The 2DEG as a non-invasive tool for determining the magnetic interactions and the switching behaviour in sub-micron cobalt "needle" arrays

T. McMullen, E. Skuras, K. Kirk, J. H. Davies and A. R. Long

Nanoelectronics Research Centre, University of Glasgow, Glasgow, G12 8QQ, UK

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 the stray field modulates the underlying 2-Dimensional Electron Gas (2DEG) periodically. This gives rise to classical commensurability effects, where the cyclotron orbit diameter 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 such arrays of magnetic elements. We deposited arrays of cobalt needles on the surface of GaAs/AlGaAs Hall-bars with various orientations on a (100) wafer. The period of the needle arrays 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 studying 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. Inclined fields are selected so that the in-plane component of field is directed along the length of the needle array. At $\theta = 70°$ however a perpendicular field component is present 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 find that the magnetic behaviour of the needle array is most clearly revealed by measuring at $\theta = 90°$ (in-plane field only) at 50K and forming the sum and the difference of the longitudinal magnetoresistances (MR) from the two sides of the Hall-bar.

The anti-symmetric longitudinal difference signal is also associated with the difference of the Hall voltages at the two pairs of Hall contacts, and is produced by flux leakage from the array. It shows a hysteresis loop with the elements switching between reverse fields of 50 and 250 mT. We observe novel features occurring near zero magnetisation and when reverse saturation is reached, which we ascribe to interactions occurring in the array. The summed (symmetric) MR signal shows prominent minima where the magnetisation of the array 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, and 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.

We have also studied the effect of demagnetising the array in a large perpendicular field and then re-measuring at $\theta = 90°$. The antisymmetric MR component confirms that the net magnetisation after this process is small and that the hysteresis loop is only fully recovered after a complete field cycle. As expected, the symmetric MR also starts from a low value in the demagnetised state, and rises as the array is magnetised.

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)