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SECTION 3. Nanotechnology. Physics

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THE DEPENDENCE OF THE ENERGY ABSORBED PHOTON ON THE MAGNETIC FIELD IN SEMICONDUCTORS

Abstract: *Compared change the oscillation of the joint density of states by the energy absorbed photon for different Landau levels in the non-parabolic and parabolic zone. It is shown that in the non-quadratic dispersion law the maximum frequency of the absorbed light and the band gap nonlinearly depend on the magnetic field. The theoretical results are compared with experimental results, obtained for InAs.*

Key words: *joint density of states, Landau levels, non-parabolic and parabolic zone, photon, semiconductor.*

Language: *English*

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1. INTRODUCTION

In the past decade, oscillations magneto-absorption were observed in the absorption spectra of many semiconductor crystals. The study of magneto-optical effects in semiconductors - one of the most powerful sources of information about their band structure. In [1] explained the dependence of the integrated absorption in semiconductors on the magnetic field observed experimentally at low temperatures. On the basis of the integral absorption it shows that the samples examined in the strong magnetic field generated diamagnetic exciton polaritons. In [2,3] studied the temperature dependence of the edge of the fundamental optical and magneto-optical absorption of long structures $In_xGa_{1-x}As/GaAs$ with different numbers of quantum wells. The experimental results are interpreted using the exciton-polariton light transfer mechanism involving localized excitons in confined structures with a finite number of quantum wells. Interest in the study of the oscillations of the Shubnikov-de Haas (ShdH) and de Haas-van Alphen (dHvA) increased after their detection in low-dimensional systems, for example in silicon nanostructures [4] and cadmium fluoride in superconducting shells. In this case, the energy position of the size quantization levels determine the spectrum of the Landau levels. In [5] have been discovered and investigated the effect of oscillations dHvA depending on the temperature of nanoscale semiconductors. All effects, depending on the density of states, may under certain conditions to oscillate with a period determined by the interval between two successive coincidences Landau level.

This fact is reflected in the fact that many of the expressed electron gas thermodynamic, electrical and optical values, expressed in terms of the density of states, under certain conditions, will oscillate when the magnetic induction and low temperatures [6-8]. However, these studies did not consider the changes of the combined density of states in the non-parabolic dispersion law in the presence of a magnetic field.

The aim of this work to study the dependence of the absorbed photon energy from the magnetic field in semiconductors with Kane dispersion law and a comparison of the theory with experimental data.

2. THEORETICAL PART

2.1. The dependence of the oscillation joint density of states on the energy absorbed photon in semiconductors with the nonparabolic dispersion law

Consider the change of oscillations joint density of states (JDOS) in semiconductors with nonparabolic dispersion. Non parabolic conduction band for the electrons can be wrote the following expression [9]:

$$E_c = -\frac{E_g}{2} + \frac{1}{2}\sqrt{E_g^2 + 4E_g\left[\left(N+\frac{1}{2}\right)\hbar\omega_c + \frac{\hbar^2 k_z^2}{2m_n}\right]} \quad (1)$$

The beginning of the energy scale is selected the bottom of the conduction band. Hence, nonquadratic dispersion law holes recorded in the same way:

$$E_v = -Ec - E_g =$$

$$-\frac{E_g}{2} - \frac{1}{2}\sqrt{E_g^2 + 4E_g\left[\left(N+\frac{1}{2}\right)\hbar\omega_c + \frac{\hbar^2 k_{pz}^2}{2m_p}\right]} \quad (2)$$

Here, E_v- energy ceiling valence band. Note that both the dispersion law (1) and (2) are isotropic, the effective mass of holes and electrons are equal: $m_n=m_p=m$. his behavior of the spectra of holes and electrons is related to the internal symmetry of narrow-gap semiconductors [10, 11]. The law of conservation of quasi-momentum will be as follows: $k_h = k_c = k$. Here, k_h, k_c- the wave vectors of holes and electrons are respectively [11].

