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Extraction of overlapping radiation-induced magnetoresistance oscillations and bell-shaped giant magnetoresistance in the GaAs/AlGaAs 2DES using a multiconduction model

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Abstract. We present an experimental study aimed at extracting the microwave radiation-induced magnetoresistance oscillations from the bell-shape giant magnetoresistance in high mobility GaAs/AlGaAs devices using a multi-conduction model. The results show that the multi-conduction model describes the observed giant magnetoresistance effect and the model helps to extract radiation-induced magnetoresistance oscillations, over a wider parameter space.

1. Introduction

Interest in the GaAs/AlGaAs heterostructure two-dimensional electron systems (2DES) has been motivated by the enhanced physical and electrical properties of this system, including 2D electron mobilities well above 10^7 cm^2 /Vs. This 2DES shows interesting physical phenomena such as novel microwave induced zero-resistance states and associated radiation- induced magnetoresistance oscillations, [1-14] and Giant Magneto-Resistance (GMR) [14-18]. Photo-excited magnetotransport has been studied over the past decade, while negative GMR, which is proportional to the square of magnetic field, B^2, has been known since the initial report in 1983 [15]. Studies of negative GMR have revealed the influence of various factors [15-18]. Typically, the bell-shape negative GMR effect is fit with a parabolic magnetic –field-dependence (B^2- fit) model [17,18]. However, from the experimental perspective, there is more to the bell-shape negative GMR than the initial parabolic term.

In this study, we examine the overlap of microwave induced magnetoresistance oscillations with the bell-shape positive and negative-GMR in GaAs/AlGaAs 2DES. The aim of this study is to develop a technique to separate coexisting GMR and microwave induced magnetoresistance oscillations's and extract associated features. We utilized the multi-conduction model to fit the GMR effect [16]. Subtracting the multi-conduction fit results from the experimental data helps to isolate the microwave induced magnetoresistance oscillations.

2. Experimental

Electrical measurements were carried out at $T \leq 1.7$ K using low frequency lock-in-based techniques on a 2DES with mobility and electron density of 10^7 cm^2/V s and 2.4 x 10^{11} cm^{-2} respectively. Both a constant I_{ac} = 2 μA and a variable I_{dc} were applied along the Hall bar direction. The magnetoresistance $R_{xx}= V_{xx}/I_{ac}$. Microwaves at frequency f=70.1GHz were conveyed to the sample via a waveguide.

3. Results and Data fit

The solid lines of Fig. 1(a) exhibit the R_{xx} vs. B at 1.7 K under microwave excitation at f=70.1 GHz. Microwave induced magnetoresistance oscillations are evident in the range $-0.2 < B < 0.2$ Tesla. In addition, a close study of the data reveals sharp negative-magnetoresistance in the range of -0.01 ≤ B ≤ 0.01 Tesla, with a peak at B=0 Tesla, which looks like the weak-Localization (WL) effect [19,20]. Above 0.05 T, Fig. 1(a) shows positive magnetoresistance. In Fig. 1 (a), the amplitude of the microwave induced magnetoresistance oscillations decreases with decreasing MW power. Figure 1(b) illustrates that the amplitude of microwave induced magnetoresistance oscillations decreases with increasing the I_{dc}. Also, a large bell-shaped negative GMR develops with increasing I_{dc}. The WL-peak is unaffected by either P or I_{dc}.

In order to extract microwave induced magnetoresistance oscillations from the overlapping magnetoresistive effects, we introduced a fitting model that addresses the WL-effect and the bell-shaped GMR effect. Weak localization effect is modelled using the 2D WL theory by neglecting spin-

