Magneto-gyrotropic photogalvanic effects due to inter-subband absorption in quantum wells

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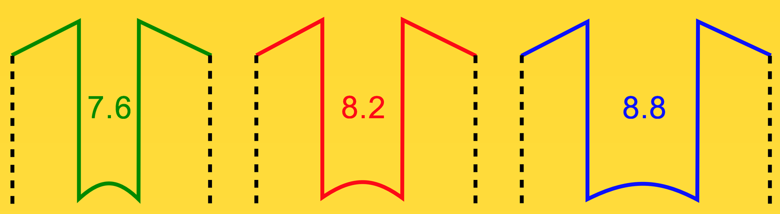
Abstract

Here we present the first observation of the magneto-gyroropic photogalvanic effect (MPGE) due to *inter*-subband transitions in (001)-grown GaAs quantum wells [1]. This effect is related to the gyrotropic properties of the structures. The inter-subband absorption of linearly polarized radiation may lead to spin-related as well as spin independent photocurrents if an external magnetic field is applied in the plane of the quantum well. The experimental results are analysed in terms of the phenomenological theory and microscopic models of MPGE based on either asymmetric optical excitation or asymmetric relaxation of carriers in $\boldsymbol{k}$-space. We observed resonant photocurrents not only at oblique incidence of radiation but also at normal incidence demonstrating that conventionally applied selection rules for the *inter*-subband optical transitions are not rigorous.

Experiment

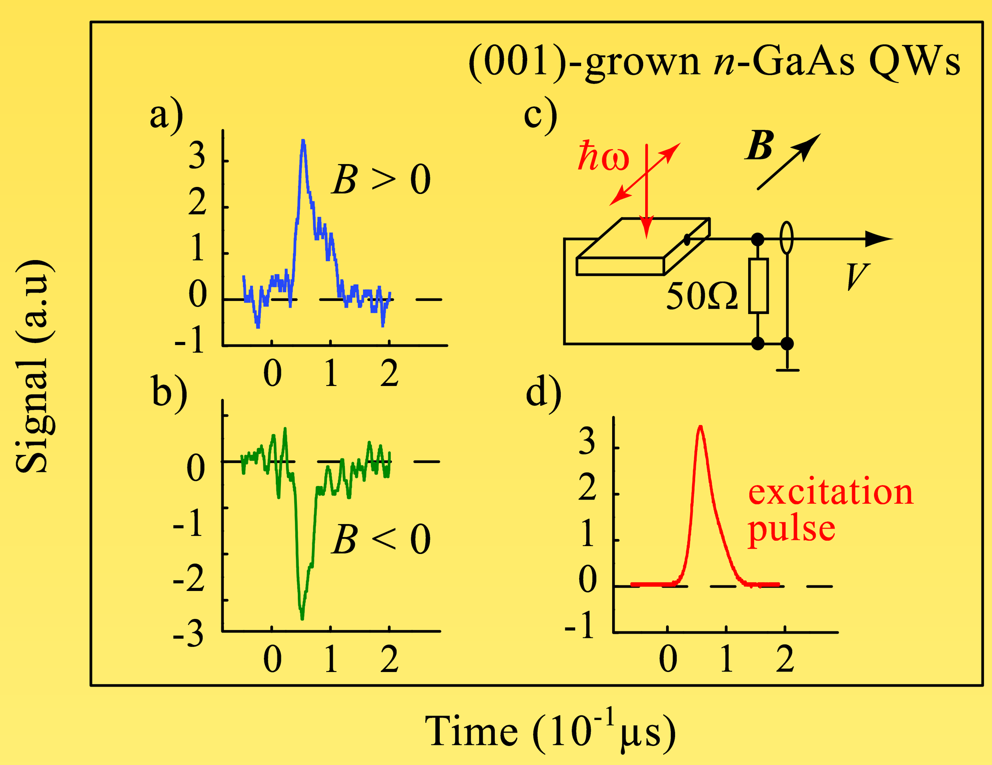
The samples are (001)-grown n-doped GaAs/AlGaAs quantum wells ($L_W = 7.6 \div 8.8$ nm, $N_s = 3 \cdot 10^{11}$ cm^{-2}, C_{2v} point group).