For these energy bands from the expression (1) and (2):

$$E = h\nu = E_c(k_z, B) - E_v(k_z, B) =$$

$$\sqrt{E_g^2 + 4E_g\left[\left(N+\frac{1}{2}\right)\hbar\omega_c + \frac{\hbar^2 k_z^2}{2m}\right]} \quad (3)$$

Here, $h\nu -$ energy absorbed photon.

We now find JDOS with energies in the range between Landau levels. Using the expression $m_c = \frac{\hbar^2}{2\pi}\frac{\partial S}{\partial E}$ for the cyclotron mass, we find the difference in basal area of two equal-energy surfaces, which differ on energy $\Delta E = \hbar\omega_c$:

$$\Delta S = \frac{2\pi m_c}{\hbar^2}\Delta E = \frac{2\pi m_c}{\hbar^2}\hbar\omega_c$$

The number of states per unit area in a plane $k_x k_y$ for quantization, due to cyclic conditions as well $\frac{L_x L_y}{(2\pi)^2}$. That the number of states between two quantum orbits equal

$$\frac{L_x L_y}{(2\pi)^2}\Delta S = \frac{m\omega_c}{2\pi\hbar}L_x L_y$$

From equation (3) we define k_z:

$$k_z = \frac{(2m)^{\frac{1}{2}}}{\hbar} \times$$

$$\sqrt{\frac{(h\nu)^2}{E_g} - (E_g + 4(N+\frac{1}{2})\hbar\omega_c)} \quad (4)$$

We now turn to the calculation of JDOS with nonparabolic dispersion in a quantizing magnetic field. Free movement of electrons along the z axis, is not quantized by k_z. That is:

$$k_Z = \frac{2\pi}{L_Z}n_Z \quad (5)$$

According to the expression (4) and (5) the number of states in the range energy on $(N+\frac{1}{2})\hbar\omega_c$ to E

$$n_Z = \frac{(m)^{\frac{1}{2}}L_z}{2^{\frac{1}{2}}\pi\hbar}\cdot\sqrt{\frac{(h\nu)^2}{E_g} - (E_g + 4(N+\frac{1}{2})\hbar\omega_c)} \quad (6)$$

The total number of JDOS with energies less than E, as well

$$N(E,B) = \frac{L_x L_y L_z m^{\frac{3}{2}}}{2^{\frac{3}{2}}\pi^2\hbar^3}\hbar\omega_c \times$$

$$\sum_{N=0}^{N_{\max}}\sqrt{\frac{(h\nu)^2}{E_g} - (E_g + 4(N+\frac{1}{2})\hbar\omega_c)} \quad (7)$$

As a result, we define JDOS per unit volume with Kane dispersion law:

$$N_{jds}^n(h\nu, B) = \frac{dN(h\nu, B)}{dh\nu} =$$

$$\frac{(m)^{3/2}}{(2)^{1/2}\pi^2\hbar^3}\frac{\hbar\omega_c}{2}\sum_{N=0}^{N_{\max}}\frac{\frac{h\nu}{E_g}}{\sqrt{\frac{(h\nu)^2}{E_g} - (E_g + 4\hbar\omega_c(N+\frac{1}{2}))}} \quad (8)$$

Here, $N_{jds}^{n}(h\nu, B)$-JDOS with the nonparabolic dispersion law at quantizing magnetic field.

With the help of formula (8), we calculate JDOS in narrow-gap semiconductors in a quantizing magnetic field at nonparabolic dispersion law. In the figure 1 shows JDOS for InSb (Eg(0)=0,234 eV) in the magnetic field B=5 Тл. As can be seen from these figures, oscillations JDOS we observe, starting $h\nu = 0.44eV$ in non-quadratic dispersion law. Here, $h\nu -$ energy absorbed photon. Also, by using the expression (8) can be explained by the absorption coefficient of the magnetic field in nonparabolic dispersion law.

