Interferometric measurement of an electrically-biased tip perturbation

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We present an original method to characterize the size and shape of the local perturbation induced by an electrically biased scanning probe microscope tip into a two-dimensional electron system (2DES). The method relies on scanning gate microscopy measurements on a quantum point contact (QPC) – a quantum constriction defined in a 2DES.

Introduction

The scanning gate microscopy (SGM) allows us to perform local-scale investigation of the electron transport inside mesoscopic devices. This technique is derived from atomic force microscopy (AFM), and consists in measuring the conductance of a device at low temperature as an electrically-polarized metallic AFM tip introduces a moving local electrostatic perturbation for charge carriers inside the device. By recording the device conductance as a function of tip position, one can image quantum transport phenomena in semiconductor nanostructures[1,2,3]. The SGM conductance maps allows to get real-space insights in the underlying physics of nanodevices down to very low temperatures. In the literature, the interpretation of SGM mappings usually relies on very simplified models of the electrostatic perturbation induced by the tip inside the nanodevice[1,2] which is not always well measured. Our main objective is to improve existing methods to measure and to describe this model of tip perturbation in real devices, and to devise new methods for this purpose.

Measurements and discussion

The quantum point contact (QPC) represents the simplest mesoscopic device that can be designed on a high mobility two-dimensional electron gas (2DEG), and is the tool of choice to study conductance quantization in 1D systems.
We defined a QPC using two metal finger gates deposited on top of a 2DEG hosted in a GaAs/AlGaAs semiconductor heterostructure, with a 2DEG buried 57 nm below the surface. We used the SGM technique to extract local information about electron transport through this nanodevice.
The electrostatic tip perturbation locally depletes the 2DEG in front of the constriction and in its vicinity. Electrons transmitted through the constriction are impinging on the tip-induced depleted area, and part of them are backscattered in the direction of the constriction (Fig. 1a). A Fabry-Pérot cavity is therefore formed between the quantum constriction and the tip-induced depletion region. In the coherent regime of transport, interference fringes are observed in the electrical conductance of the device, separated

by half a Fermi wavelength [1,3] (Fig. 1b). Measuring the behaviour of these interference fringes as we vary various parameters such as the tip-2DEG vertical distance (Fig. 1c) and the tip voltage gives direct information on the tip-induced perturbation, as experienced by electrons in the 2DEG. We examine in particular peculiar effects such as the local differences in electron density due to defects, the regime where interferences are observed while the tip is not depleting the 2DEG, and the unexpected fringes observed for a positive tip bias. The information obtained through interferometry is compared with data obtained from other more classical methods, such as the direct electrostatic coupling between the tip and the QPC.

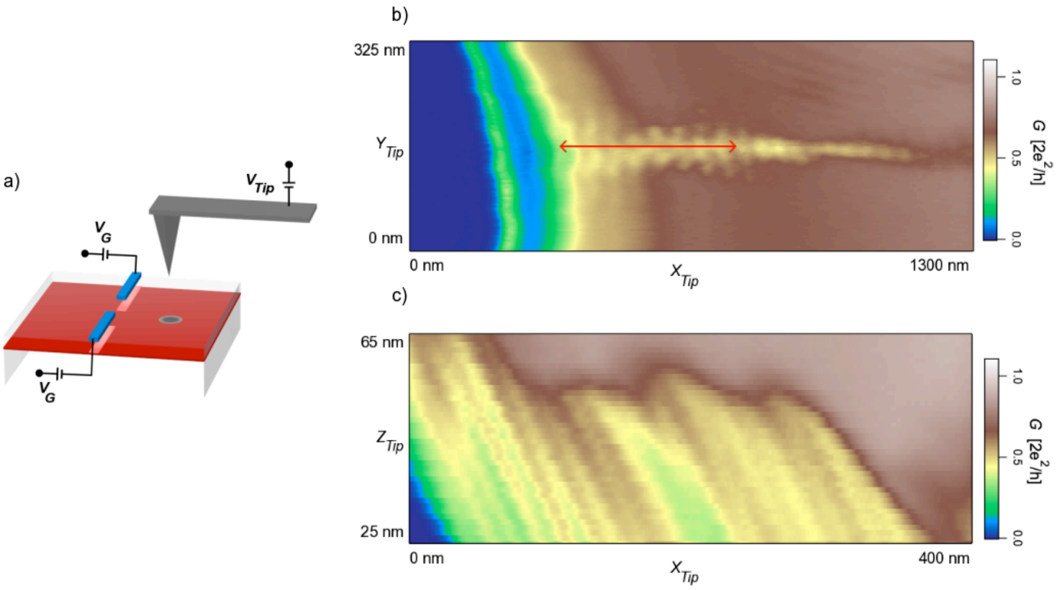

Figure 1. a) Schematics of the scanning gate microscopy experiment on a QPC. The red plane is the 2DEG (buried below the surface), and the top metal gates (in blue) are electrically biased in order to define a QPC whose conductance is measured while scanning the tip. b) Scanning gate image (QPC conductance G as a function of tip position) measured at tip voltage V_{Tip} = - 6 V, tip-2DEG distance z_{Tip} = 30 nm and gate voltage V_G = -0.95 V. The QPC is located on the left of the image. c) Evolution of the profile of interference fringe pattern for varying tip-2DES distance measured at tip voltage V_{Tip} = - 6 V and gate voltage V_G = -0.92 V. The scan was performed along the red line shown in b).

Conclusion

We present a new way to accurately measure the tip potential in the context of SGM measurements, based on electron interferometry. The interferometer is based on a Fabry-Pérot cavity formed in a 2DEG using a QPC and the SGM tip-induced depletion area as mirrors. The observed interference fringes are used to extract information about the tip-induced perturbation potential.

References

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