We have applied the lineraly polarized light with photon energies from 114 meV to 135 meV both under normal and oblique incidence and an external magnetic field $\boldsymbol{B}$ up to 1 Tesla in the plane of the 2DEG.

Normal Incidence

Normally incident linearly polarized radiation at $\boldsymbol{B} = 0$ causes no photocurrent. However, in the presence of the magnetic field (say: B_y) a photocurrent response (J_x) in the perpendicular direction was obtained.

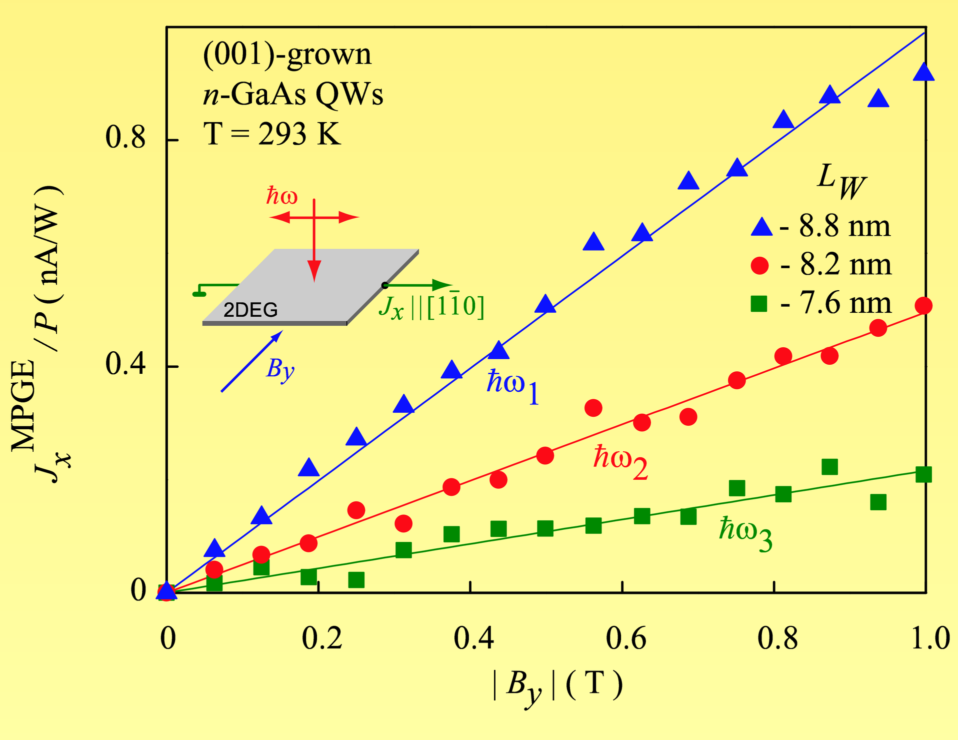


Oblique Incidence

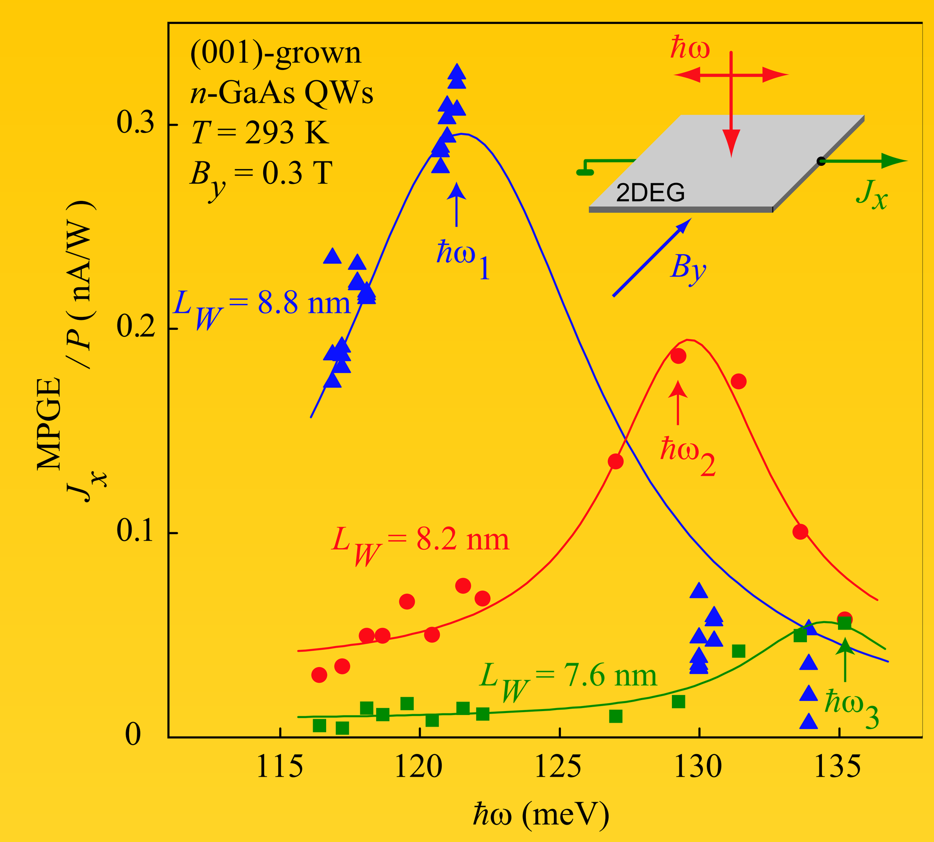
Under oblique incidence we have measured the currents for B_y^+ and B_y^- and evaluated the data after