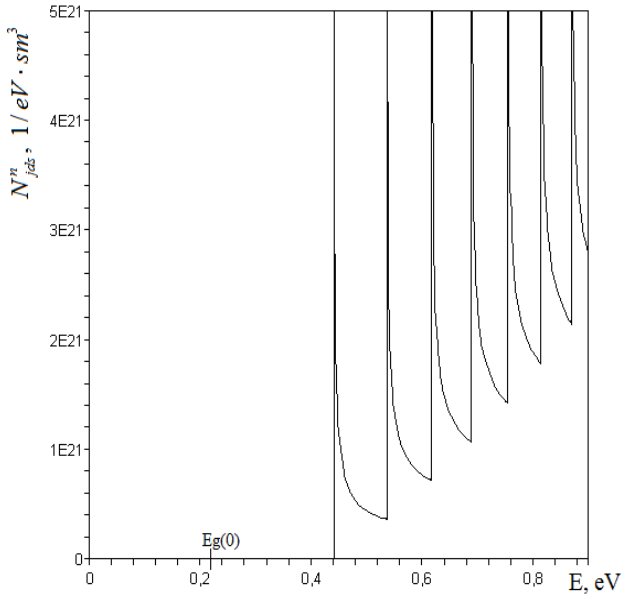


Fig.1. The dependence of oscillations JDOS on the energy absorbed photon in InSb with the nonparabolic dispersion law, calculated using the formula (8). Here, B=5 T.

Now we compare the oscillation JDOS in a parabolic dispersion and nonparabolic laws. From [12] we obtain oscillations JDOS with a quadratic dispersion law :

$$N_{jds}^{p}(E,H) = (\frac{2m_r}{\hbar^2})^{3/2}\mu_r H \times \sum_N \frac{1}{\sqrt{\hbar\omega - E_g - (2N+1)\mu_r H}} \qquad (9)$$

Here, $N_{jds}^{p}(E,H)$ - oscillations JDOS at parabolic dispersion law, $\hbar\omega -$ energy absorbed photon.

In figure 2 shows the change oscillations JDOS for the two types of zones. Here, N=0..20, B=2 T, for InSb. In these figures, in the range of E = 0..1,45 eV we have seen 20 of the Landau levels in nonparabolic zone, but in a parabolic zone number of Landau levels is equal to 6. Hence, it is clear that with increasing distance between Landau levels reduced electron energy curve JDOS moves to larger values JDOS and moved in up the density of states of the axis.

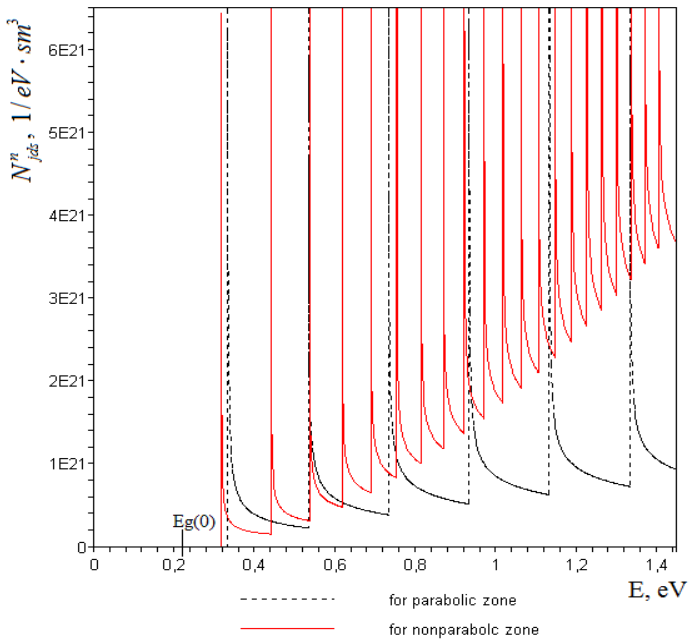


Fig.2. Oscillations JDOS in a strong magnetic field(B=2T.) at the parabolic and non-parabolic dispersion law