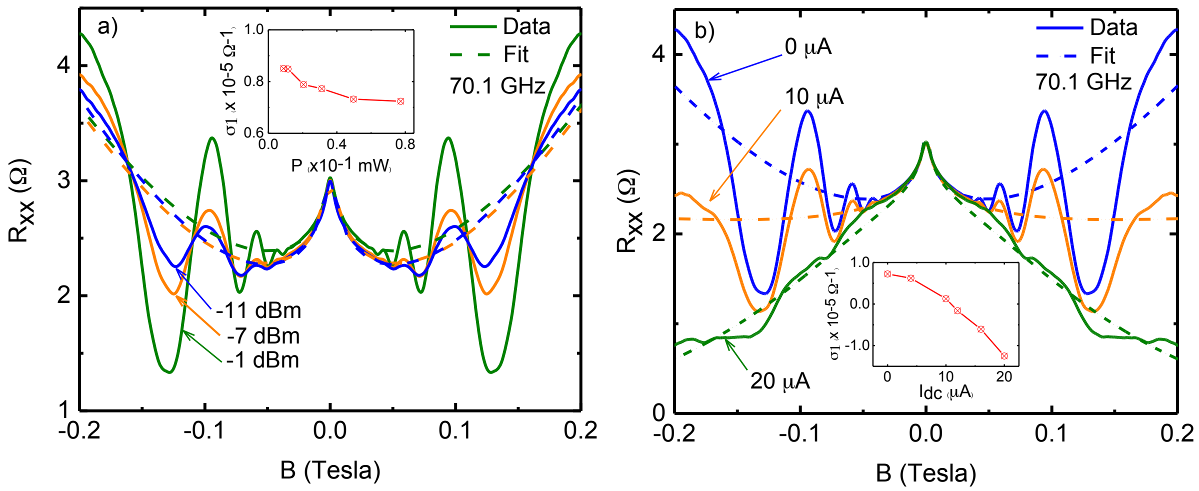

Figure 1. This panel exhibits the R_{xx} vs. B (solid lines) under photo-excitation at f=70.1 GHz, at T = 1.7 K, also shown are the fits (dashed-lines) to the data using multi-conduction model, see text. a) Exhibits the R_{xx} at various MW-powers, P ranging from 0.1 mW to 0.8 mW, at I_{dc}= 0 μA. Insert shows the fit extracted σ_1 as a function of P. b) Exhibits the R_{xx} at different dc-bias, I_{dc} from 0 μA to 20 μA, the insert illustrates the fit extracted σ_1 as a function of I_{dc}

orbit and spin scattering [19-20]. The bell-shape negative GMR effect is addressed with the multi-conduction model [16]. To account for the experimentally observed bell-shape GMR, an additional conductivity term described by conductivity, σ_1 and mobility, μ_1 is introduced to the multi-conduction model, eqns. 3 and 4 in Ref 16. Thus, the total diagonal conductivity, σ_{xx} and off-diagonal conductivity, σ_{xy} are given as follows,

$$\sigma_{xx} = \left\{ \sigma_0 / [1 + (\mu_0 B)^2] \right\} + \left\{ \sigma_1 / [1 + (\mu_1 B)^2] \right\} \tag{1}$$

$$\sigma_{xy} = \left\{ \sigma_0 \mu_0 B / [1 + (\mu_0 B)^2] \right\} + \left\{ \sigma_1 \mu_1 B / [1 + (\mu_1 B)^2] \right\} \tag{2}$$

The zeroth conductivity terms, in eqns. (1) and (2) represents the high mobility electrons in 2D-electron system, thus $\sigma^0_{xx}=n_0 e \mu_0$ where n_0, electron density and μ_0, electron mobility of the 2DES. The number of free parameters in the fit model has been reduced to two, by holding constant the values of n_0 and μ_0, respectively.

Dashed lines in Fig. 1 exhibit the fitting results to the experimental data. Also, fit extracted μ_I= 1.9 x 10^4 cm^2/V s is unaffected by *P* in Fig. 1(a). However, the fit result shows I_{dc} dependency of μ_I: as I_{dc} changes from 0 μA to 20 μA, μ_I increases from 1.9 to 6.2 x 10^4 cm^2/V s.

Insets in Fig. 1 exhibit the fit extracted additional conductivity term σ_I, which captures the bell-shape GMR effect observed in the experimental data. As shown in Fig. 1(a) (inset), the σ_I is not significantly affected by the applied *P*, however, it slightly decreases at higher power. In contrast, in Fig. 1(b) (inset), the σ_I shows significant change as a function of I_{dc}. One can observe a clear transition of σ_I from positive to a negative value with increasing dc-bias from 0 μA to 20 μA. The transition occurs in the range of 10 μA < I_{dc}< 12 μA.

