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Comparative study of microwave radiation-induced magneto-resistance oscillations induced by circularly- and linearly- polarized microwaves

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Abstract. A systematic comparative study of radiation-induced magneto-resistance oscillations using circularly polarized- and linearly polarized microwaves was carried out on the high mobility GaAs/AlGaAs heterostructure two dimensional electron system (2DES). The results showed that, the sinusoidal sensitivity in the amplitude of the radiation-induced magneto-resistance oscillations observed under launcher rotation for linearly polarized microwaves, is remarkably absent in the similar experiment carried out with circularly polarized microwaves.

1. Introduction

Microwave radiation induced zero resistance states and associated microwave radiation-induced magnetoresistance oscillations in the 2D electron system [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11] have been a topic of interest over the past decade. The role of the microwave polarization in such experiments is thought to be a discriminating feature among existing theories, see discussion in [12], and therefore, the effect of rotation of the polarization of linearly polarized microwaves has been heavily investigated.[12, 13, 14, 15, 16, 17, 18] Associated experiments have shown, remarkably, that the amplitude of the radiation-induced magnetoresistance oscillations varies sinusoidally with the linear polarization angle, following a cosine-square function.[13] So far as circularly polarized microwave photo-excitation is concerned, only one experimental study[19] examined the magnetotransport response for such polarization and it reported immunity of the radiation-induced magnetoresistance oscillations to the polarization orientation for both circularly polarized and linearly polarized radiation. On the theoretical side, Lei and Liu examined radiation-induced magnetoresistance oscillations under a variety of polarization conditions, and found that the amplitude of the magnetoresistance oscillations differs with the type of polarization of the radiation. [20, 21]

Here, we summarize a systematic comparative study of radiation-induced magnetoresistance oscillations using circularly polarized- and linearly polarized- microwaves, measured in the same sample, in a single cooldown, under nearly the same experimental conditions. The results show a striking sensitivity in the amplitude of the radiation-induced magnetoresistance

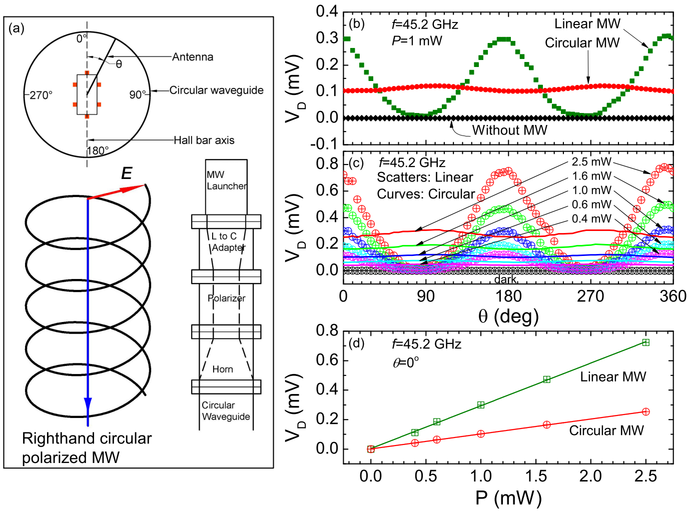

Figure 1. (a) Schematic diagram of the polarization-dependence measurement-geometry. Top-left: Hall bar sample is located at the waveguide center. Bottom-left: Right-handed circularly polarized microwaves. Bottom-right: The linear-to-circularly-polarized microwave converter. (b) Received microwave power at the bottom of the sample holder as a function of launcher antenna angle for linearly and circularly polarized microwaves. (c) Same as panel (b) but at different microwave powers. (d) Microwave power detector response as a function of source microwave power for linearly and circularly polarized microwaves at 0^o polarization angle.