3. EXPERIMENTAL PART

3.1. The dependence of the band gap and the frequency of absorbed light on the magnetic field in nonparabolic dispersion law

Consider the change in the frequency of the absorbed light and the band gap in the non-quadratic dispersion law in the presence of a magnetic field. The sum of N (8) and (9) extends to all values of N, for which under radical expression is not negative. Those values ω, N *and* B, for which under radical expression in (8) and (9) is equal to zero, determine singular points of the absorption coefficient. These points correspond to the following condition:

$$\hbar\omega_{\max} = E_g + (2N+1)\mu_r H \qquad (10)$$

$$\hbar\omega_{\max} = \sqrt{E_g^2 + 4E_g(N+\frac{1}{2})\hbar\omega_c} \qquad (11)$$

Here ω_{max}- frequency of absorbed light is corresponding to the absorption maximum. In figures 3 and 4 are shows the maximum changes in the frequency of absorbed light in the magnetic field. From (10) we see that for a given N frequency ω_{max} absorbed light is linearly dependent on the magnetic field, and from (11) we see that the maximum frequency of light absorbed depends nonlinearly on the magnetic field at different Landau levels. From Figure 4, we see that with increasing number of Landau levels is enhanced nonlinearity ω_{max}.

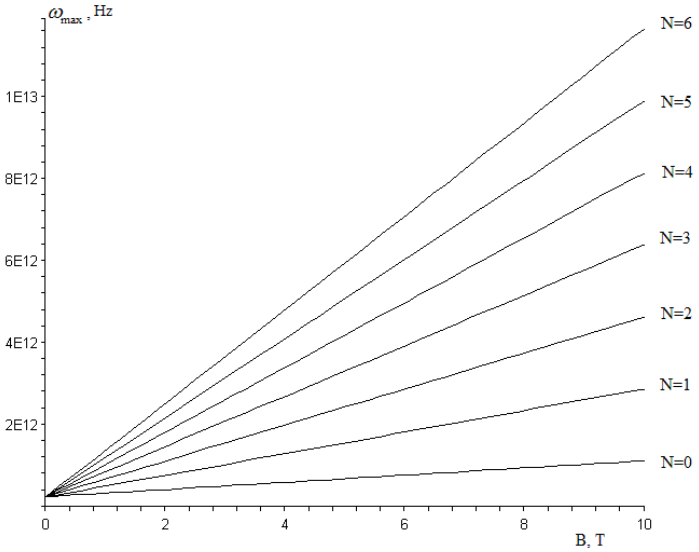


Fig.3. The dependence of the maximum frequency of absorbed light on the magnetic field for different Landau levels in a parabolic dispersion law [12].

