The 2DEG as a Non-Invasive Tool for Determining the Switching Behaviour in Cobalt "Needle" Arrays

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Magnetic Surface Superlattices (MSSLs) have been studied extensively in recent years They can be patterned either in 1 or in 2 dimensions [1,2]. When deposited on the surface of a GaAs/AlGaAs heterostructure Hall-bar and subjected to an external magnetic field they modulate the underlying 2-Dimensional Electron Gas (2DEG) periodically. This gives rise to classical commensurability effects, where an electron's cyclotron orbit becomes commensurate with the period of the modulation. In this study we show that the 2DEG can be used as non-invasive tool for determining the magnetisation of arrays of magnetic elements. We deposited arrays of cobalt needles on the surface of GaAs/AlGaAs Hall-bars with [011] and [01-1] orientations on a (100) wafer. These Hall-bars had standard four-voltage-probe geometry with 30μm separating adjacent voltage probes and a 10μm current channel. The needle array overlapped the voltage probes by 2.5μm at either end. The carrier concentration of the material used was $3.3\times10^{15}m^{-2}$ and mobility of $40m^2V^{-1}s^{-1}$. The period of the needle array was 360nm×120nm, with each individual element having dimensions of 300nm×60nm×50nm thick. The current flow in the Hall-bar was always parallel to the long axis of the needles. These needles are expected to remain magnetised along their length at zero applied field, unlike the squares studied earlier[2] which reverted to a flux closed state at zero field.

We have investigated a number of techniques for determining the magnetisation of the needle array over positive and negative field sweeps. In perpendicular field ($\theta = 0°$, where θ is the angle the field makes relative to the sample's normal) the low temperature magnetoresistance traces show prominent low field positive magnetoresistance (PMR) and weak commensurability oscillations (COs). The minima of the COs confirm that the period of modulation is 360nm. At inclined fields ($\theta = 70°$), most of the external field is directed along the length of the needle array. However a perpendicular field component is present at this angle and thus PMR and COs are observed, although the magnetisation signals are distorted by strain effects. Above 20K, the PMR rapidly diminishes, and vanishes by 50K. We reveal the magnetic behaviour of the needle array by measuring at $\theta = 90°$ (in plane field only) and forming the sum (Fig. 1) and the difference (Fig.2) of the longitudinal magnetoresistances from the two sides of the Hall-bar.

The longitudinal difference signal (Fig.2) can also be associated with the difference of the Hall voltages at the two pairs of Hall contacts, and is produced by flux leakage from the array. Measurements of the Hall voltage at each pair independently confirm that this is correct. The hysteresis loop shows that the elements switch between reverse fields of 50 and 250 mT. We are unable at present to account for the novel features occurring near zero magnetisation and at reverse saturation but is believed to result from the details of magnetisation reversal processes in the array. The summed signal (Fig. 1) shows deep minima when the magnetic field has been reversed. Comparing the two figures, it is apparent that the minima correspond to the region where the magnetisation is reversing; there is a resistance contribution of around 1% in fields where the magnetisations of the elements of the array are aligned. This signal is observed at $\theta = 90°$, so is not related to the low temperature PMR. It is observed at all values of θ around this angle, and is only weakly temperature dependent. We do not at present have full understanding of the mechanism responsible for it.