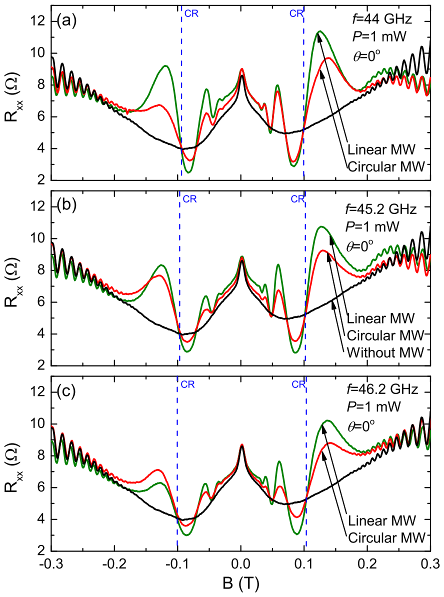

Figure 2. (a) Magnetoresistance measurements of a GaAs/AlGaAs 2DES sample with microwave excitation at (a) 44 GHz, (b) 45.2 GHz, and (c) 46.2 GHz. Dashed lines mark the nominal magnetic field for cyclotron resonance (CR).

oscillations under launcher rotation for linearly polarized microwaves, which is absent in the similar experiment carried out with circularly polarized microwaves.

2. Experiments and results

Experiments were carried out on Hall bars fabricated from high mobility GaAs/AlGaAs heterojunctions. A long cylindrical waveguide sample holder with the sample mounted at the end was inserted into a variable temperature insert (VTI), inside the bore of a superconducting solenoid. A temperature of 1.5 K was realized by pumping on liquid helium. The specimens reached the high mobility condition after brief illumination with a red light-emitting-diode. A commercially available microwave synthesizer was used to provide microwave excitation via a launcher at the top of the sample holder. For the linearly polarized microwaves, the microwave launcher was connected with the circular waveguide through a rectangular to circular adaptor. For the circularly polarized microwaves, a commercially available circular polarizer and horn assembly was inserted between the adapter and the circular waveguide, see Fig. 1 (a). This assembly converts the linearly polarized microwaves to right-hand circularly polarized microwaves within the frequency band $43 \leq f \leq 50$ GHz.

In order to determine and test the microwave polarization, the launcher was rotated as a power sensor was located at the bottom of the sample holder (Fig. 1b). Here, the polarization angle is defined as the angle between the antenna and a reference mark on the circular waveguide. (During magnetotransport measurements, the Hall bar sample is located at the center of the

