New Anisotropic Behavior of Quantum Hall Resistance in (110) GaAs Heterostructures at mK Temperatures and Fractional Filling Factors

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Abstract

Transport experiments in high mobility (110) GaAs heterostructures have been performed at very low temperatures (8 mK). At higher Landau-Levels we observe a transport anisotropy that bears some similarity with what is already seen at half-odd-integer filling on (001) oriented substrates. In addition we report the first observation of transport anisotropies within the lowest Landau-Level. This remarkable new anisotropy is independent of the current direction and depends on the polarity of the magnetic field.

Key words: Quantum Hall Anisotropy, (110) GaAs, low-temperature transport, high-mobility 2DEG

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1. Introduction

Recently there has been increasing interest in transport anisotropies of the longitudinal resistance at half-odd-integer filling factors from $\nu = 9/2$ upwards [1]. The anisotropy is observed in high-mobility (001) oriented GaAs/AlGaAs modulation-doped heterostructures with the low resistance direction typically aligned along the [110] direction, however alignment along the [101] direction has also been observed depending on electron density or in-plane magnetic fields [3,2]. To explain this effect, new types of ground states have been proposed within high Landau levels of the quantum Hall effect (QHE) which are based on striped phases that align parallel to the low-resistivity direction [5].

2. Sample

To learn more about the influence of crystal orientation on possible anisotropies, we use a different substrate orientation, namely (110) GaAs. The 2-dimensional electron gas (2DEG) is made in a MBE-grown GaAs/AlGaAs $\delta$-doped heterostructure with a spacer thickness of 800 Å resulting in peak-mobilities up to $\mu = 4.2 \times 10^6$ cm$^2$/Vs at densities...
\( n = 2.1 \times 10^{11} \text{ /cm}^2 \). In comparison with (001) grown structures, the two in-plane orthogonal crystal directions on (110), namely [110] and [001], have explicitly different crystallographic symmetry.

For optimizing the mobility of our 2DEGs we grew a variety of substrates where we varied the temperature, measured by a pyrometer, between \( T = 450 \degree C \) and \( T = 530 \degree C \), with \( T = 480 \degree C \) giving the best morphologies and mobilities. The As-flux, measured as beam equivalent pressure, has been varied between \( P_{\text{As}} = 3.5 \times 10^{-5} \text{ mbar} \) and \( P_{\text{As}} = 6 \times 10^{-5} \text{ mbar} \), leading to the result that the highest As-flux gives the best morphologies and the highest doping efficiencies of 0.7 relative to the doping efficiencies on (001). These findings are in agreement with work previously being done on growth of (110) GaAs [4]. Due to the fragile nature of the anisotropic ground states it is useful to measure at very low temperatures, especially in the case of (110) 2DEG’s where the mobility is not as high as in (001)-based systems. The measurements are performed in a dilution refrigerator cryostat with a base bath temperature of \( T = 5 \text{ mK} \) and a magnetic field up to \( B = 7.2 \text{ T} \). To have the best possible thermal coupling to the electron system it is crucial to make the contact resistance as low as possible. For this reason we modified the usual square-sample van-der-Pauw contacting scheme by substituting two out of eight contacts with small openings leading to large contacts with lower resistance and thus, better thermal coupling (Fig. 3 bottom right inset).

3. Experimental results

Fig. 2 shows a trace of the longitudinal resistance for the two perpendicular current directions, drawn in the inset, at \( T = 14 \text{ mK} \). We examine first the case of exactly half-filled levels (i.e. the resistance at the center of each peak structure). With \( \nu < 4 \) \((B < 2T)\), designated by arrows at exactly \( \nu = 7/2, 5/2 \) and \( 3/2 \) the resistances in the two directions are similar, staying within a factor of 2 of each other, whereas \( \nu > 4 \) \((B < 2T)\) half-filled levels show a highly anisotropic behavior differing by a factor of \( \sim 20 \) in resistance, similar to anisotropies in (001) systems. Following previous authors we define the low-resistance trace as “easy” and the high-resistance trace as the “hard” [2].

