbar^2}\frac{1}{2}g\mu_B B\sigma_z + \frac{2m(E)}{\hbar^2}E\}\chi(y) = 0 \quad (6)$$

where$y_0 = \frac{\hbar k_x}{m_0\Omega}$ is the location of the center of magnetic oscillations , $\Omega = \frac{eB}{m_0}$is cyclotron frequency, g is effective g factor. When applying the change of variables;

$$\xi = \sqrt{\frac{2m_0\Omega}{\hbar}}(y - y_0 - \gamma_{\boldsymbol{B}}) \quad (7)$$

Where

$$\gamma_{\boldsymbol{B}} = \frac{eUm(E)}{m_0^2 a\Omega^2}$$

Inserting expression (7) in to equation (6) and some algebra, after some algebra, following equation is expression (8).

$$\{\,\frac{d^2}{d\xi^2} - \frac{\xi^2}{4} - c\}\chi(y) = 0 \quad (8)$$

Here c;

$$c = -\frac{m(E)}{m_0}\frac{1}{\hbar\Omega}\left(E - \frac{eU}{2} + \frac{eU}{2a}(2y_0 + \gamma_B) - \frac{p_z^2}{2m(E)} - \frac{1}{2}g\mu_B B\sigma_z\right) \quad (9)$$

Solving of (8) equation is as follow [7].

$$\chi(y) = W(c, \xi) = A_1 U(c, \xi) + B_1 V(c, \xi) \quad (10)$$

Where; $U(c, \xi)$and $V\,(c, \xi)$are parabolic cylinder function.

According to boundary condition in y=-a/2 and y=a/2,wave function is zero in these points. The matching conditions give rise to a set of linear homogeneous algebraic equations and the requirement of vanishing the determinant of this linear system for important solution eventuate following equation.

$$U(c,-\tfrac{a}{2})V(c,\tfrac{a}{2}) = U(c,\tfrac{a}{2})V(c,-\tfrac{a}{2}) \quad (11)$$

We found the resulting equation determines the discrete energy eigenvalues E (y_0) in the plane perpendicular to B as functions of B, F and a. Also Equation (11)is needed for calculation of energy of electrons.

The effective electron g-factor can be obtained by the following expression, whichis calculated by using Zeeman splitting

$$g(E) = \frac{E_\uparrow - E_\downarrow}{\mu_B B} \quad (12)$$

Here $E_\uparrow$and$E_\downarrow$energy of electrons shows respectively for spin up and spin down. It was used in this calculation that Eq. (12), for GaAs type quantum wells for the fixed magnetic field value B=200T, U=0 and 0.8 (in Fig.2 and 3) and 200T, a=10nm, m=0.067 x m*. The following band parameters have been used for GaAsE_g= 1.52 eV, Δ=0.34 eV [13].

3.Findings

In Fig.2the electron g-factor is shown as a function of oscillation center y_0 of infinite quantum well for GaAs.

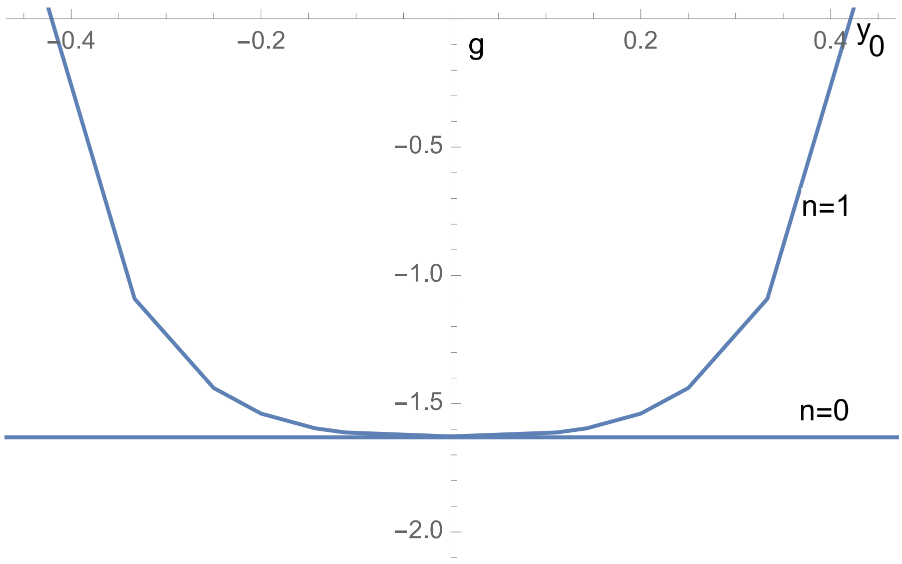

Figure 2. Effective g-factor of electron as a function of oscillation center y_0 (Where U=0, B=200T, a=10nm)

Effective g-factor of electron as a function of oscillation center y_0 is shown to be constant for n=0 quantum level, parabolic for n=1 quantum level without electric field in Fig. 2.

Then, Fig. 3 shows that constant electric field is applied constantly in this model.

