The Multimeter at the Nanoscale

Charge Transport at the Nanoscale Measured by a Multi-Tip Scanning Probe Microscope

A multi-tip scanning tunneling microscope (STM) specifically designed for charge transport measurements at the nanoscale is described. This versatile tool gives insight into fundamental transport properties at the nanoscale. We exploit the capabilities of the instrument by measuring resistance profiles along freestanding GaAs nanowires, by the acquisition of nanoscale potential maps, and by the identification of an anisotropy in the surface conductivity at a silicon surface.

Introduction

Since microelectronics evolves into nanoelectronics, it is essential to perform electronic transport measurements at the nanoscale. The standard approach to this is to use lithographic methods for contacting nanostructures. However, in research and development stages other methods to contact nanoelectronic devices may be more suitable. An alternative approach for the contacting of nanostructures is to use the tips of a multi-tip scanning probe microscope, in analogy to the test leads of a multimeter used at the macroscale. The advantages of this approach are: (a) Flexible positioning of contact tips and different contact configurations are easy to realize, while lithographic contacts are permanent. (b) In situ contacting of “as grown” nanostructures still under vacuum allows to keep delicate nanostructures free from contaminations which can be induced by lithography steps performed for contacting. (c) Probing with sharp tips can be non-invasive (high ohmic), while lithographic contacts are invasive (low ohmic).

In order to use a scanning tunneling microscope (STM) [1] for electrical measurements at nanostructures, more than one tip is required. Thus, we developed an ultra-stable multi-tip instrument which gives access to the above outlined advantages in nanoprobing [2]. This is in accord with the recent paradigm shift in scanning probe microscopy which transforms from “just imaging” to extended measurements at the nanoscale.
Multi-Tip Microscope

The instrument (fig. 1) comprises four scanning units allowing for a completely independent motion of all four tips. A scanning electron microscope (SEM) image of the four tips brought close to the sample under study is shown in the eye-catcher image of this article.

Imaging with the secondary electrons leads to a shadow effect (dark shadow image of the tip apex) giving access to the tip sample distance. Recently, a startup company [4] has been founded which offers this instrument. In the following, we demonstrate the capabilities of the instrument for nanoscale charge transport measurements by presenting some examples.

Resistance Profiling along Nanowires

As a first example, we present nanoscale resistance mapping along freestanding GaAs nanowires with a diameter of $\sim 100$ nm [5], which are still “as grown” upright and attached to the substrate. The schematics in figure 4a, and in an SEM image in figure 4b shows three tips brought into contact with a nanowire, realizing a four-point resistance measurement.

In the STM based approach of nano-contacting, four-point measurements can be performed not only in one single configuration, as it is the case for the lithographic approach, but many configurations can be measured by moving the tips along the nanowire (a movie of this can be accessed in the web [4]). In this way we can measure a resistance profile along the nanowire with 50 data points.

Potential Maps

Another method giving valuable insight into the charge transport properties of nanostructures is the scanning tunneling potentiometry (STP). Nanoscale potential maps are acquired during the flow of electrical current. Implementing STP in a multi-tip setup has several advantages [6]. The potential resolution is a couple of $\mu$V. We have applied the STP technique on Si surfaces (fig. 3) and could determine the surface conductivity on the terraces as well as the step resistivity [6].

Anisotropic Conductance

The increasing importance of surface conductance compared to conductance through the bulk in modern nanoelectronic devices calls for a reliable determination of the surface conductivity. A model system for corresponding investigations is the Si(111)-7x7 surface. The challenge is to disentangle the contribution due to the surface conductivity from the bulk conductivity. We have
developed a method which uses distance dependent four-probe measurements in the linear configuration in order to determine the surface conductivity [7]. Moreover, also the anisotropy of the surface conductivity can be measured by the four-probe method, when the tips are arranged in a square arrangement and are rotated (fig. 4(a)). In the current case the anisotropy is induced by a parallel arrangement of atomic steps on the surface. The continuous behavior of the measured four-point resistance as function of the rotation angle is shown in figure 4b. From these data the step resistivity as well as the resistivity of the terraces can be determined [7].

**Conclusion and Outlook**

A multi-tip scanning tunneling microscope can be like a multimeter at the nanoscale in order to contact nanostructures by the tips and performing subsequently electrical measurements. This multi-tip based approach of nanoprobing has the advantage of a very flexible probe (re-) positioning, allowing for many different probing geometries on a single nanostructure. Moreover, contaminations of the nanostructures inherent to the lithographic approach are avoided and the probing contacts can be non-invasive. Altogether, the SPM based nanoprobing approach allows to perform a large variety of nondestructive electrical measurements at the nanoscale. Currently, the instrument is developed further towards a multi-tip AFM/STM to allow for an improved performance on partly insulating samples.

**References**


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