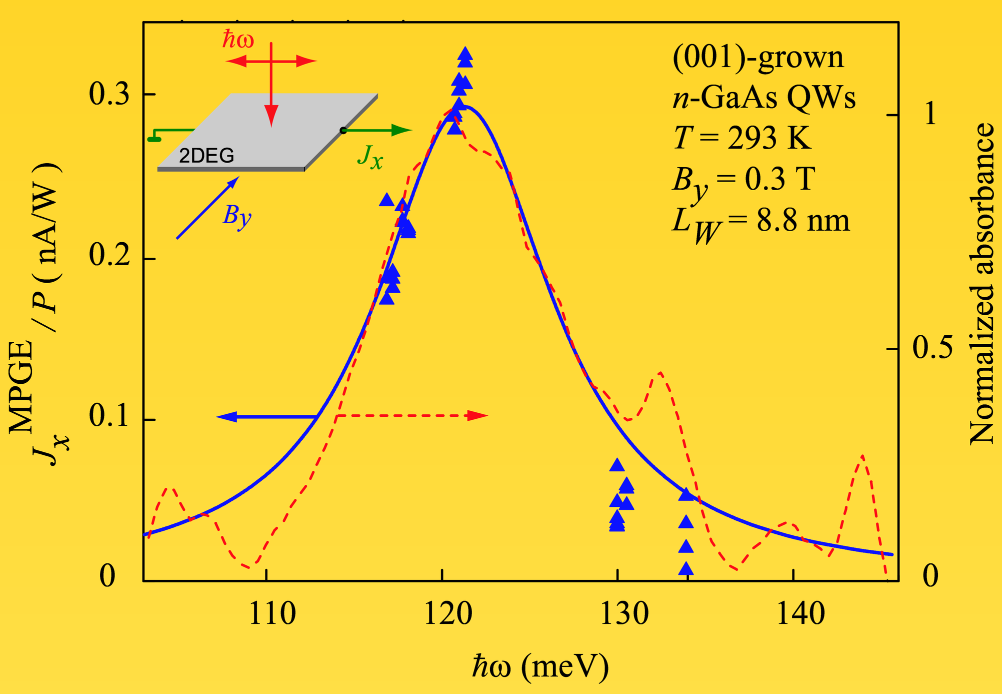
$$J_x^{MPGE} = [J_x(B_y^+) - J_x(B_y^-)]/2.$$

