Scanning probe measurements and electromigration of metallic nanostructures under ultra-high vacuum conditions

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With the ongoing process of miniaturization of electronic circuits, there is a growing interest to analyze the quantum effects which play an important role in metal contacts of nanometer size. Due to the small size it is desirable to characterize such nanostructures by scanning probe techniques. We use e-beam lithography as well as shadow evaporation through a stencil mask to fabricate nanobridges made of gold and other metals. The bridges are then thinned by a controlled cyclic electromigration process in ultra-high vacuum (UHV). While investigating e-beam lithography fabricated platinum structures with the scanning tunneling microscope (STM) in UHV we have discovered a tunneling voltage-dependent deposition of additional material, possibly carbon, of up to 10 nm thickness. We imaged the deposited material both with STM and with scanning electron microscopy (SEM).

To avoid such a deposition on the metallic bridges we have used scanning force microscopy in amplitude modulation mode to investigate the structures in UHV. While platinum wires need a larger voltage to start the electromigration process compared to gold, the gold wires show no fundamental difference of electromigration in UHV compared to electromigration under ambient conditions. We have obtained images with up to 3nm resolution. A slit is formed during the first thinning cycles and hillocks build up on one of the electrodes. By observing the additional modifications during further electromigration cycles we were able to determine the area were a nanocontact remains. Additionally, below 10 G_0 ($G_0=2e^2/h$), we have observed discrete jumps of the conductance as well as telegraph noise. In conductance histograms generated from five samples, oscillations with a period slightly smaller than 1 G_0 are observed [1]. The positions of the peaks correspond well to expected values of work-hardened gold junctions taken from literature [2] and are related to the atomic structure of the resulting gold nanocontacts. We believe that controlled electromigration enhances the probability to obtain equilibrium atomic positions compared to the mechanically controlled break junctions, because the junctions are heated to approximately 350 K.

References:

[1] R. Hoffmann et al., Appl. Phys. Lett. 93, (2008) 043118.
[2] I. K. Yanson et al., Phys. Rev. Lett. 95, (2005) 256806.

Figures:

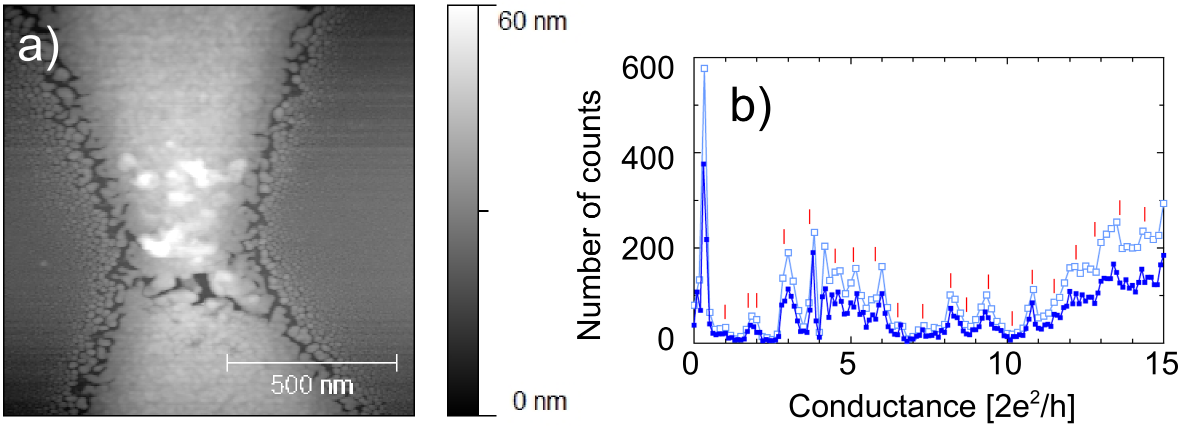

Fig. 1: a) Scanning force microscopy image of a Au nanostructure on an oxidized Si substrate after feed-back controlled electromigration. A slit has developed through the thinning process and hillocks have build up on one electrode. b) Conductance histogram obtained from five samples. Red lines mark the positions of the peaks taken from literature [2].