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Imaging the Current Distribution in the Quantum Hall Effect

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Abstract. In this paper we describe a new imaging technique for probing the spatial distribution of current in a two-dimensional electron gas (2DEG) in the quantum Hall effect (QHE). We also present preliminary results which indicate that the current is carried by edge states in the QHE.

Introduction

The role of edge currents in the QHE is discussed in a number of theoretical papers [1,2]. It is believed that in a finite 2DEG, currents flow along one-dimensional edge channels which interact with the voltage contacts of a Hall device. The number of edge channels and hence the value of the quantised Hall resistance depends on the filling factor. Experimental studies of the current distribution in the QHE have been made by Zheng and co-workers [3] using samples with internal contacts. They found that the current bunched into a narrow channel at one edge of the 2DEG but this did not swap sides when the current or magnetic field direction was reversed and was attributed to a density gradient in the 2DEG. A contactless method for probing the potential distribution has been demonstrated by Fontein and co-workers [4]. They observed sharp increases in potential implying a concentration of charge at the two edges of the sample. Nevertheless, the experimental picture regarding the contribution of edge currents in the QHE and their dependence on filling factor, field and current direction is still not complete. In this paper we describe a new "phonoconductivity" technique which we have used to make 2-D images of the current distribution in a 2DEG in the QHE.

Experimental techniques

The imaging system is described in detail elsewhere [5]. The sample was based on a (100) GaAs/AlGaAs heterojunction with a 2DEG concentration of $7.8\times10^{15}\mathrm{m}^{-2}$ and a 4.2K mobility of $70\mathrm{m}^2\mathrm{V}^{-1}\mathrm{s}^{-1}$. A 3 x 1mm device was defined by etching and a pair of Au/Ge contacts formed at its ends. The opposite side of the standard 380μm wafer was polished and coated with a 100nm constantan film. The sample was held at a temperature of 2K in an optical cryostat. Bursts of acoustic phonons were generated by thermalising a 100ns infrared pulse from a Q-switched Nd-YAG laser in the constantan film. These traverse the GaAs wafer and interact with the 2DEG causing a transient change in the device resistance. A constant bias current is passed through the device and the corresponding voltage pulse is amplified and detected. Phonon focusing effects in the substrate [6] cause about 70% of the phonon flux to be concentrated in an area about 100μm across, directly opposite the spot where the laser pulse hit the metal film, the rest is spread out over a large area. Therefore, the signal seen is due to the interaction of the phonons with only a small region of the 2DEG. By raster (x,y) scanning the laser over the metal film a two dimensional map of the interaction can be built up. The voltage signal $\delta V(x,y)$ is given by the product of the temperature sensitivity of the 2DEG, $\{dR(x,y)/dT\}\delta T$, and the current density, $J(x,y)$. By making a few assumptions about the form of $dR(x,y)/dT$ a qualitative picture of the current distribution may be obtained.

Results and discussion

Figure 1 shows a set of four images corresponding to the four permutations of magnetic field and current direction. The images were recorded at a filling factor of 15 and the magnitude of the bias current was 10μA. The bright region at the corner of the current entry contact corresponds to a reduction in the device resistance. It switches to the adjacent corner of the contact when the magnetic field is reversed. We believe that this effect is due to thermally activated conduction in the disordered region near the contact. At this stage we can offer no explanation for why it is only seen at the current entry contact. Similar work on Si MOSFETS [7] showed activated conduction at both contacts, one of which gave a stronger signal, and no change with current direction was seen. It is possible that our contacts could be behaving like imperfect diodes with strongly