Magnetic Field Dependence

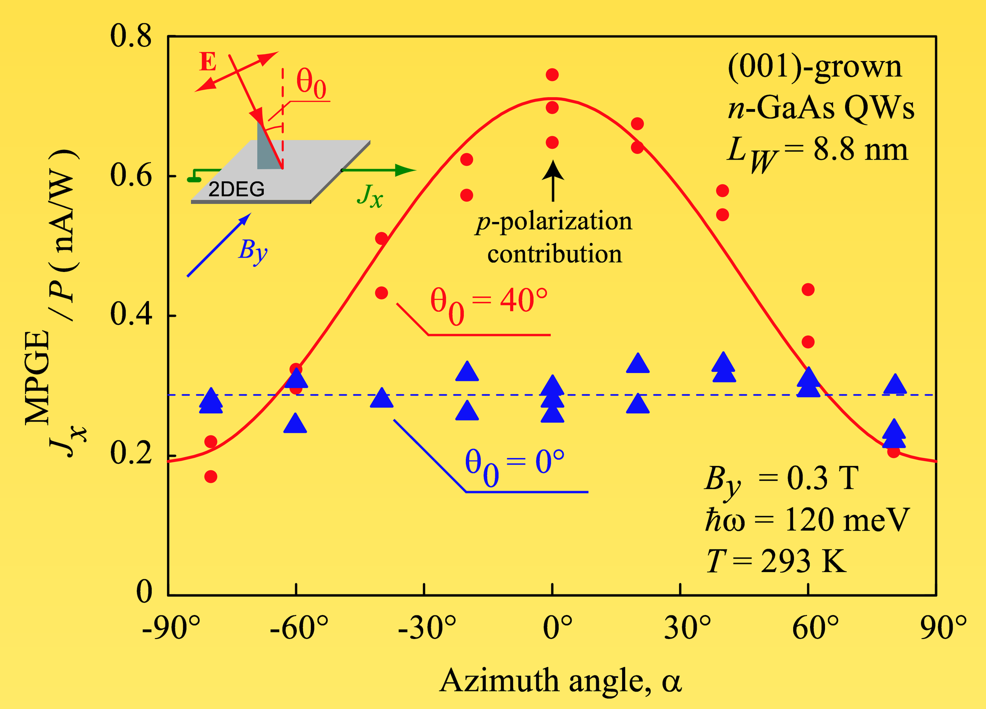


Spectral Dependence





Polarization Dependence



We suppose that

$$J_x^{MPGE} \propto B_y \eta(\alpha, \theta),$$

where the structure absorbance $\eta(\alpha, \theta)$ is described by [2, 3]

$$\eta(\alpha,\theta) = t_p^2 \cos^2\alpha \left(\eta_\parallel \cos^2\theta + \eta_z \sin^2\theta\right) + t_s^2 \eta_\parallel \sin^2\alpha.$$

The data can be fitted well for the ratio $\eta_z/\eta_\parallel \approx 50$.

The non-zero $\eta_\parallel$-absorption is due to admixture of valence to the conduction band (Kane model) [4] and demonstrates that the polarization selection rule is not rigorous [5].

Phenomenological Analysis

For gyrotropic zinc-blende QWs the current in the presence of a magnetic field $\boldsymbol{B}$ and under irradiation with linearly polarized light $\boldsymbol{E}$ can be described as [6]

$$j_\alpha = \sum_{\beta\gamma\delta} \phi_{\alpha\beta\gamma\delta} B_\beta \frac{E_\gamma E_\delta^* + E_\delta E_\gamma^*}{2},$$

where ϕ is a fourth-rank pseudotensor. For QWs of C_{2v} symmetry and $\boldsymbol{B} \parallel y$ the j^{MPGE} components are

$$j_x = \left[C_1(e_x^2 + e_y^2) + C_2(e_x^2 - e_y^2) + C_3 e_z^2\right] B_y I,$$

$$j_y = C_4 e_x e_y B_y I,$$

where (e_x, e_y, e_z) are components of the unit polarization vector $\boldsymbol{e}$ and $C_1 \div C_4$ are related to components of the tensor $\phi_{\alpha\beta\gamma\delta}$.

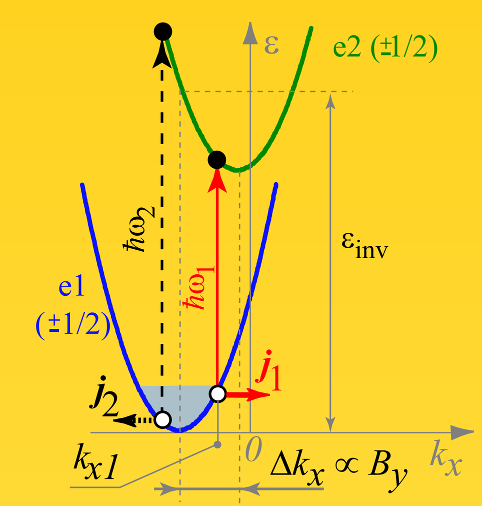
For normal incident measurements the coefficients C_2 and C_4 are negligibly small, C_1 is the main contribution. For oblique incidence the coefficient C_3 is also detected and becomes predominant ($C_3 \gg C_1$).

