THEORY OF OPTICAL ORIENTATION AND ALIGNMENT IN QUANTUM WELLS

I.A.Merkulov, V.I.Perel, M.E. Portnoi

A.F.Ioffe Physico-Technical Institute, 194021, Leningrad, USSR

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The momentum distribution function and the average spin of photoexcited electrons in a quantum well are calculated for polarized optical excitation normal to the quantum well plane. In the case of small light hole-heavy hole mass ratio the dependencies of alignment parameter and spin on 2D motion energy are shown to have peculiarities at small energies. For the high-frequency edge of hot photoluminescence, the theoretical dependencies of linear and circular polarization on the excited electron energy are presented.

Introduction

In semiconductors with complex valence band structure, absorption of linearly polarized light results in momentum alignment of photoexcited carriers while circular polarization leads to their spin orientation producing respectively linear or circular polarization of hot luminescence [1]. Similar effects were observed for hot photoexcited carriers in quantum wells [2].

We present theoretical results on optical orientation and alignment of electrons in quantum wells. In order to find out the main features of the phenomenon the simplest model of an infinitely deep symmetric quantum well is considered. The absence of an inversion centre in a *GaAs*-type crystal is also not taken into account. The valence band is considered to be described by the Luttinger matrix Hamiltonian.

Momentum Alignment and Spin Orientation

Selection rules for interband optical transitions [1] show that the momentum distribution of electrons created by linearly polarized light propagating normal to the QW plane is anisotropic. The distribution function $\mathcal{F}(\vec{k})$ at the instant of photogeneration is given (see [3]) by:

$$\mathcal{F}(\vec{k}) = F_0(k)\,[\,1 + \alpha_0 \cos(2\varphi)\,], \qquad (1)$$

where $\vec{k}$ is 2D wave vector of electron, k is its absolute value, φ is the angle between $\vec{k}$ and the electric field vector of the exciting light. Here the spherical approximation is used, $F_0(k)$ and alignment degree α_0 depend only on the energy of the photoexcited electron.

If the exciting light is circularly polarized, the momentum distribution is isotropic in well's plane but a spin orientation appears. The average electron spin s_0 at the instant of photocreation (under excitation by right circularly polarized light) is parallel to the z-axis and also depends on the electron energy.

Both parameters α_0 and s_0 are influenced by the numbers of quantum levels in the valence and conduction bands which participate in the optical transition. Our calculation [3] gives the following expressions for α_0 and s_0

$$\alpha_o = -\frac{2W_\pm}{1+W_\pm^2}\ ; \quad s_o = -\frac{1}{2}\frac{(1-W_\pm^2)}{(1+W_\pm^2)}\ . \quad (2)$$

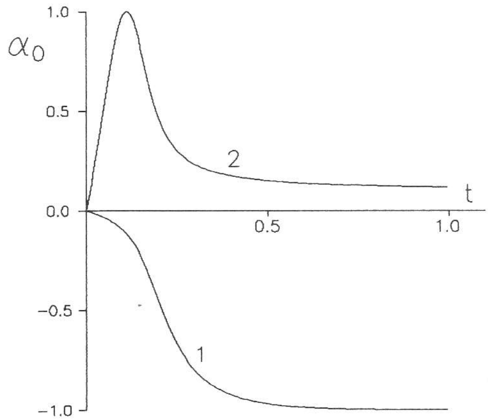
Here $W_\pm$ is the parameter characterizing the band mixing:

$$W_\pm = \frac{\nu+1}{2}\left[1-\frac{t_o}{t} \pm \sqrt{\left(1-\frac{t_o}{t}\right)^2+\frac{t_o}{1+\nu}}\right] \quad (3)$$

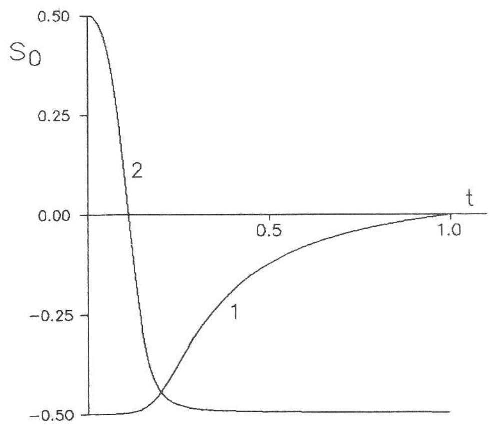
where $\nu = m_l/m_h$ is the light hole - heavy hole mass ratio; $t_o = \frac{4\nu}{3(1+\nu)}$; $t = \varepsilon_\parallel/\varepsilon$, $\varepsilon_\parallel = \hbar^2k^2/2m_h$ is the kinetic energy of heavy hole motion in the quantum well plane, ε is the full hole kinetic energy (including the size quantization energy), and $\varepsilon = 0$ corresponds to the top of the valence band in bulk material. W_+ relates to the transitions between the heavy hole and the electron confined levels with numbers of equal parity or between light hole and electron levels with numbers of opposite parity. W_- describes all the remaining transitions. The ordering of levels is made at $k = 0$. **Fig.1** shows the dependencies of α_o and s_o on t. Curves 1 have been calculated using W_+, curves 2 are connected with W_-. The value $\nu = 0.18$ that is used corresponds to a spherical approximation for *GaAs*. The minus sign in **Fig.1(b)** means that the average electron spin is directed opposite to the angular momenta of the exciting photons.

