Surface acoustic wave study of a double layer AlGaAs/GaAs 2D hole system


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Abstract

The temperature and frequency dependence of the surface acoustic wave (SAW) velocity shift has been studied in a double layer 2DHS for 0.34–4.2 K and 112–560 MHz. The measured velocity shift has been compared to the velocity shift calculated from conventional transport techniques. At \( v = 1, 2, 4, 6 \) and \( 8 \) maxima in SAW velocity shift have been detected. A hysteretic feature at \( v = 2 \) has been observed in both conventional magnetotransport and SAW measurements, which is probably due to slight parallel conduction.

Keywords: Surface acoustic wave; Double layer hole systems; Quantum Hall effect

Surface acoustic wave (SAW) techniques have played an important role in establishing the composite fermion theory of the quantum Hall effect in single layer 2D systems. A minimum in SAW velocity shift was observed at \( v = \frac{1}{2} \) in both 2D electron [1–3] and hole systems (2DHS) [2,3] which was not evident in conventional magnetotransport measurements.

For the double layer AlGaAs/GaAs 2DHS, conventional magnetotransport measurements have shown that the odd integer \( v = 3, 5, 7 \ldots \) quantum Hall effect states are absent due to weak tunnelling [4]. At a total filling factor of \( v = 1 \) (i.e., \( v = \frac{1}{2} \) in each well) magnetotransport [4–6] and magnetothermopower [7] measurements have provided evidence for a finite temperature phase transition. Insulating behaviour has been observed for \( v < 1 \), which provides strong evidence for the existence of a double layer correlated Wigner solid state [4–7]. In this paper, we report the first SAW investigation of double layer AlGaAs/GaAs 2D hole systems.

Our double layer 2D hole system was grown by molecular beam epitaxy on the (3 1 1)A orientated surface of GaAs. It consisted of two modulation doped GaAs quantum wells (thickness 10 nm), separated by a 3 nm AlAs barrier [8]. The sample had a total carrier density \( n \) of \( 2 \times 10^{11} \text{cm}^{-2} \) and a mobility \( (\mu) \) of \( 1.5 \times 10^{5} \text{cm}^{2}/\text{V}s \) (at 340 mK). Several samples from the same wafer were studied and showed similar behaviour.

Hall bars were fabricated orientated along the [011] direction. The interdigital transducers that generate and detect the SAWs were made by photolithography. The SAW path length was 3 mm.
The sample was mounted in a He³ cryostat. For conventional transport measurements, standard four-terminal, low-frequency (13 Hz) AC measurements were made with a sample current of 10 nA. For SAW measurements, SAW pulses of 500 ns duration were launched across the Hall bar at kHz repetition rates. The SAW velocity shift ($\Delta v/v$) was measured using homodyne detection and averaged with a box-car detector.

The longitudinal ($\rho_{xx}$) and Hall ($\rho_{xy}$) resistivity at 340 mK are shown in Fig. 1. Several interesting features are evident, which have previously been reported in similar double layer hole systems. Only the integer QHE $v = 1, 2, 4, 6, 8 \ldots$ states are present [4]. The strong $v = 1$ minimum at 8.4 T indicates that the carrier density in each well is similar [7]. Close examination of the minimum at $v = 2$ reveals extra structure (see Fig. 1 inset) whose nature depends on the direction in which the magnetic field is being swept. The hysteretic feature at $v = 2$ has been studied previously in magnetotransport [9] and magneto-thermopower [7] and is probably due to a slight parallel conduction path (at the bottom interface) which only occurs in ungated samples [9,10].

Fig. 2 shows the measured SAW velocity shift for 560 MHz. Clear maxima are observed at $v = 1, 2, 4, 6$ and 8. The maximum at $v = 1$ confirms that the effect is not due to composite fermions. Higher frequency experiments are underway to study the development of the velocity shift at $v = 1$.

The hysteretic behaviour in $\rho_{xx}$ at $v = 2$ manifests itself as a prominent hysteretic feature in the SAW velocity shift. The SAW velocity shift can be calculated from the conventional transport measurements and is given by

$$\frac{\Delta v}{v} = \frac{k_{eff}^2}{2} \frac{1}{1 + (\sigma_{xx}/\sigma_M)^2},$$

where $k_{eff}^2$ is the electromechanical coupling constant, $\sigma_{xx}$ is the conductivity, and $\sigma_M = (\varepsilon_0 + \varepsilon_p)v_{SAW}$. Here, $\varepsilon_0$ is the dielectric constant of vacuum, $\varepsilon_p$ is the dielectric constant of GaAs and $v_{SAW}$ is the surface acoustic wave velocity [11]. $\sigma_{xx}$ can be calculated from the resistivity components in Fig. 1 using matrix inversion. The calculated SAW velocity shift is also shown in Fig. 2.

The following values have been used: $k_{eff}^2 = 8.65 \times 10^{-4}$, $\sigma_M = 3.3 \times 10^{-7}\Omega^{-1}$ and $v_{SAW} = 2970\text{ms}^{-1}$ [12]. Fig. 2 inset shows a magnified view of the calculated velocity shift at $v = 2$; qualitative agreement is obtained with the measured values. The increased background of the measured velocity shift will be discussed later.

The temperature dependence of the measured SAW velocity shifts is shown in Fig. 3(b), alongside
Fig. 3. Temperature dependence of (a) the calculated and (b) the measured velocity shift at 560 MHz for 340, 540, 950 mK and 4.2 K. Traces are offset by 50 ppm for clarity. The inset is a magnified view of the calculated velocity shift around $v = 1$ at 340, 540 and 950 mK (with no offset).

Fig. 4. The frequency dependence of the velocity shift at (a) 112 MHz (the fundamental-dashed line) and (b) 560 MHz (the fifth harmonic-solid line).

studied in a double layer 2DHS. At $v = 1, 2, 4, 6$ and 8 maxima in velocity shift have been observed. A hysteretic feature at $v = 2$ has been observed in both conventional magnetotransport and SAW measurements, which is probably due to slight parallel conduction in the ungated sample. Qualitative agreement has been found between the measured velocity shift and the velocity shift calculated from conventional transport techniques.

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References