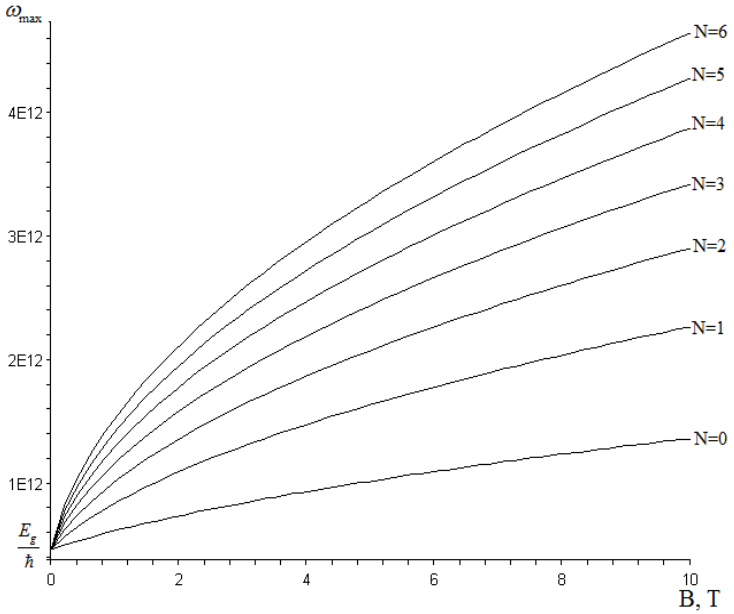
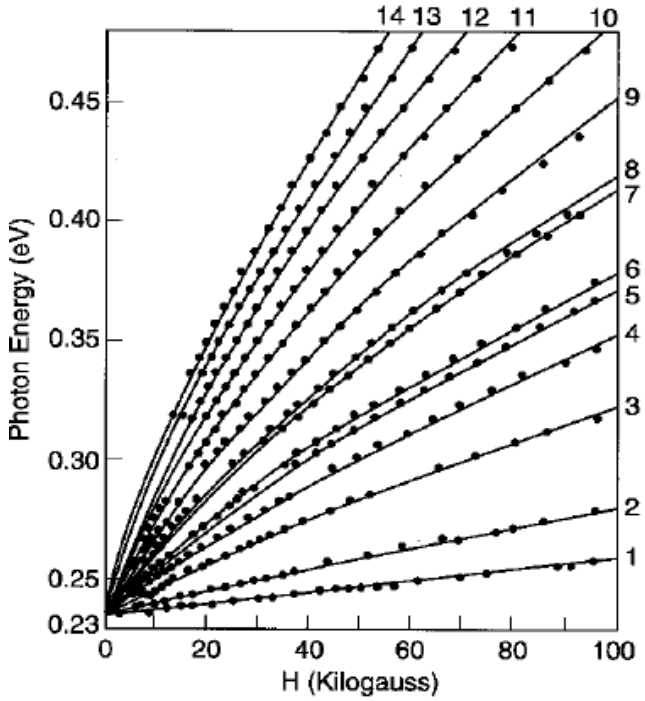
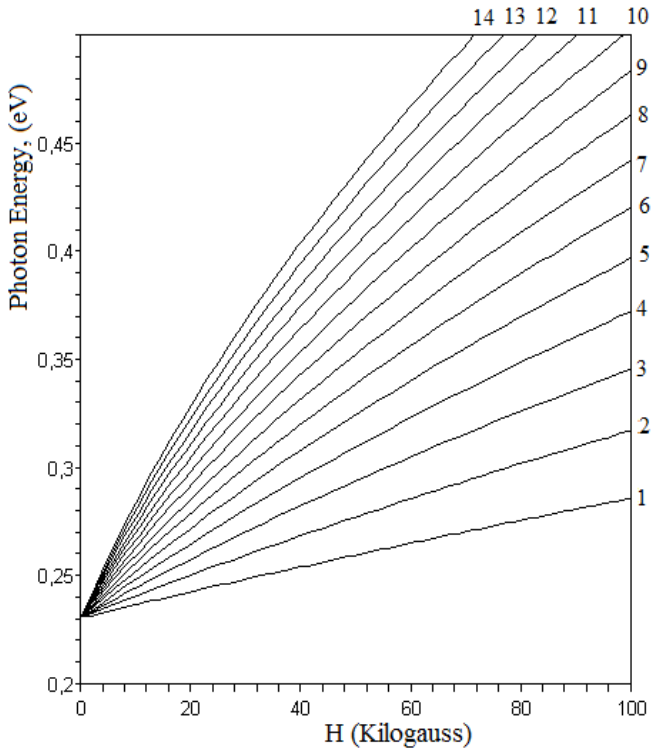


Fig.4. The influence of magnetic field on the maximum frequency of the absorbed light in nonparabolic dispersion law, by the formula (11).