To calculate the spectra of α_o and s_o from equations (2,3) it is necessary to know the dependence $\varepsilon(k)$, but it is clear even from (3) that in the case of small ν, the orientation and the alignment change rapidly at small $k \approx \nu/L$ ($t \approx t_o$), where L is the well's width.

The dependencies of α_o and s_o on k for transitions from different valence band size-quantized levels to the first conduction band level are presented in **Fig.2**.



(a)



(b)

Fig.1 Momentum alignment degree (a) and average spin (b) of photoexcited electrons as functions of universal parameter $t = \hbar^2k^2/(2m_h\varepsilon)$. Light hole - heavy hole mass ratio $\nu = m_l/m_h = 0.18$. Curves 1 for transitions between heavy hole and electron levels with numbers of equal parity or between light hole and electron levels with numbers of opposite parity. Curves 2 for all the remaining transitions.

Photoluminescence Polarization

Orientation and alignment are usually detected by measuring of circular (P_c) and linear (P_l) polarization degrees of recombination radiation.

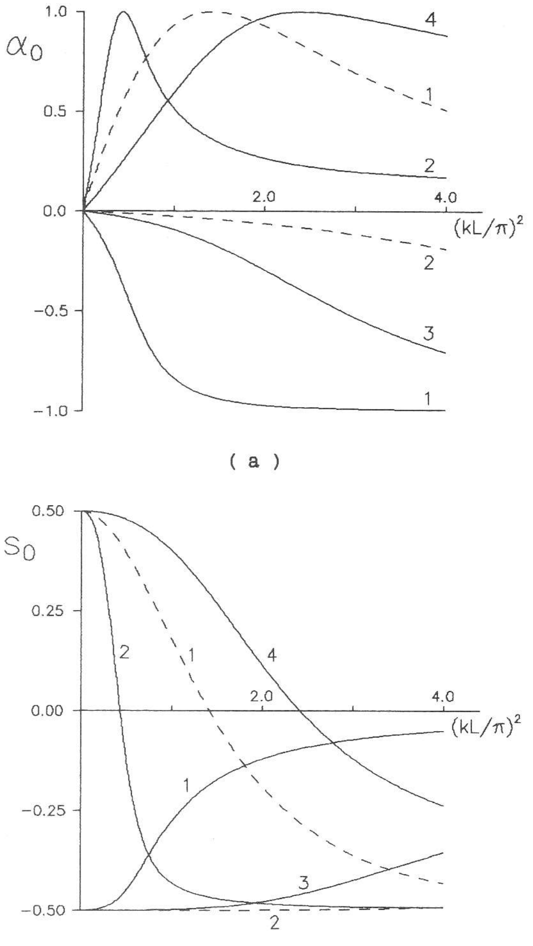


Fig.2 Momentum alignment degree (a) and average spin (b) of electrons excited into the first conduction band confined level from different valence band levels against squared 2D wave vector.
Numbers correspond to hole sublevels participating in optical transitions. Solid lines for transitions from heavy hole levels, dashed - from light hole levels.

For radiation propagating in the direction of the exciting light-beam at the high-frequency edge of hot photoluminescence, the calculation [3] gives:

$$P_l = \frac{\alpha_0^2}{2}; \qquad P_c = 4\, s_0^2 \tag{4}$$

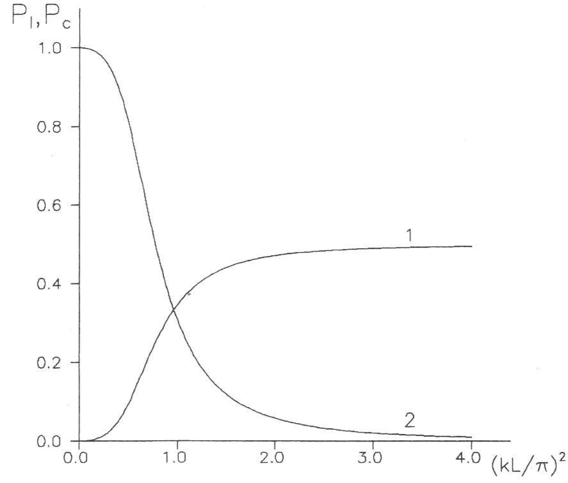


Fig.3 Calculated dependencies of linear (curve 1) and circular (curve 2) polarization degrees at the high-frequency edge of the luminescence on 2D wave vector of photoexcited electron.

The theoretical dependencies of P_l and P_c on k for transition $1hh$ - $1e$ - $1hh$ are depicted in **Fig.3**.
One can see that linear polarization increases with exciting photon energy while circular polarization decreases. These results are in qualitative agreement with experimental data [2,4]. More wide comparison of this theory with experiment is given in our paper [3].

Summary

The momentum and spin distributions of 2D electrons generated by polarized light are shown to be anisotropic. The degree of momentum alignment and spin polarization depend strongly on exciting photon energy. Contrary to 3D case, these dependencies are very sharp, especially if the light hole - heavy hole mass ratio (m_l/m_h) is small. Such peculiarities are due to the sharp reconstruction of the hole wave function at small values of 2D wave vector $k \approx$

$\sqrt{m_l/m_h}/L$, where L is the well's width. These peculiarities appear also in the spectral dependencies of the degree of linear and circular polarization of luminescence.

References

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