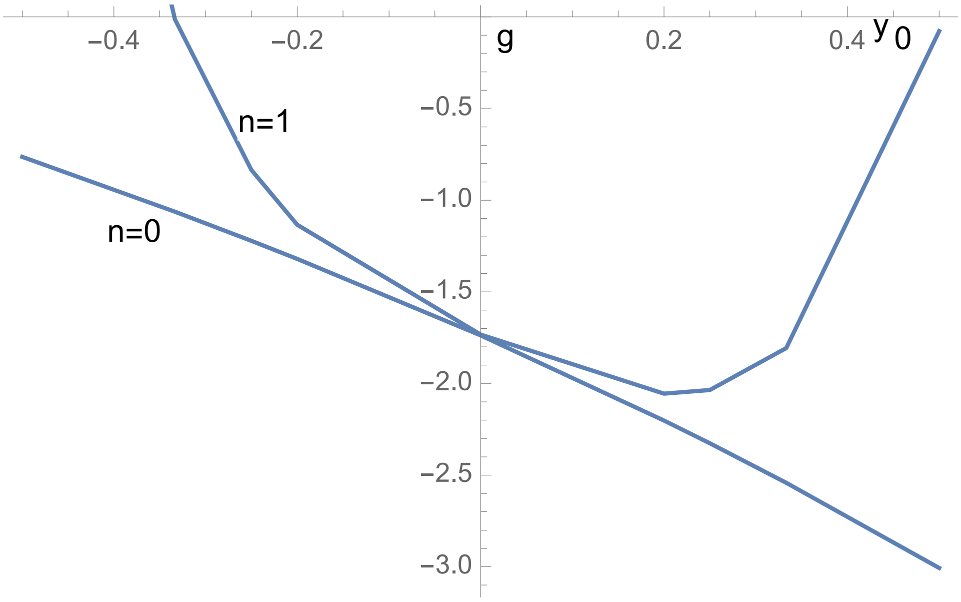

Figure 3. Effective g-factor of electron as a function of oscillation center y_0 (Where U=0.8, B=200T, a=10nm)

Effective g-factor values of electron is observed to reduce linearly for quantum level n=0, and to deteriorate in a parabolic for quantum level n=1 in electric field in Fig.3. It has also been observed that a serious approach between the quantum levels (n=0 and n=1) exists when both the electric field and without electric field in the y_0=0 position (in Fig.2 and Fig. 3).

Fig.4 shows g-factor of electron as a function of electric field.

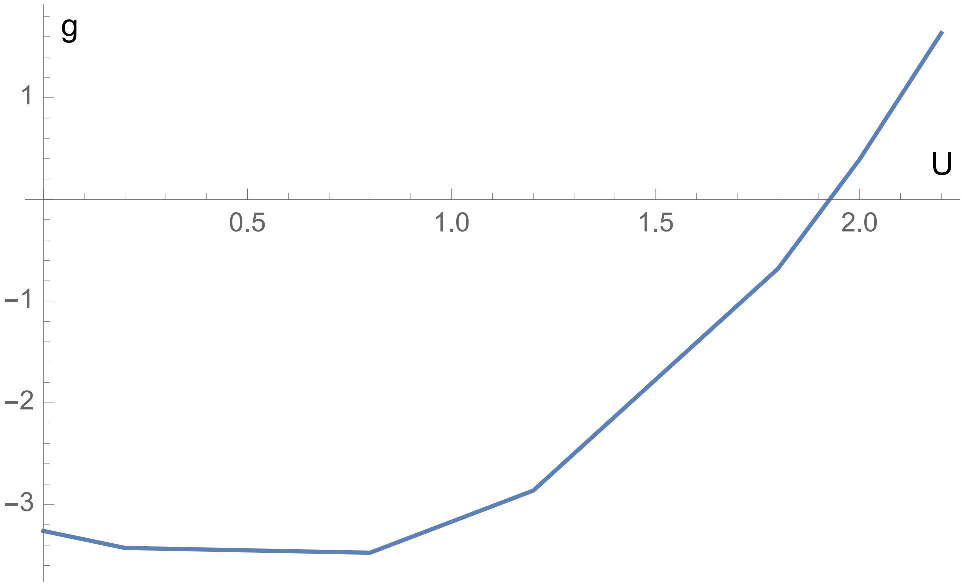

Figure 4. g-factor of electron as a function of electric field (Where B=200T)

Where magnetic field is fixed at 200T. Furthermore, g factor of electron as a function electric field has increased (In Fig.4).

4. Discussion and Results

In this study, we theoretically investigated g-factor of electron on Kane type semiconductor GaAs in with and without electric field. Uniform magnetic field, which directed along z-axis was applied. Under this condition, g-factor according to y_0 oscillation center was constant for n=0 quantum level and g-factor changed parabolic for n=1 quantum level. Then, uniform electric field that was directed along y-axis was applied on system. g-factor has linear decrease for n=0 quantum number and nonparabolic for n=1 quantum number in electric fields. Also anticrossing have been observed for two situations, both with and without electric field was in n=0 and n=1 quantum numbers in the oscillation center y_0=0. Change of g-factor investigated for various electric fields under the uniform magnetic field. We have found out that g-factor as a function of the electric field increases.

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Arif Babanlı e-mail: arifbabanli@sdu.edu.tr