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Gate voltage controlled spin photocurrents in heterojunctions

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Abstract. The spin-galvanic effect and the recently observed magneto-gyrotropic are investigated in GaAs heterojunctions as a function of voltage applied by a semitransparent gate electrode. It is shown that in a certain experimental geometry, the spin-galvanic current can be tuned by the variation of the gate voltage over a wide range providing an experimental access to the Rashba spin-orbit coupling. Furthermore in response to linear polarized radiation the magento-gyrotropic effect is detected and by control of the gate voltage a sign inversion of the magneto-gyrotropic current is observed.

Introduction

The manipulation of the spin of charge carriers in semiconductors is one of the key problems in the field of spintronics. Spin polarization may be tuned applying gate bias voltage by means of the Rashba spin-orbit coupling [1] in low dimensional structures. Here we demonstrate that a gate voltage applied to heterojunctions strongly affects the formation of spin photocurrents [2] excited by terahertz radiation. The most striking influence of the gate voltage is observed in GaAs heterojunctions excited by linearly polarized radiation in the presence of external magnetic field. The current caused by the magneto-gyrotropic effect [3] at positive biases reverses its direction. In additional we show that the strength of the spin-galvanic effect [4] excited in GaAs heterojunctions by circularly polarized radiation for a certain experimental geometry depends linearly on the gate voltage as expected from Rashba-like spin splitting.

1. Experimental

The experiments are carried out at room temperature on (001)-oriented n-type GaAs heterojunctions having C_{2v} point group symmetry. All samples have two pairs of ohmic contacts at the corners corresponding to the $x \parallel [100]$ and $y \parallel [010]$ directions. A semitransparent metallic gate electrode was prepared on the top of the structure a shown in the inset of Fig. 1. The voltage in the range between -17 V and +5 V was applied between the gate and the two-dimensional channel. For optical spin orientation we use a high power pulsed molecular far-infrared NH_3 laser operating at 148 μm wavelength. Radiation is linearly or circularly polarized. The terahertz radiation induces free carrier absorption in the lowest conduction subband $e1$ because the photon energy is smaller than the subband separation and much larger than the $\boldsymbol{k}$-linear spin splitting. The samples are irradiated along the growth direction. The in-plane external magnetic field $B = 0.3\,\mathrm{T}$ is applied parallel to the [100]-axis. The photocurrent $\boldsymbol{j}$ was measured at room temperature in unbiased structures via the voltage drop across a 50 Ω load resistor in closed circuit configuration with a fast storage oscilloscope. The measured current pulses of 100 ns duration reflected the corresponding laser pulses.

Irradiation of the samples subjected to an in-plane magnetic field with normally incident *circularly* polarized radiation yields a helicity dependent current. The polarity of the current changes upon reversal of the applied magnetic field as well as upon changing the light helicity from right- to left-handed indicating the spin-galvanic effect [4]. The effect is caused by the optical orientation of carriers, subsequent Larmor precession of the oriented electronic spins, and an asymmetric spin relaxation processes. Though, in general, the spin-galvanic current does not require an application of magnetic field, it may be considered as a magneto-photogalvanic effect under the above experimental conditions. Fig. 1 shows the dependence of the spin-galvanic effect on the bias voltage. It is measured along the magnetic field. The current depends almost linearly on the bias voltage. As we showed previously [5] for the $j \parallel B \parallel [100]$ geometry the spin-galvanic effect is due to the Rashba spin splitting of the band only as the Dresselhaus contribution to the current vanishes. The strength of the Rashba contribution depends linearly on the gate voltage. On the other hand the spin-galvanic current is proportional to the strength of spin-splitting. Therefore the observed gate voltage dependence is in fully agreement with the expected current behaviour. The gate voltage dependence of spin-galvanic current reflects the