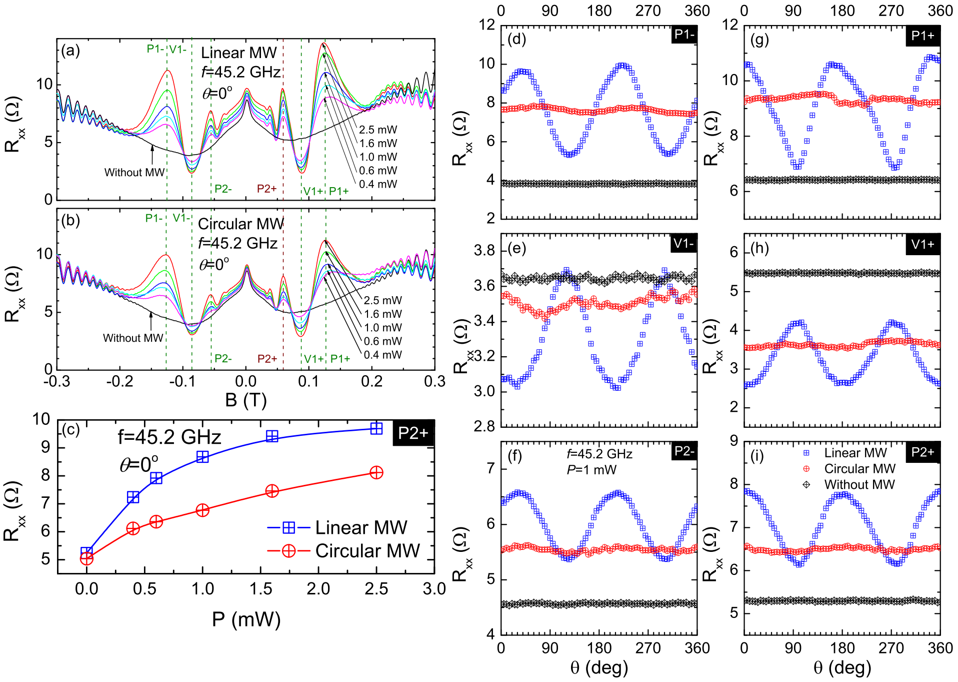

Figure 3. (Color online) Microwave power dependence of R_{xx} for (a) linearly polarized and (b) circularly polarized microwave radiation. (c) Diagonal resistance as a function of microwave power for linearly and circularly polarized microwaves at the peak labelled P2+. Diagonal resistance as a function of polarization angle for linearly polarized (blue symbols) microwaves, circularly polarized (red symbols) microwaves, and without microwave (black symbols) at the magnetic field corresponding to (d)P1-, (e)V1-, (f)P2-, (g)P1+, (h)V1+ and (i)P2+.

circular waveguide with its long axis aligned with the reference mark on the circular waveguide). Fig. 1 (b) exhibits the measurement for both linearly and circularly polarized microwaves with f = 45.2 GHz with a microwave diode detector attached at the bottom end of waveguide sample holder. Black line shows the microwave detector response in the absence of microwaves. The green curve shows the sinusoidal change in the microwave intensity with linearly polarized microwaves as the highest intensity appears at around zero degree, which means that the antenna in the launcher is parallel to the antenna in the detector. The red curve exhibits the microwave intensity with circularly polarized microwaves. Here, the power dependence was also checked by measuring microwave intensity versus polarization angle at microwave powers ranging from 0 to 2.5 mW, see Fig. 1 (c). It is clear from Fig. 1 (d), that at the bottom end of circular waveguide, at fixed polarization angle, the microwave power changes linearly with the source power, for both linearly polarized or circularly polarized microwaves.

Figure 2 exhibits microwave radiation-induced magnetoresistance oscillations for both linearly and circularly polarized microwaves at several frequencies. For both types of polarization, the magnetoresistance oscillations are periodic in $1/B$ and exhibit the 1/4-cycle phase shift. However, the oscillatory amplitude differs for the two types of polarizations. At every frequency, the amplitude of oscillations for circularly polarized microwaves is always smaller than the amplitude for linearly polarized microwaves, except for the first peak on the left in the 46.2 GHz trace. Here, although the height of oscillatory peak for circularly polarized microwaves is higher than the oscillatory peak for linearly polarized microwaves, the overall amplitude (from top of the peak to bottom of the valley) is the same for both polarizations.

Figure 3 (a) and (b) exhibit the microwave power dependence of the diagonal resistance R_{xx} both linearly and circularly polarized microwaves. As the microwave power increases, the amplitude of the microwave induced oscillations increases in both cases. However, the increase in the oscillatory response at the peaks is nonlinear with the power, see Fig. 3 (c). Here, it is worth noting that the two R_{xx} vs P curves start to split more as the microwave power increases. Fig. 3 (d) to (i) shows the launcher angle dependence of R_{xx} for both polarizations at the magnetic fields corresponding to P1-, V1-, P2- and P1+, V1+, P2+ (marked by dashed lines in Fig. 3 (a) and (b)). The angular dependence of R_{xx} for the linearly polarized microwaves (blue curves) is sinusoidal at all the peaks and valleys. In contrast, however, the R_{xx} traces for the circularly polarized radiation always exhibit launcher angle insensitivity while being shifted away from the dark curve.

3. Summary

We carried out a comparative study of microwave radiation-induced magnetoresistance oscillations induced by linearly- and circularly polarized radiation. For the linearly polarized radiation, the magneto-resistive response is a strong sinusoidal function of the linear polarization angle, θ. For circularly polarized radiation, the oscillatory magneto-resistive response is hardly sensitive to θ. Finally, for circular polarized radiation, the magneto-resistive response for the cyclotron resonance active and inactive conditions is approximately the same over the entire field range.

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