In Fig.5a shows the change in the maximum energy of the absorbed photon by the strong magnetic field for InSb [13]. In these works there is a direct interband magneto-optical transitions in InSb at the temperature of liquid helium, using magnetic fields to 96,5 kOe. From this, we calculate the dependence of the maximum energy of the photon absorbed by a strong magnetic field in InSb with the aid of formula (11). As a result, we obtain the dependence of the absorbed photon energy from the magnetic field nonparabolic dispersion in InSb (Fig.5b). These figures show that the change in the maximum energy of the absorbed photon from the strong magnetic field of non-linear.



a)



b)

Fig. 5. Changing the maximum energy of the absorbed photon from the strong magnetic field for InSb. a) Experimental data [13], b) calculation of by the formula (11).

Fig. 6 shows the dependence of the band gap of indium arsenide on the magnetic field [14,15]. These figures show that the change in the band gap of the nonlinear zone. From (11) we determine the dependence of the band gap of the magnetic field at a constant energy of the absorbed photon:

$$E_g(B) = \frac{1}{2}[(2N+1)\hbar\omega_c + \sqrt{[(N+\frac{1}{2})\hbar\omega_c]^2 + (\hbar\omega)^2}] \qquad (12)$$

From (12) it is clear that the change of the band gap is not proportional to B. Figure 6 is a plot of the band gap of the magnetic field $E_g(H)$. Where a continuous line of theoretical calculations and experimental point of a plot of the band gap of the magnetic field [14,15]. In strong magnetic fields, as can be seen from this figure, theory and experiment are in good agreement.

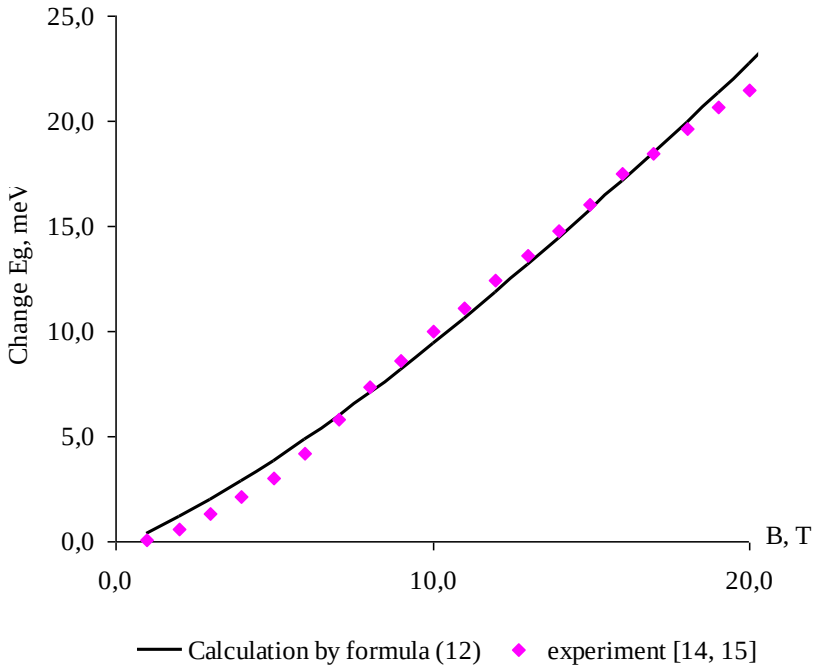


Fig. 6. The dependence of the band gap on magnetic field in InAs.

4. CONCLUSION

On the basis of this work the technique of determining the dependence of the oscillation JDOS on the energy absorbed photon in semiconductors with the nonparabolic dispersion. Explaining the nonlinear dependence of the maximum frequency of the absorbed light and the band gap of the quantizing magnetic field in a semiconductor with nonquadratic dispersion law. We compared the changes in the oscillation of the combined density of states at the absorbed photon energy for different Landau levels with parabolic and non-parabolic dispersion law. The calculation results are in good agreement with the experimental data in InAs.

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