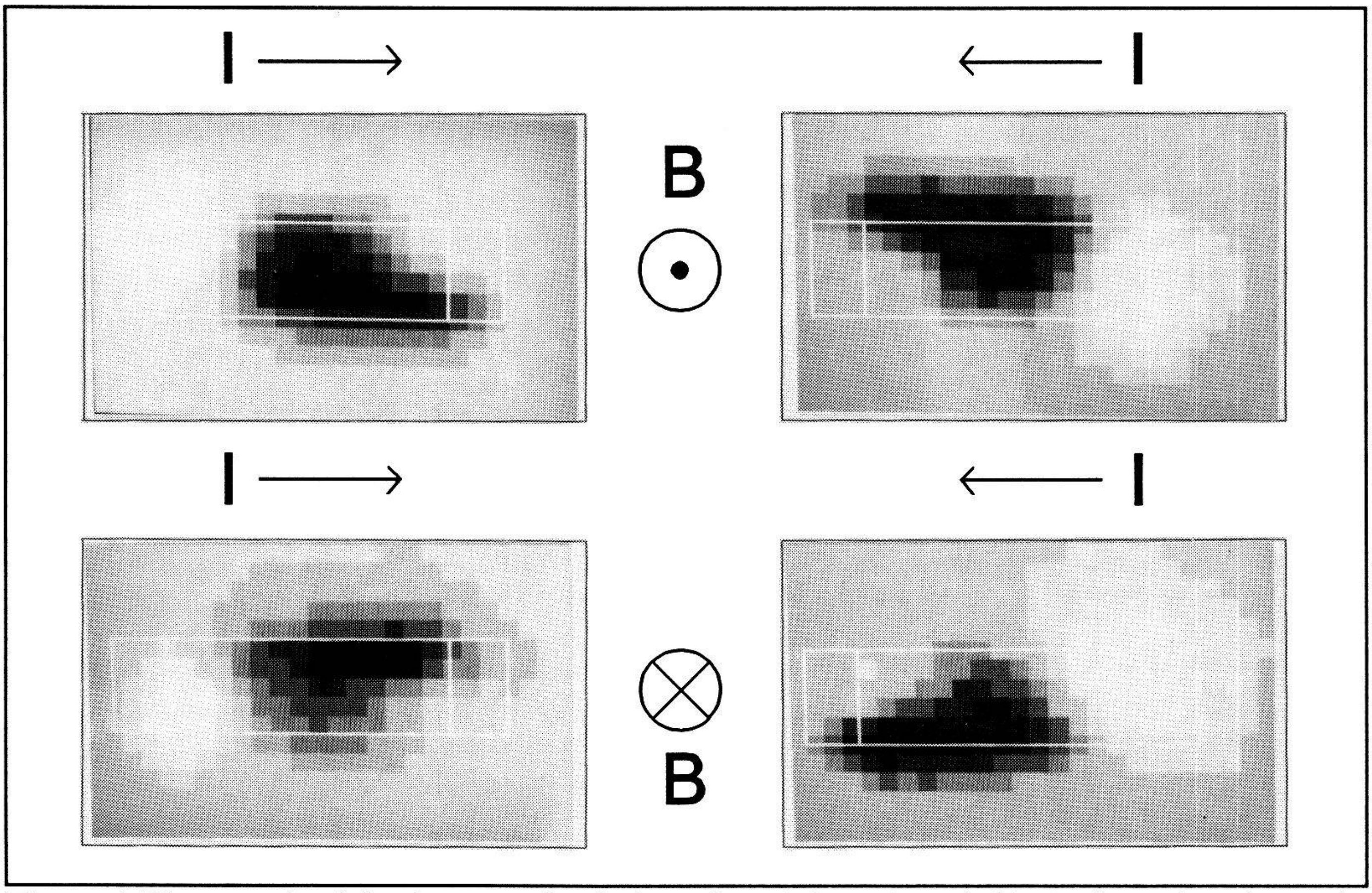

Figure 1 Phonoconductivity images of a 3x1mm 2DEG in a GaAs/AlGaAs heterojunction. the device outline is shown on the images.

temperature dependent reverse characteristics. Assuming that the contacts are homogeneous the results indicate that the current density exhibits a local maximum at the corner of the contact through which the current enters the 2DEG. The other main feature in the images, the dark region, corresponds to an increase in the device resistance when the phonons interact with the 2DEG. It starts at the current exit (electron injection) point, runs along one edge and extends across the device to meet the current entry point. This is where one might expect the current to flow if the edge state picture is accurate. The edge signal swaps sides when the current or magnetic field direction is reversed. We believe that cyclotron phonons are responsible for scattering electrons out of the edge states into the bulk, where dissipation takes place. We estimate that the metal film reaches about 10K. Assuming that the phonon spectrum is approximately Planckian, the dominant phonon frequency is 600GHz, which is greater than the cyclotron frequency at 1T (400GHz) where these images were made. Isotope scattering in the substrate causes a cut-off in the phonon transmission above about 1THz which might explain why we are unable to observe the edge effects at fields above about 3T.

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