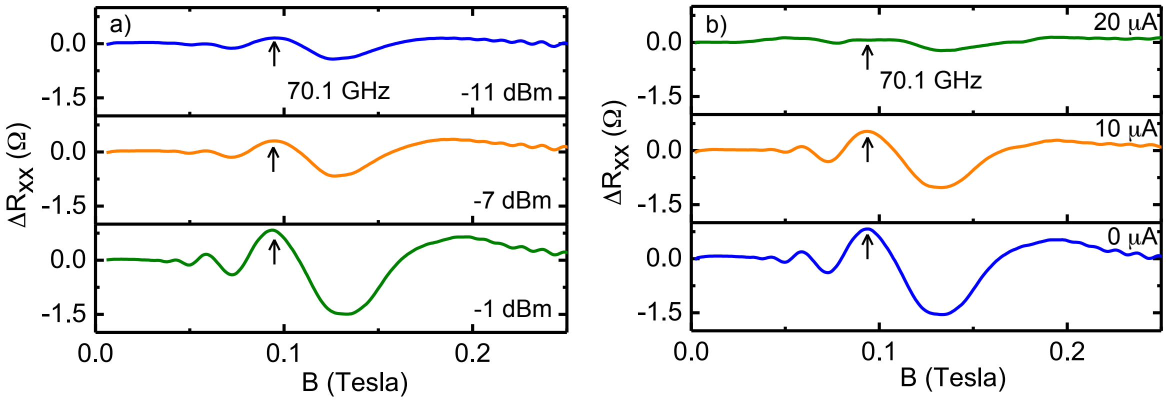

Figure 2. This figure shows the extracted microwave induced magnetoresistance oscillations, ΔR_{xx}, after subtracting the fit results from the experimental data, in the positive magnetic field. a) Exhibits the influence of power, *P* on the microwave induced magnetoresistance oscillations, b) Exhibits the effect of I_{dc} on the microwave induced magnetoresistance oscillations, at given conditions as indicated.

In Figure 2, ΔR_{xx} is obtained by subtracting the GMR fit results from the experimental data. One can observe clear microwave induced magnetoresistance oscillations without indication of other magnetoresistance effects. In Fig. 2(a), the height of the microwave induced magnetoresistance oscillations peak indicated by arrow (↑) has decreased by about 80% upon reducing the MW-power by a factor of eight. On the other hand, as shown in Fig. 2(b), the microwave induced magnetoresistance oscillations peaks disappear at I_{dc}=20 μA. Also, the peaks do not show any phase shift as a function of either MW-power or dc-bias.

4. Discussion

Magnetoresistance in the 2DES, under the photo-excitation and applied dc-bias, over the examined magnetic field range can arise from a number of mechanisms such as the weak localization effect, microwave-induced magnetoresistance oscillations, and bell-shape GMR. One might also examine the interplay of these effects with an applied I_{dc}. The weak localization effect observed at low magnetic fields is mainly a low-temperature disorder induced effect [16,19,20]. On the other hand, microwave radiation-induced magnetoresistance oscillations have been studied as a function of radiation frequency, power, polarization angle, etc. [1-14]. Studies report a nonlinear growth of microwave induced magnetoresistance oscillations with the radiation power *P* [11]. In this study, we found an increase in microwave induced magnetoresistance oscillations amplitude as a function of the microwave power by examining the ΔR_{xx} obtained by subtracting the fit result from the R_{xx}. Experimental studies have reported the effect of an applied I_{dc}, and the interplay of dc-bias and microwaves in the magneto transport of GaAs/AlGaAs 2DES [22-24]. In this study, quenching of microwave induced magnetoresistance oscillations was observed at about I_{dc} = 20 μA. Our results indicate a non-linear behaviour in the fit extracted σ_1. Also, bell-shape GMR effect, parameterized by σ_1, varies from positive to negative value as a function of dc-bias.

5. Conclusion

In summary, this study has shown that the multiconduction model along with weak-localization term provides a good fit to the non-oscillatory experimental data, as it also captures the essential features in bell-shape GMR effect, over various experimental parameters. In addition, the model serves to extract coexisting effects such as, radiation induced magnetoresistance oscillations, from the bell-shape GMR.

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