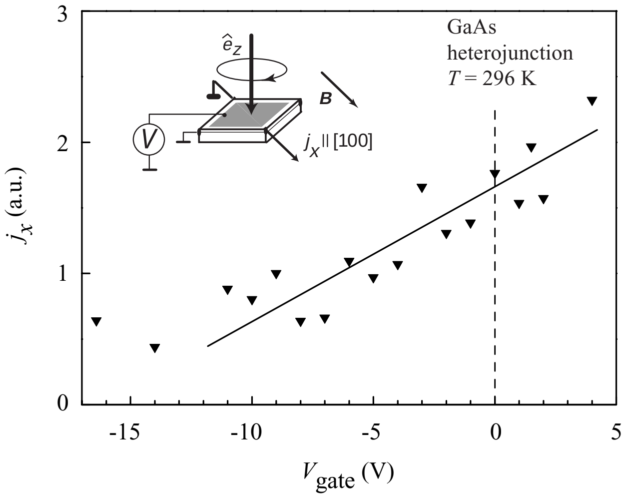

Fig. 1. Dependence of the spin-galvanic effect on the gate bias voltage. Inset shows the geometry of the experiment. Circularly polarized radiation of the wavelength 148 μm is normally applied through a semitransparent gate to GaAs heterojunction.

modulation of the strength of spin-orbit coupling in the low dimensional structure providing a direct experimental access to this important parameter.

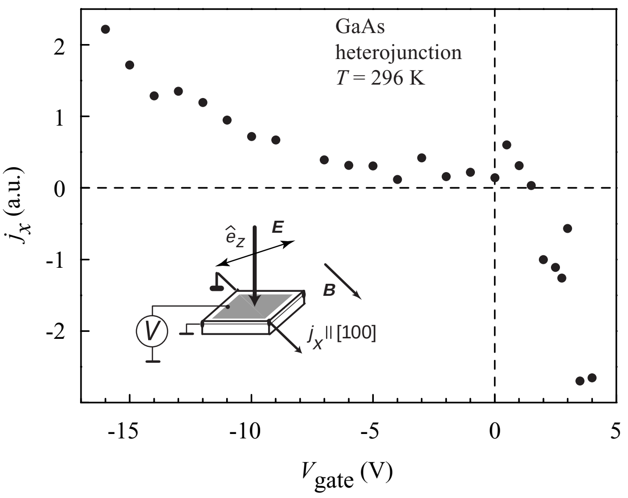

Fig. 2. Bias voltage dependence of the magneto-gyrotropic effect excited by linearly polarized radiation. Inset shows the geometry of experiment.

Applying linearly polarized radiation a current parallel as well as perpendicular to the magnetic field is observed. The current changes its direction upon the magnetic field reversal. It is due to the recently observed magneto-gyrotropic effect caused by Drude absorption of terahertz radiation [3]. This current may be induced either by an asymmetry of optical excitation and/or by an asymmetry of relaxation.

On the bases of polarization dependences we conclude that in our samples the magneto-gyrotropic current is dominated by an asymmetry of relaxation of photoexcited carriers. In this mechanism the current is caused by the asymmetric part of electron-phonon interaction [6]. The light absorption by free electrons leads to an electron gas heating, i.e. to a non-equilibrium energy distribution of electrons. Due to the asymmetry of the electron-phonon interaction hot electrons with opposite $\boldsymbol{k}$ have different relaxation rates. As a result, an electric current is generated. Whether $-k$ or $+k$ states relax preferentially, depends on the spin direction. It is because the electron-phonon asymmetry is spin-dependent. The currents in spin-up and spin-down subbands flow in opposite directions. For $B = 0$ the currents cancel each other exactly. In the presence of a magnetic field the currents moving in the opposite directions do not cancel due to the non-equal population of the spin subbands and a net electric current flows. This current is spin polarized and can be independent of light polarization.

In additional to the current due to asymmetry of relaxation a small contribution (about 30 percent) of a magneto-gyrotropic effect due to an asymmetry of optical excitation [3] was also detected. This contribution yields a characteristic polarization dependences being in agreement with the phenomenological theory.

Fig. 2 shows the gate voltage dependence of the magneto-gyrotropic current for longitudinal and parallel to magnetic field geometry. It is seen that the current reverses its sign at small positive bias voltages. Measurements of polarization dependences showed that the ratio and the relative sign of both, "relaxation" and "excitation" contributions, remains unchanged. The microscopic mechanism of this striking feature is not well understood as yet.

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