In-situ electrical measurements of Graphene Nanoribbons fabricated through Scanning Transmission Electron Microscopy

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We recently demonstrated a controllable and reproducible method to obtain suspended monolayer graphene nanoribbons with atomically defined edge shape [1]. Our method exploits the electron-beam of a Scanning Transmission Electron Microscope (accelerated at 300 kV) to create vacancies in the lattice by knock-on damage and pattern graphene in any designed shape. The small beam spot size (0.1 nm) enables close-to-atomic cutting precision, while heating graphene at 600^{o} C during the patterning process avoids formation of beam-induced Carbon deposition and allows self-repair of the graphene lattice. Self-repair mechanism is essential to obtain well-defined (zig-zag or armchair) edge shape and, if the electron beam dose is lowered, to perform non-destructive imaging of the graphene nanoribbons.

Drawing the electron-beam path with a software script, we were able to obtain reproducible graphene nanoribbons with sub 10 nm width. Using an in-house built microscopy holder equipped with electrical feedthroughs, we performed 2 and 4 wire measurements on several graphene nanoribbons, with different number of layers. Results show that our nanoribbons exhibit ohmic behaviour, with conductivity linearly proportional to the width. We also measured the conductivity as a function of temperature in the range 300-900 K, and found that it follows a semiconductor-like dependence, rather than metallic.

The fabricated nanoribbons were stable for several weeks after TEM sculpting. Ex-situ measurements were carried in a liquid Helium cryostat, where a small band gap opening was observed at 4 K temperature.

Our STEM sculpting capabilities also allow to fabricate nanoribbons with embedded nanopores, with diameters as small as 5 nm, as shown in Fig. 2. Such structure could be used for DNA sequencing purposes [2].

References

[1] Q.Xu, M. Wu, G. F. Schneider, L. Houben, S.K. Malladi, C. Dekker, E. Yucelen, R.E. Dunin-Borkowski, and H.W. Zandbergen, ACS Nano 7 (**2**), 2013, pp. 1566-1572.

[2] K.K. Saha, M. Drndić, and B. K. Nikolić, Nano Lett.,12 (**1**), 2012, pp 50–55

Figures

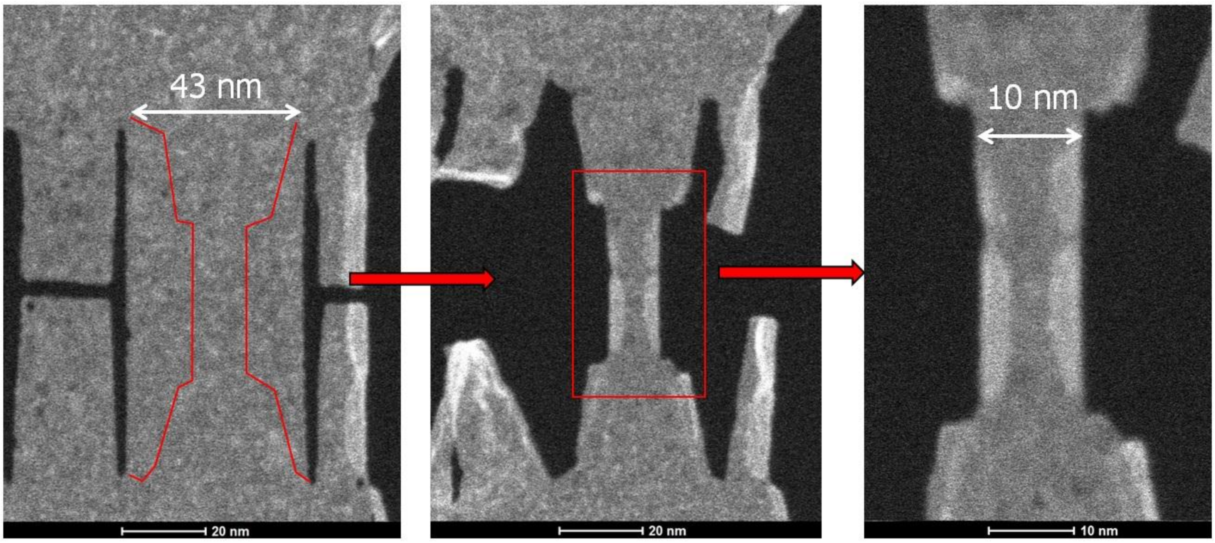

Fig. 1. STEM images of a four layer graphene sample, showing the sculpting procedure realized in-situ with the microscope electron beam. Graphene is fully suspended and it is displayed in grey/white color, the empty background appears in black.

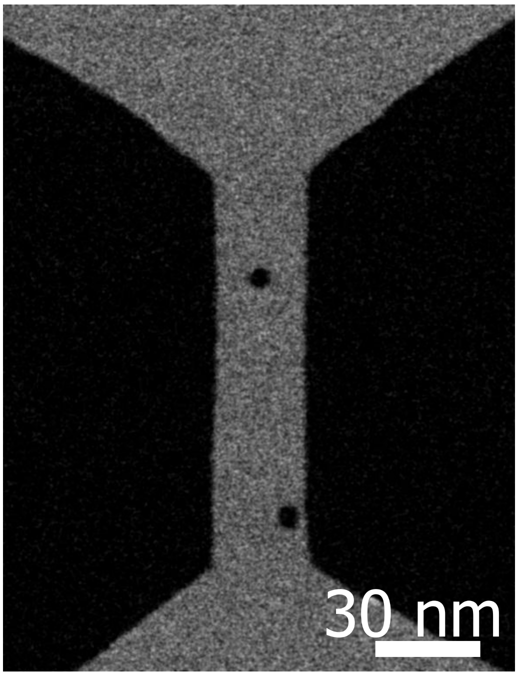

Fig. 2. STEM image of a graphene ribbon, 30 nm wide, in which two nanopores were sculpted, each 5 nm in diameter.