Scanning Gate Microscopy of Graphene and Semiconductor Heterostructures

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Introduction

Miniaturized Hall devices based on high mobility semiconductor materials and atomically thin graphene have been increasingly used as high sensitivity devices for the detection of localized magnetic fields. Characterisation of graphene and semiconductor sensors under uniform magnetic field is very common. However, for applications such as head and nanomagnet detection, it is necessary to calibrate the Hall devices locally. We have demonstrated the calibration of 2-dimensional electron gas (2DEG) and graphene Hall devices under non-uniform, in-homogenous magnetic and electric fields using scanning gate technique.

Sample

2DEG Hall devices

Graphene Hall devices

Scanning gate microscopy

Modelling

The material is modelled in 2-D domain with 2-D conductivity tensor as:

$$\sigma = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{xy} & \sigma_{yy} \end{bmatrix}$$

Function $\gamma(t)$ represents the local potential profile due to the tip-sample capacitive coupling, here described as a Gaussian potential barrier.

The tip is modelled as a truncated cone and the magnetic coating as a 20 nm thick uniformly magnetized layer.

Results and Observations

SGM on 2DEG devices

- The transverse voltage mapping at $V_{tip}=0$ shows uniform distribution of Hall voltage at centre of cross.

- A two-fold symmetry appears with the introduction of $V_{tip}$.

- Peak voltage observed at the corners, with opposite corners having same polarity.

- The two-fold symmetry rotates with polarity of tip bias.

- The two-fold symmetry has been confirmed using numerical modelling.

- Capacitive coupling constant in 2DEG has been calculated to be $C = 4.7 \times 10^{-14}$ F/m

- Two-fold symmetry at the corners is mainly due to electrostatics.

- The signal at the centre of the cross is irrespective of the $V_{tip}$.

- The signal at the cross centre is the response to the Lorentz force resulting from magnetic field.

- Graphene has an order higher coupling constant than 2DEG and hence higher sensitivity.

- Magnetic sensing region in graphene is reduced by 23% due to the edge effects related to electrostatics.

- This reduction can be compensated by applying a gate voltage.

- Capacitive coupling constant in graphene has been calculated to be $C = 3.2 \times 10^{-13}$ F/m

Key points

References