Carbon fiber tips for scanning probe microscopes and molecular electronics experiments

Gabino Rubio-Bollinger[1], Andres Castellanos-Gomez[1,2], Stefan Bilan[3], Linda A. Zotti[3], Carlos R. Arroyo[1], Nicolás Agraït[1,4], Juan Carlos Cuevas[3]

[1] Departamento de Física de la Materia Condensada (C–III). Universidad Autónoma de Madrid, Campus de Cantoblanco, E-28049 Madrid, Spain.
[2] Kavli Institute of Nanoscience, Delft University of Technology,
Post Office Box 5046, 2600 GA Delft, Netherlands.
[3] Departamento de Física Teórica de la Materia Condensada (C–III). Universidad Autónoma de Madrid, Campus de Cantoblanco, 28049 Madrid, Spain.
[4] Instituto Madrileño de Estudios Avanzados en Nanociencia IMDEA-Nanociencia, E-28049 Madrid, Spain.
gabino.rubio@uam.es

Introduction

The tip is certainly one of the most important components of a scanning probe microscope because it is the one directly interacting with the surface under study. We have developed carbon fiber tips which optimize the performance of combined scanning tunneling and atomic force microscopes (STM/AFM). The remarkable electrical and mechanical properties of carbon fiber make these tips more suitable for combined and/or simultaneous STM and AFM than conventional metallic tips. For instance, carbon fiber tips are shown lightweight, rigid and much more robust against accidental tip crashes than metallic tips. Moreover, we have fond that tunnel currents of up to 100 pA can be obtained while in the attractive force regime, that is, in the non-contact regime. This indicates that the carbon fiber tip apex remains clean and oxide-free even under room conditions.

Additionally, we have demonstrated the suitability of these carbon-based tips as contact electrodes to form single molecule junctions. Conductance vs. stretching traces, measured on gold/octanethiol/carbon tip junctions, show well defined plateaus at 5.9×10^{-6} G_0, which we attribute to be the conductance value for a single octanethiol molecule. This ensures that carbon tips provide a proper mechanical linking to molecules with a methyl ending group allowing to routinely form single-molecule bridges.

Experimental

Although in STM the use of mechanically fabricated tips (by simply cutting a metallic wire) is rather common, the AFM resolution strongly depends on the tip sharpness because of the presence of long range interactions between the tip and the sample. In this work we have thus developed an electrochemical procedure to etch carbon fiber tips [1].

A 5-10 mm long fiber is extracted from the fiber rope. One end of the fiber is immersed a few microns into a drop of 4M KOH solution suspended in a 4 mm inner diameter gold ring . A voltage bias difference of 5-6 Volts is applied between the unimmersed fiber end and the gold ring which is grounded. The etching takes place over a period of tens of seconds until the fiber breaks, opening the electrical circuit and stopping the etching. Afterwards the fiber is rinsed with distilled water. Reproducible tips with sub-100 nm apex radius can be obtained following this procedure as shown in figure 1.

Results and discussion

Several traces of conductance as a function of tip retraction distance $G(z)$ are shown in Fig. 2(a). The conductance traces show plateaus at specific values which are the signature of the formation of molecular junctions [2]. The conductance plateaus do not always occur at the same conductance values because of variations in the microscopic details of the molecule arrangement between the electrodes. To overcome junction-to-junction fluctuations we have performed a statistical analysis in which all junction realizations, without selecting conductance traces, are represented as a histogram (Fig. 2(b)).

We follow the procedure described in ref. [3] to remove the background tunneling contribution from the histogram in order to better resolve its structure. We find that there are two Gaussian peaks whose centers are located at $G_1 = (5.9 \pm 4.1) \times 10^{-6}\, G_0$ and $G_2 = (1.3 \pm 0.5) \times 10^{-5}\, G_0$. The presence of multiple peaks in the histogram in previous STM break junction experiments on molecular junctions has been attributed to a varying number of molecules contributing to the transport [2].

References

A. Castellanos-Gomez, N. Agrait, and G. Rubio-Bollinger, Nanotechnology **21**, (2010), 145702.
B. Xu, and N. J. Tao, Science **301**, (2003) 1221.
J. L. Xia, I. Diez-Perez, and N. J. Tao, Nano Lett. **8**, (2008) 1960.

Figures

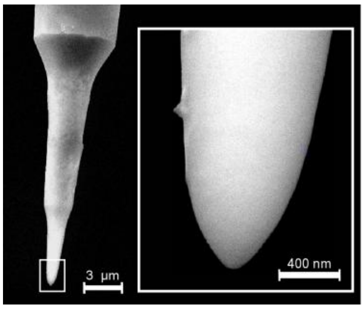

Fig. 1. Scanning electron micrograph of a carbon fibre tip electrochemically etched following the procedure described above. The curvature radius of the tip apex is estimated to be 55 nm..

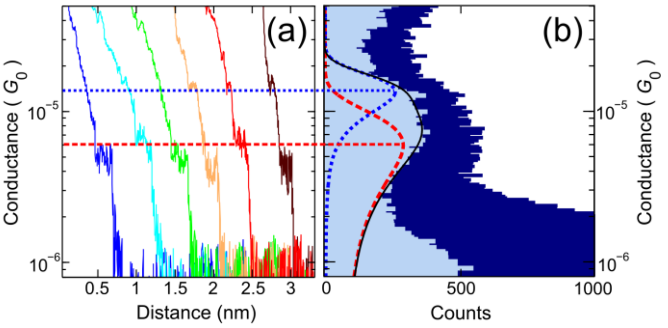

Fig. 2. (a) Conductance traces (shifted horizontally by 0.5 nm for clarity) showing characteristic conductance plateaus. Below a conductance of 1.5×10^{-6} G_0 the measurements are limited by the noise level of the current amplifier. (b) Conductance histogram built from 740 traces (dark blue) and corrected histogram (light blue) after subtracting the tunnelling contribution.