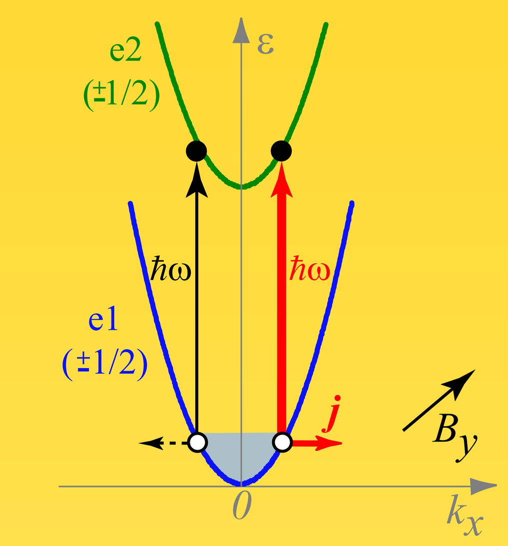
Microscopic Theory

Diamagnetic term: For $\boldsymbol{B} \neq 0$ the linear-in-$\boldsymbol{k}$ correction to the effective Hamiltonian has the form [7]

$$H_{dia} \propto (B_x k_y - B_y k_x).$$

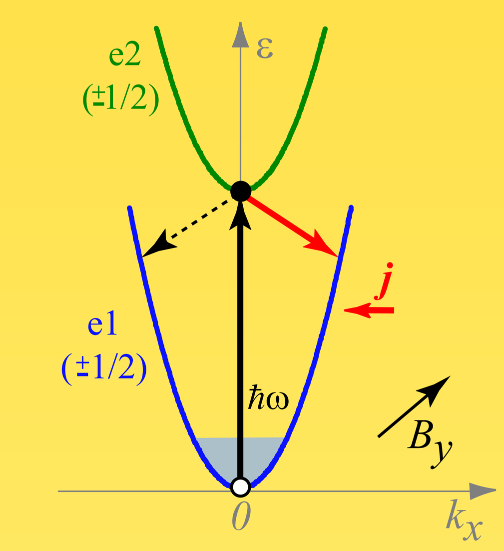
Diamagnetic mechanisms:
(a) Current induced by asymmetric optical excitation due to diamagnetic shift of subbands in $\boldsymbol{k}$-space [8].

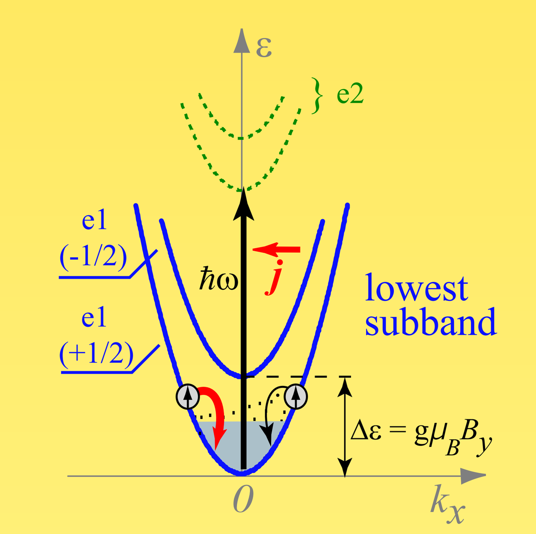




(b) Current induced by asymmetric optical excitation due to $(B_x k_y - B_y k_x)$-term in the optical transition matrix elements.

(c) Current induced by asymetric free carrier relaxation $(e_2, 0) \rightarrow (e_1, \boldsymbol{k})$ due to $(B_x k_y - B_y k_x)$-term in the scattering amplitude.





Spin related mechanism:
(d) Current induced by asymmetric free carrier relaxation due to spin-dependent asymmetry of energy relaxation [9].

The estimations show that the scattering process (c) is the predominant for MPGE.

Acknowledgments

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