Vertical charge transport on the nano scale across a graphene–Si interface

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Abstract

The in-plane charge and spin transport characteristics of graphene have been extensively studied and high carrier mobility [1] and long spin relaxation length [2], at room temperature, demonstrated. Recently vertical device geometries that use a graphene/Si interface were fabricated, to explore charge transport in the out-of-plane direction in graphene [3]. Further, in different device geometries, graphene was used as a tunnel barrier [4] between two ferromagnetic electrodes in a magnetic tunnel junction as well as used as a spin-polarized tunnel barrier contact for electrical spin injection into silicon [5].

In order to fabricate functional devices from graphene, the current perpendicular to plane (CPP) transport needs to be understood. By using the Ballistic Electron Emission Microscope (BEEM) we can investigate CPP transport at the nanoscale. Figure 1a shows a schematic view of this technique. It is based on a Scanning Tunneling Microscope, but has an additional electrode at the back which records the BEEM current, I_B. This current consists of electrons having the necessary energy and proper momentum at the metal-semiconductor (M-S) interface to surpass the Schottky barrier (SB), (see figure 1 b and c). The two orange cones visualize the momentum spread of the injected and collected electrons and leads to a high spatial resolution in BEEM. Furthermore, this technique allows us to simultaneously map the surface topography and the transmitted current in the buried layers of the device. Additionally, one can do spectroscopy by varying the voltage and keeping the tip at one location, in order to extract local SB heights.

Our device scheme is depicted in figure 2, where (multi layer) graphene flakes are scattered over the Si surface and is capped by Au. In this study we found that (multi layer) graphene forms a SB with the underlying n-type Si of 1.19 eV and shows very low leakage and good rectification (~10^6). Furthermore on p-type Si it was found that the SB was similar. Normally one would expect the difference in barrier heights, on p- and n-type Si, to reflect the band gap of the semiconductor. However in this case extrinsic doping (e.g. water vapor) of the (multi layer) graphene, which causes a Fermi level shift, might be responsible for the deviation in SB. The nature and passivation of the underlying Silicon surface was found to influence the local BEEM transmission and the band alignments at the Gr/Si interface.

