CUTTING OF SUSPENDED GRAPHENE BY NANOPARTICLES: NANOSCALE PAC-MAN LIVE IN TEM

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Recently, the method of patterning graphene with catalytic metal nanoparticles has been investigated [1-6], due to a number of inherent advantages compared to conventional lithography: the particles etch tracks which can be less than 10 nm in diameter, has a roughness smaller than 1 nanometer, and most has the unique feature of being directed along well defined crystal lattice directions. The process avoids resist mask and the possibility of parallel fabrication, by many particles at the same time. Perhaps the most unique feature is the crystallographic orientation, as this is so far the only known method of patterning graphene purely along particular crystallographic directions to leave edges consisting of a pure chirality a prerequisite for a number of electronic applications of graphene. Previous studies of channelling behaviour have been limited by the need to perform the experiment ex-situ, i.e. comparing single "before" and "after" images [3]. In ex-situ experiments velocities must be inferred from the length of channels and heating time after completion of the experiment, assuming that the process is constant. This is not necessarily the case.
Here we report, for the first time, the nanoscale observation of this channelling process by silver particles in an oxygen atmosphere, on suspended mono-and bilayer graphene. The experiment was done in an environmental transmission electron microscope (FEI TITAN ETEM), enabling direct concurrent observation of the process. The use of suspended graphene membranes of large area and known number of layers is an advantage for the tracking of particles and analysis of the behavior. While the channeling follows the crystal direction, the particle velocity is Poisson-distributed rather than constant, which we explain by the discrete removal of carbon atoms from the graphene layer. We are able to determine the ensemble activation energy for the process based on the velocity distributions at 0.557±0.016 eV. Measurement of the particle velocities in-situ in the ETEM is a highly accurate way to determine the activation energy for this process. We discuss the challenges and perspectives for turning this process into a method for patterning graphene with sub-Å disorder, sub-10 nm linewidth, and high throughput.

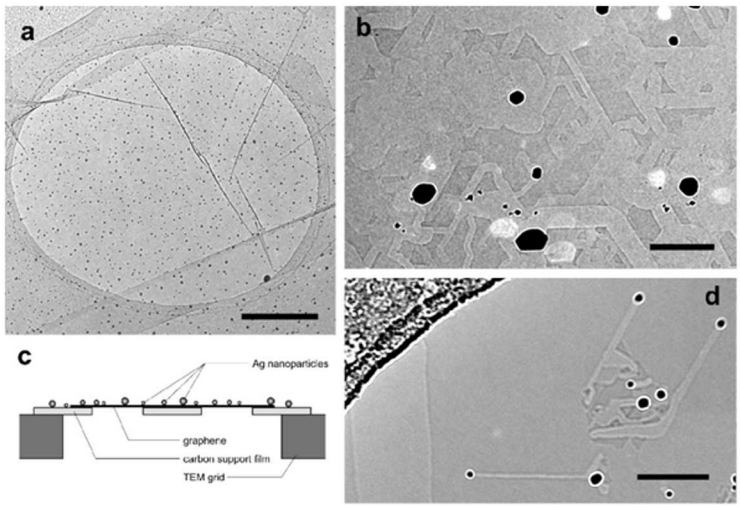

Figure 1: a) TEM micrograph of an aperture with suspended few layer graphene after evaporation of Ag (visible as dark spots). Scale bar 500 nm. b) Few layer suspended graphene film showing many channels. Scale bar 100 nm. c) Diagram of sample construction. d) Multiple nanoparticles channelling through a monolayer graphene sheet. Carbon support film and vacuum are visible at the left of the image. Scale bar 100 nm.

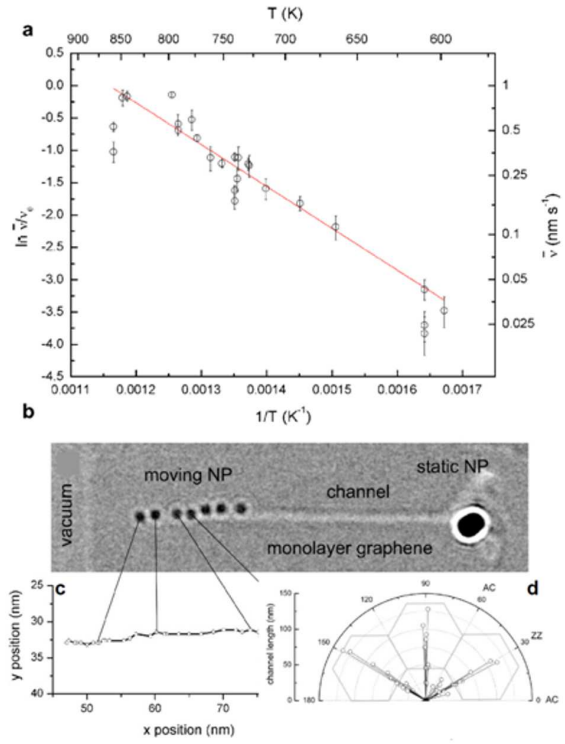

Figure 2: a) Arrhenius plot of ln(etch rate) vs T^{-1} vs ln(etch rate). b) Single nanoparticle etching suspended monolayer graphene. Seven exposures are overlaid at intervals of 124s. c) Distance moved by particle in a every 12.7 seconds. d) Crystallographic orientation of etched channels all following the ZZ direction.

References

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