Magneto-Gyrotropic Photocurrents Induced by Intersubband Transitions in Quantum Wells

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***Abstract*—We present experimental and theoretical studies of photocurrents induced by intersubband optical transitions in quantum wells in the presence of an in-plane magnetic field. The analysis evidences that the observed photocurrents are related to gyrotropy of quantum wells, which is caused by bulk and/or structure inversion asymmetry.**

Experiments have been done at room and liquid helium temperatures on MBE-grown (001)-oriented n-doped GaAs/AlGaAs multiple QWs. Each quantum well of 8.8 nm width contains two-dimensional electron gas with the carrier density of $3 \cdot 10^{11}$ cm^{-2} at 4.2 K. The sample was irradiated by linearly polarized light of a Q-switched CO_2-laser with the operating spectral range between 9.2 and 10.6 μm. The spectral range corresponds to direct intersubband optical transitions from the ground $(e1)$ to the first excited $(e2)$ electron subband, that was verified by means of the Fourier transform infrared spectroscopy. The external magnetic field B up to 0.3 T was applied parallel to the interface plane. To measure electric currents, two pairs of Ohmic contacts were centered at opposite sample edges oriented along $x \parallel [1\bar{1}0]$ and $y \parallel [110]$. The photocurrent was measured in the unbiased structure via the voltage drop across a 50 Ω load resistor.

The magnetic field dependent photocurrent has been observed at oblique and even normal incidence of the linearly polarized radiation. The direction of the magneto-induced photocurrent is determined by orientation of the magnetic field in the QW plane. The spectral dependence of the photocurrent corresponds to that of the intersubband absorption measured by means of the Fourier transform infrared spectroscopy (see Fig. 1). The temperature decrease to 12 K results in "blue" shift of the photocurrent curve. At oblique incidence of the radiation, the magneto-induced photocurrent is polarization dependent: it reaches maximum for the radiation polarized in the incidence plane (p-polarization) and minimum for polarization in the QW plane (s-polarization), see Fig. 2.

All these features demonstrate that the observed photocurrent is caused by the intersubband transitions. The study of the polarization dependence allows us to address the problem of validity of the selection rules for the intersubband optical transitions. We find that in our QW structure the ratio $\eta_z/\eta_{\parallel} \approx 50$, where η_z and $\eta_{\parallel}$ are the QW absorbance for light polarized along the growth direction z and in the QW plane, respectively.

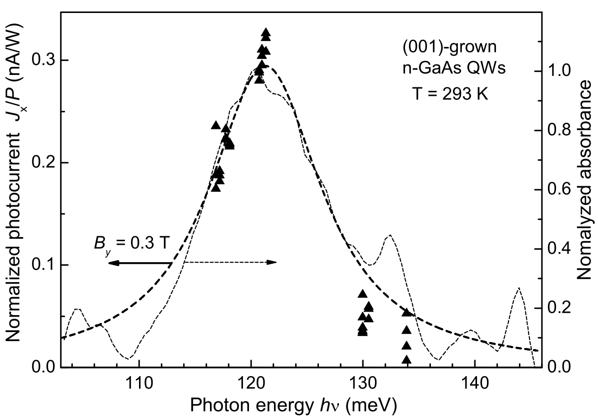

Fig. 1. Spectral dependence of the magneto-induced photocurrent J_x at the magnetic field $B_y = 0.3$ T. The current is measured under normal incidence of the light at room temperature. Solid curve is fit to experimental data (triangles) by the Lorentz function. Normalized absorbance spectrum is shown by dashed curve.

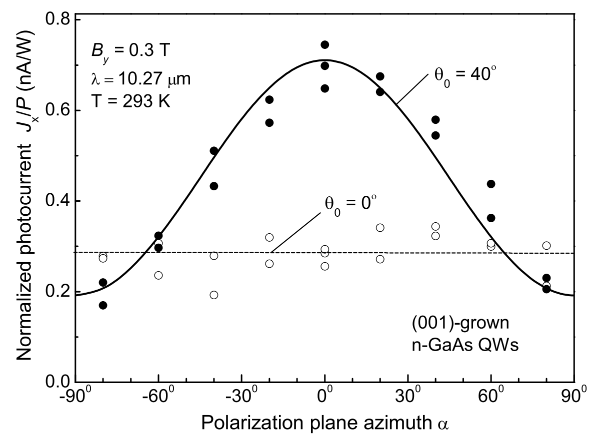

Fig. 2. Dependence of the magneto-induced photocurrent J_x on the azimuth of the light polarization plane measured at oblique ($\theta_0 = 40°$) and normal ($\theta_0 = 0°$) incidence. Solid and dashed curves are fit by analytical expression describing the light refraction and propagation in QW structures.

While excitation of the QW at oblique incidence results in a measurable electric current even at zero magnetic field (due to linear photogalvanic and photon drag effects [1]), the photocurrent response at normal incidence is observed only in the presence of an in-plane magnetic field. The direction and magnitude of the photocurrent excited at normal incidence is independent of the light polarization and is determined by the magnetic field only. In particular, application of the magnetic field along y results in the photocurrent along the x axis. The photocurrent increases linearly with the magnetic field strength and reverses its direction upon the field inversion.

The phenomenological analysis based on the theory of space group representations shows that the magneto-induced photocurrents in QWs are related to gyrotropy of the structures, which is caused by structure and/or bulk inversion asymmetry [2]. We have also developed the microscopic theory of the effect demonstrating that the photocurrent includes both paramagnetic (spin-dependent) [3] and pure diamagnetic contributions.

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