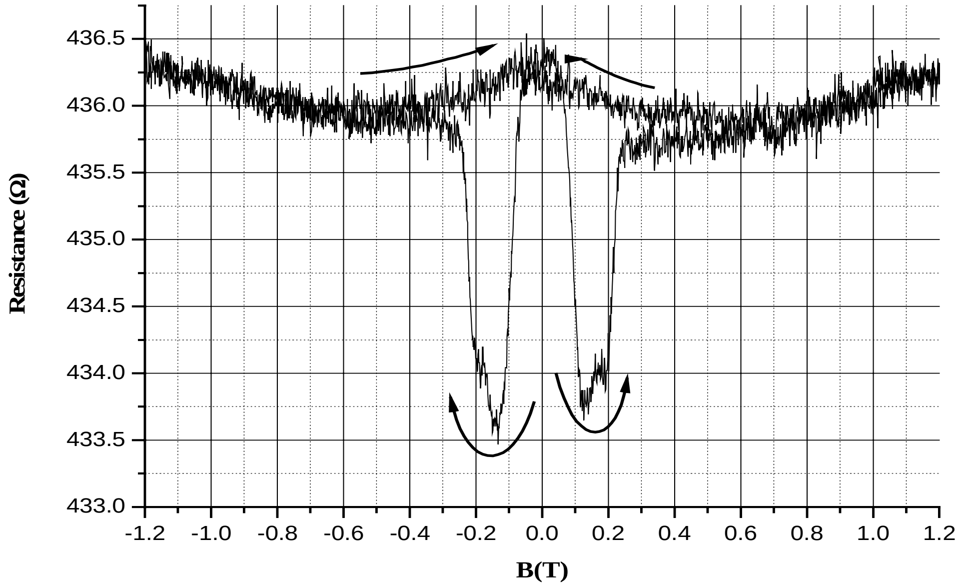

Figure 1: The sum of the longitudinal resistances from the two sides of the Hall-bar at a temperature of 49K. Arrows indicate the sweep directions

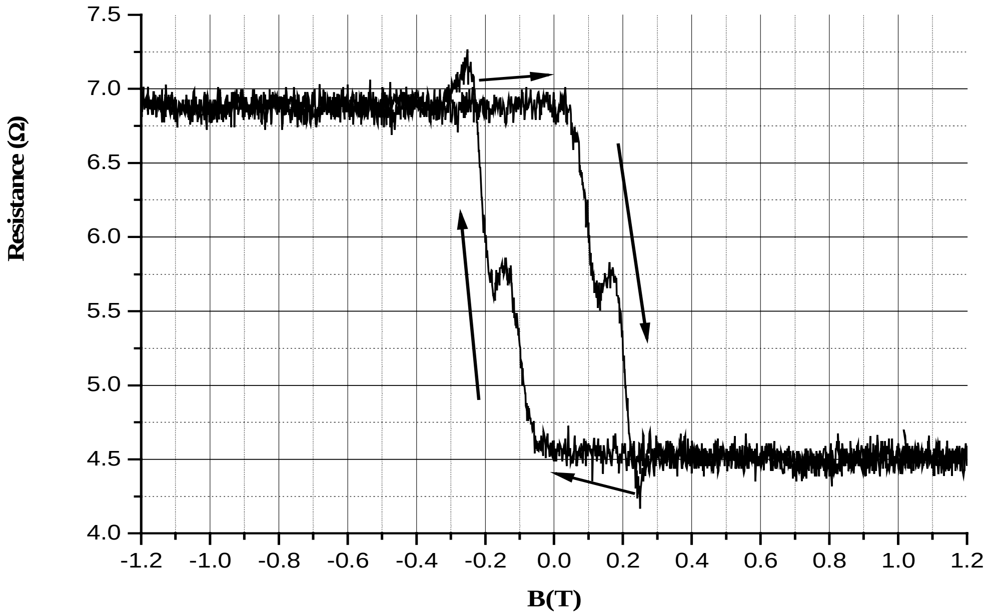

Figure 2: Difference between the longitudinal resistances from the two sides of the Hall-bar at 49K. Arrows indicate the sweep directions

1. P. D. Ye, D. Weiss, M. Seeger, K. von Klitzing, K. Eberl, and H. Nickel, Appl. Phys. Lett. **67**, 1441 (1995)
2. E. Skuras, A. R. Long, S. Chowdhury, M. Rahman, K. Kirk and J. H. Davies. J. Appl. Phys. **90**, 2623 (2001)