References

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Figures

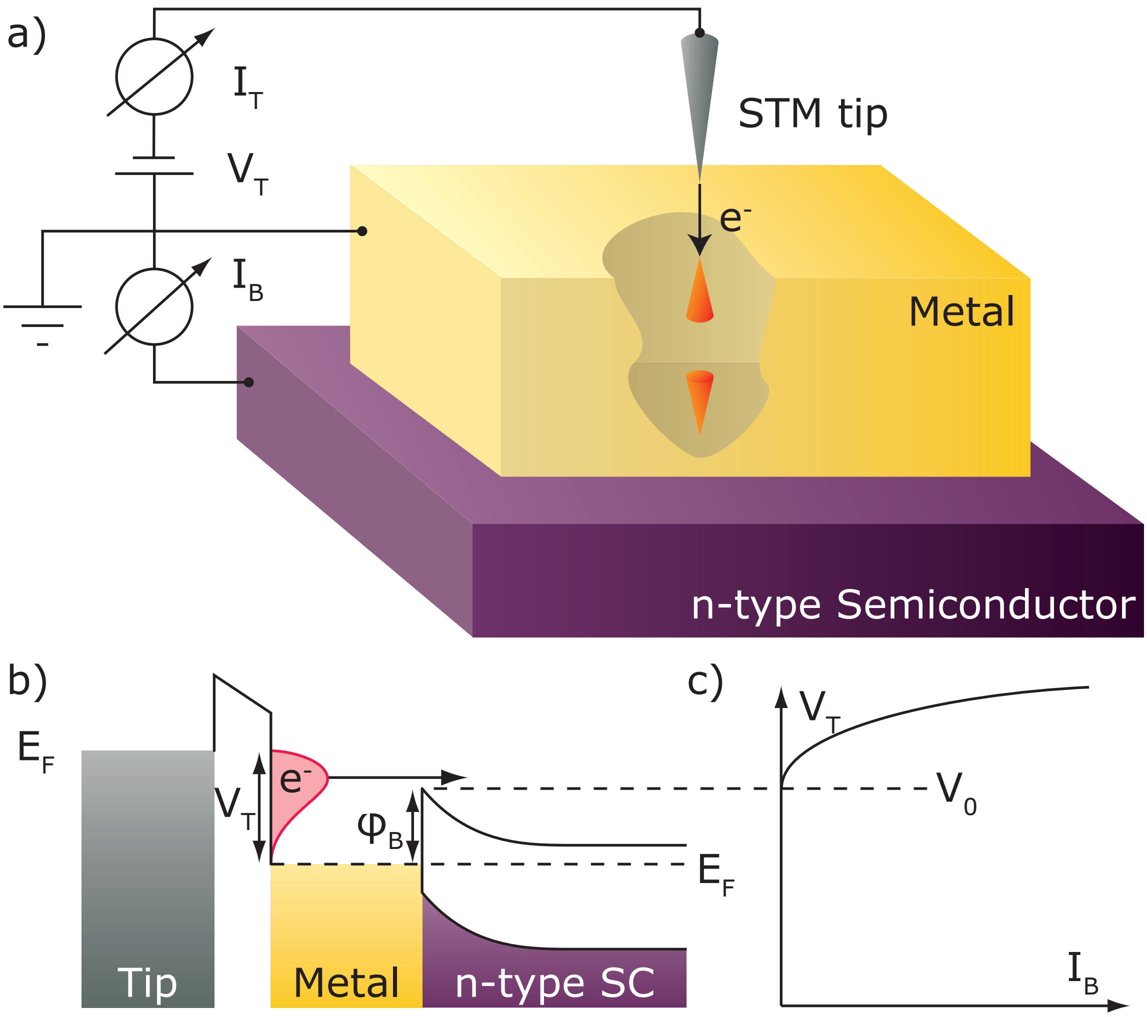

Figure 1: a) Schematic representation of BEEM with the electrical connects. **b)** Energy schematics of the metal-semiconductor device along with the STM tip. The tip is biased negatively and a distribution of hot electrons is injected into the metal. **c)** The measured BEEM current I_B, consists of electrons with proper energy and momentum to surpass the Schottky barrier (φ_B), as a function of the tunneling voltage V_T.

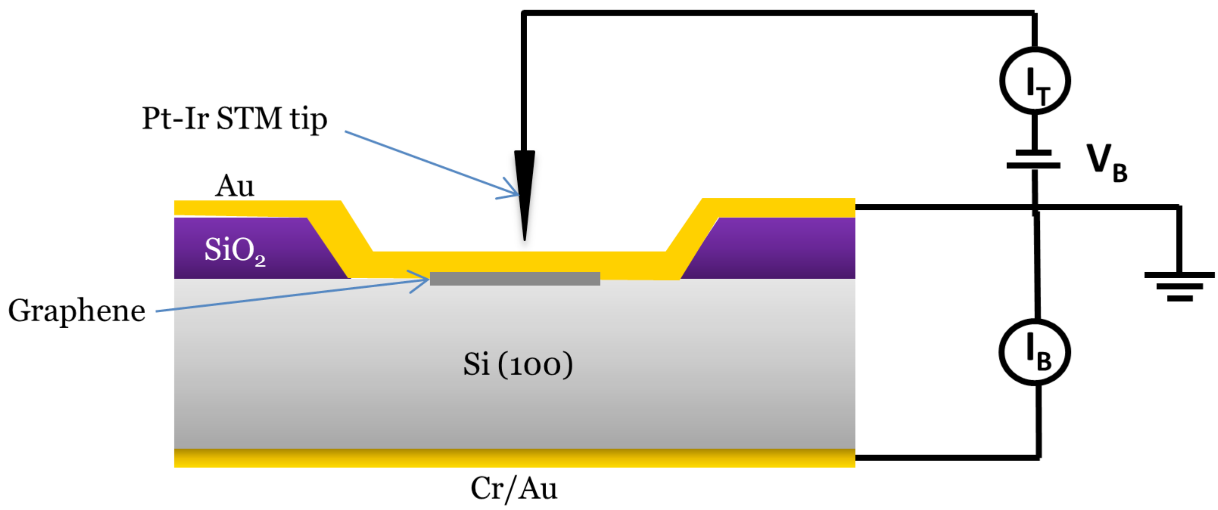

Figure 2: Schematic side view of our device scheme. Hot electrons tunnel from the STM tip into the Au from which they travel to the graphene. The transmissted hot electron current at the graphene/Si interface is collected as the BEEM current I_B.