Rashba Spin-Orbit Coupling Investigated by Far-Infrared Spectroscopy

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Abstract

One of the challenges of semiconductor spintronics is to manipulate the motion of spin by changing the charge states (*i.e.*, play with spin using a battery) [1]. Gate-dependent large Rashba spin-orbit coupling found in the two-dimensional electron system (2DES) of InAs and InGaAs [2] seems to provide us the most promising tool. Up to now, this highly interested effect has been mostly studied via magneto transport experiment which measures the spin-orbit coupling parameter α indirectly. The obtained value as well as the gate-voltage dependence of α are rather controversial [3]. Due to the much smaller matrix element for transitions involving spin-flip processes [4], infrared spectroscopy that is powerful in directly measuring energy gap and effective mass m* is not easy to be used to determine the spin-related band parameters like the Landé g factor or α.

In this work, we report resistively detected cyclotron resonance and spin-flip excitation in a 2DES formed in an InAs quantum well. Our technique that combines magneto-transport with spectroscopy has the advantages of high sensitivity as well as high spectroscopic resolution [5]. By fitting the measured magnetic-field dependence of the transition energies to a band structure model [6], we determine $m^* = 0.039\ m_e$, g = -8.7 and $\alpha = 2.38 \times 10^{-11}$ eVm for the InAs 2DEG with $N_s = 6.6 \times 10^{11}$ cm^{-2}. Comparing these data to the result obtained from the magneto transport experiment performed *in situ* on the same sample, we conclude that missing a beating pattern in Shubnikov-de Haas oscillation does not simply mean the spin-orbit coupling parameter α equals to zero. Our results therefore shed light on the mystery of α studied by transport experiment [2, 3]. Most interestingly, by studying the magnetic-field dependence of the oscillator strength, we find that the spin-flip excitation is strongly damped at odd filling factors, demonstrating the collective nature of the excitation. The result is in accordance to a theoretical prediction [7] that both Kohn's theorem [8] and Larmor's theorem [7] are broken for long wavelength resonance that changes both the Landau and spin quantum numbers.

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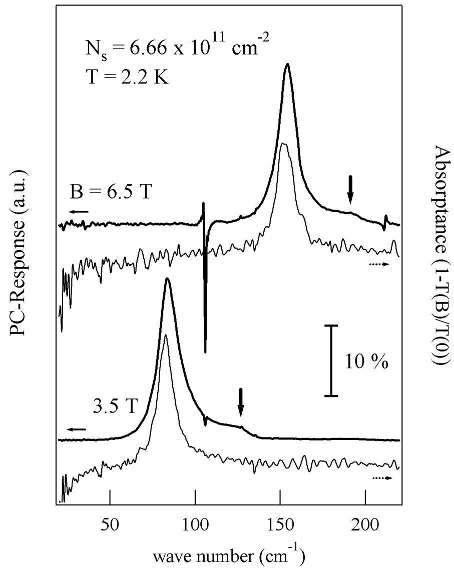

Figure 1. FIR-photo-conductivity spectra (thick lines) measured at two magnetic fields in comparison with conventional absorption spectra (thin lines) under the same experimental conditions using a Si bolometer. In addition to the CR, thick arrows indicate the weak spin-flip excitations which are only observable using the high sensitive photo-conductivity technique.

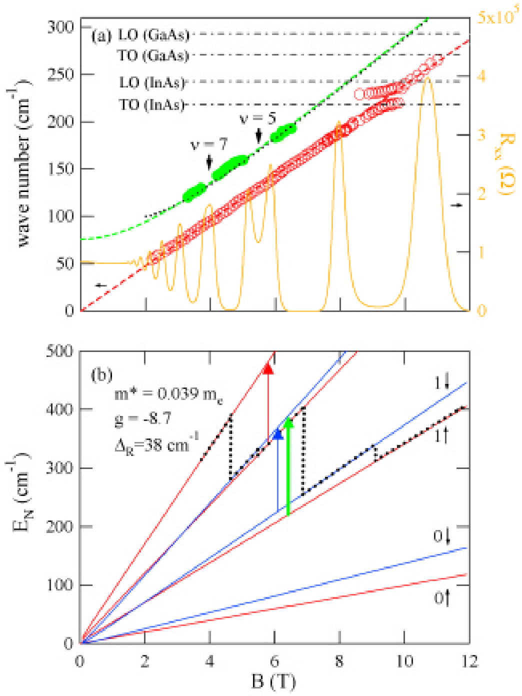

Figure 2. (a) Resonance dispersions determined from the photo-conductivity spectra and magnetoresistance R_{xx} measured by transport experiment. The dashed line and curve are fits for CR and spin-flip excitation using a band structure model including spin-orbit coupling. Dash-dotted lines indicate the optical phonon energies of InAs and GaAs. (b) Landau-levels calculated using the band parameters obtained from the fit in (a). Dotted lines indicate the Fermi energy. Thin and thick arrows illustrate the CR and spin-flip excitation, respectively.