Unlike previous (001) studies, however, a striking anisotropy also develops away from half-filled levels in the neighborhood of \( \nu = 3/2 \) where fractional quantum Hall states are evident (Fig. 2) in the hard trace. This type of anisotropy has been predicted by [7]. It is especially pronounced at filling factors \( \nu = 7/4, 13/8 \) and \( 11/8 \) which correspond to the effective half-filled filling factors \( \nu^* = 3/2, 5/2 \) and \( 3/2 \) in the composite fermion

![Fig. 1. Left picture: Surface morphology of a sample grown at \( T = 480 \degree C \) and \( P_{\text{As}} = 6 \times 10^{-5} \text{ mbar} \). Right picture: Surface morphology of a sample grown at \( T = 530 \degree C \) and \( P_{\text{As}} = 6 \times 10^{-5} \text{ mbar} \). Scale is 320 \( \mu \text{m} \) x 430\( \mu \text{m} \)](image)

![Fig. 2. Trace of the longitudinal resistance \( R_{xx} \) for two perpendicular current directions indicated in the inset at \( T = 8 \text{ mK} \). As shown in the inset similar colored pairs of \( R_{xx} \) voltage contacts show the same type of \( R_{xx} \) trace, independent of the current contacts used. For example all pairs of \( R_{xx} \) voltage contacts connected by the contiguous red dotted line show \( R_{xx} \) traces proportional to the red dotted data trace. The low temperature traces develop a strong anisotropy both at \( \nu > 4 \) \((B < 2T)\) and strikingly at \( \nu < 2 \) \((B > 4.5 \text{T})\).](image)
picture of the partially filled spin-up Landau level. In Fig. 4 we see that the temperature dependence of the \( \nu = 7/4 \) peak in the fractional regime is very similar to the dependence of the anisotropy in the \( \nu = 9/2 \) peak in the higher Landau Level regime. We emphasize that all the resistivity peaks become isotropic again around 100 mK. Contrary to the longitudinal resistance there is no anisotropy to be seen in the Hall resistance (Fig. 3). The traces of the Hall resistance for the two perpendicular current directions are nearly identical.

A detailed study indicated that no matter how the current is driven thru the sample, a pair of voltage contacts on the red dotted sample boundary shown in the inset of Fig. 2 reveals the "easy" characteristic and a pair of voltage contacts on the green solid sample boundary the "hard". Unlike previously observed QHE anisotropies, the choice of current contacts is not relevant. One of the most remarkable properties of this anisotropy is a dependence on the sign of the magnetic field. The regions of the sample which show the "hard" resistance characteristic switch to showing the "easy" characteristic and vice-versa upon reversing the polarity of the magnetic field, while being remarkably insensitive to the direction of current in the sample. The switching behavior and the independence of current direction may suggest an ordered phase with symmetries different from that of a striped composite Fermion phase proposed in [7].

4. Summary

We showed that in high-mobility (110) GaAs/AlGaAs heterostructures there is an anisotropy at very low temperatures. To our knowledge it is the first observation of strong anisotropy of the longitudinal resistance in the fractional quantum Hall regime. This effect is intriguing in that it cannot be explained by existing theories for higher Landau levels of electrons, but could possibly be explained using Landau levels of composite fermions [7]. This anisotropy, confirmed in multiple samples from the same wafer, switches character from "hard" to "easy" and vice-versa upon reversing the polarity of the magnetic field, while being remarkably insensitive to the direction of current in the sample. The switching behavior and the independence of current direction may suggest an ordered phase with symmetries different from that of a striped composite Fermion phase proposed in [7].

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References

[1] M.P. Lilly, K.B. Cooper, J.P. Eisenstein, L.N. Pfeiffer, and K.W. West, Phys. Rev. Lett. 82 (1999) 394.

[2] W. Pan, R.R. Du, H.L. Stormer, D.C. Tsui, L.N. Pfeiffer, K.W. Baldwin, and K.W. West, phys. Rev. Lett. 83 (1999) 820.

[3] J. Zhu, W. Pan, H.L. Stormer, L.N. Pfeiffer, and K.W. West, Phys. Rev. Lett. 88 (2002) 116803.

[4] E.S. Tok, J.H. Neave, M.J. Ashwin, B.A. Joyce and T.S. Jones, J. of Apl. Phys. 83 (1998) 4160.

[5] For a review see: M.M. Fogler, cond-mat/01111001 (2002).

[6] According to van der Pauw, Philips Res. Rep. 13 (1958) 1, the effect of large contacts can be eliminated by using small constrictions.

[7] S.-Y. Lee, L.W. Scarola and J.K. Jain, Phys. Rev. Lett. 87 (2001) 256803-1.