Splitting of the cyclotron resonance in two-dimensional electron systems

E.A. Henriksena,* S. Syeda,1 Y.J. Wangb, M.J. Manfrac, L.N. Pfeifferc, K.W. Westc, H.L. Stormera,c

aPhysics Department, Columbia University, New York, NY 10027, USA
bNational High Magnetic Field Laboratory, Florida State University, Tallahassee, FL 32310, USA
cBell Laboratories, Lucent Technologies, Murray Hill, NJ 07974, USA

Available online 24 April 2006

Abstract

A large splitting of the cyclotron resonance line, observed in two different two-dimensional electron systems, remains unexplained. The splitting resembles an anti-level crossing with an unidentified mode of the semiconductor system. Here, we review our data on this splitting, and highlight some results of recent experiments.

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PACS: 76.40.+b; 73.40.Kp

Keywords: Cyclotron resonance; Two-dimensional electron systems; Magnetoplasmons

A large and prominent splitting of the cyclotron resonance (CR) line in two-dimensional electron systems (2DESs) is unexplained. First observed in 1984 by Schlesinger et al. [1] in AlGaAs/GaAs 2DESs, the generic 2D nature of this splitting was underlined by its recent observation in the AlGaN/GaN system [2]. Several attempts in the intervening years to explain the splitting have not resulted in a consensus on its origin [2].

The splitting resembles an anti-level crossing of the CR with another mode of the solid (see Fig. 1). The energy at which the splitting occurs, \( E_{\text{crit}} \), is seen to vary with the 2D electron density, \( n_{2D} \), as

\[
E_{\text{crit}} = \sqrt{n_{2D} e^2 / \varepsilon} = E_{\text{coul}} / \varepsilon,
\]

implying that electron-electron interactions play a role. Here, \( \varepsilon \) is the static dielectric constant and \( E_{\text{coul}} \) is the Coulomb interaction energy. The coefficient \( \varepsilon \) varies between material systems, with \( \varepsilon \approx 1 \) in AlGaAs/GaAs, and \( \varepsilon \approx 2.5 \) in AlGaN/GaN. In addition, in neither system does the splitting appear to have any dependence on the Landau level filling factor, \( \nu \), which for AlGaAs/GaAs ranges over \( \nu = 2.0 \rightarrow 3.7 \), and in AlGaN/GaN over \( \nu = 4 \rightarrow 7.5 \).

In Ref. [1], it was noted that none of the usual excitations of the 2D system or bulk semiconductor host could explain the observed energies of the splitting. Thus, recourse was made to an ad hoc model, postulating an interaction with the magnetoroton, a minimum in the 2D magnetoplasmon dispersion located at \( k = \sqrt{2 \pi} / \lambda_B \), where \( \lambda_B = \sqrt{\hbar c / eB} \) is the magnetic length and \( B \) is the applied magnetic field. Although the magnetoroton energy lies above the cyclotron energy \( \omega_c \), where \( \omega_c = eB / m^*c \) is the cyclotron frequency and \( m^* \) is the effective mass, Schlesinger et al. assumed it to decrease with increasing magnetic field. A splitting will result when the magnetoroton becomes degenerate with the CR. Since then this assumption has been addressed in some detail [3–8], but its validity remains questionable.

In Fig. 1(a) and (c), we show typical splittings in AlGaAs/GaAs and AlGaN/GaN 2DESs, respectively. In both data sets, the usual single CR peak is observable at high and low values of \( B \). However for \( B = 5.5 \) T in AlGaAs/GaAs, and \( B = 10.8 \) T in AlGaN/GaN, a clear splitting of the CR peak is observed. The position of the CR minima as a function of magnetic field is shown in Fig. 1(b) and (d) for these two systems. We characterize the
The CR splitting size, $\Delta E$, is seen to decrease dramatically with increasing sample mobility (or decreasing electron scattering). This result establishes conclusively a correlation between increasing $\Delta E$ and increasing electron scattering.

Fig. 2. CR splitting size, $\Delta E$, vs. sample mobility for AlGaAs/GaAs samples with C-doping in the quantum well. The two highest mobility samples show a broadening rather than a splitting, and so have error bars extending to zero.
In summary, the origin of the enigmatic large splitting of the CR line in 2DESs remains unexplained. The splitting has little dependence on the Landau level filling factor, but the critical energy at which the splitting occurs depends on the 2D electron density. The size of the splitting has been clearly linked to the sample mobility, confirming that electron scattering is essential for the splitting to occur.

We wish to thank C. Kallin, A. Pinczuk, D. Smirnov, and Y. Ahmadian for many helpful discussions. Funding under ONR Project no. N00014-04-1-0028 is gratefully acknowledged. A portion of this work was performed at the national High Magnetic Field Laboratory, which is supported by NSF Cooperative Agreement no. DMR-0084173 and the State of Florida. We are grateful for financial support from the W. M. Keck Foundation.

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