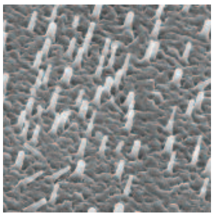


Application Note

In-situ Scanning Electron Microscope (SEM) supplements Scanning Probe Microscopy (SPM) for accurate probe positioning and electrical measurements

Knowing the nanowires electrical properties is the key to improve future electronic and optoelectronic devices. New SPM configuration with in-situ e-CLIPSE Plus SEM gives the understanding of such complex devices allowing very precise physical measurements and better understanding of the fabrication process of nanowires.

SEM / SPM / STM / In-situ / UHV / Probe positioning / Nanowires / Resistivity measurements

III-V nanowires (NWs) could be the next basis of future nanoscale electronic and optoelectronic devices. Their specific one-dimensional geometry enables new device concepts such as NWs solar cells with higher conversion yields because of their improved light trapping.
For the fabrication of novel high performance NW devices a precise control of doping density and doping profile is a requirement. However, an accurate doping control is often difficult to obtain. Moreover, the determination of the local resistivity and transport data in NWs is complicated to reach due to the nanoscaled one-dimensional geometry.

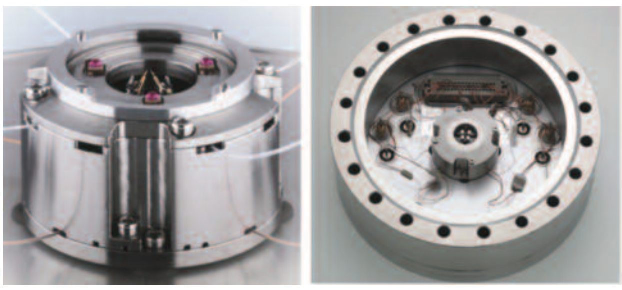


Figure 1. The ultra-compact TetraProbe STM

Instead of detaching the NWs from the surface to be analyzed, an alternatively method has risen. Multi-tip Scanning Tunneling Microscope (STM) allows to investigate the resistance along a single NW. and the measurement of its electrical properties directly while it is still attached to the substrate.

mProbes Gmbh, a spin-off company of the Forschungszentrum Jülich, Germany, founded by Professor Bert Voigtländer, has developed the TetraProbe STM (figure 1). This multi-tip STM is based on the KoalaDrive®, a piezoelectric Compact Nano-positioner developed for Scanning Probe Microscopy. It aimed to perform in-situ contacting flexible and non-invasive NW measurements. To preserve the device intact, the TetraProbe STM requires contamination free environment under Ultra-High Vacuum (UHV).

In this note a TetraProbe STM from mProbes Gmbh in combination with the UHV e-CLIPSE Plus SEM from Orsay Physics is used to conduct four point electrical measurements on the NWs. This instrument performs the quantification of the NW continuous resistance profile and so the dopant profile along the NW length (figure 2a and 2b).

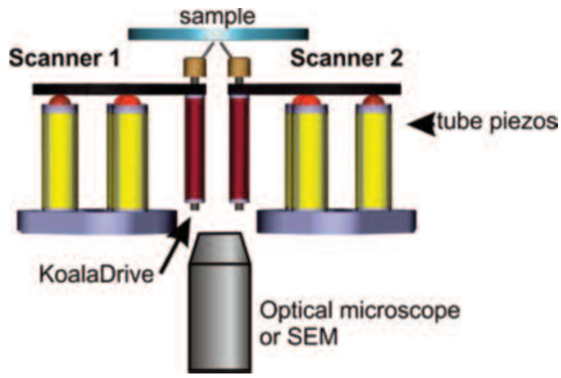


Figure 2a. *Schematic internal structure of the TetraProbe STM instrument*

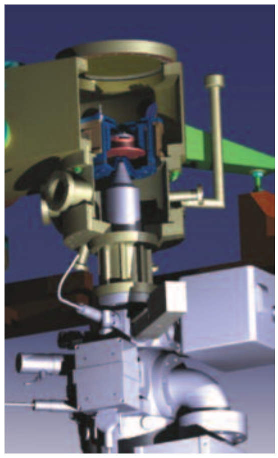


Figure 2b. *3D CAD file of the TetraProbe STM equipped with the UHV e-CLIPSE Plus SEM*

In-situ SEM and STM/SPM instrument

In this configuration, e-CLIPSE Plus objective nozzle has the advantage to be very compact contributing to the mechanical assembly with the TetraProbe STM. Thanks to e-CLIPSE Plus high resolution imaging, it gives a precise nanowire diameter measurement, an accurate tip positioning and a simplified sample navigation. Moreover, due to the e-CLIPSE Plus large Field of View possibility (up to 5mm x 5mm at 10 keV and 12mm Working distance) the four tips approach to the sample area of interest is easier.
Images are acquired by the Secondary Electron Detector (SED) located on the side. This side detection is necessary to observe the tip's shadow (see figure 3). Indeed, imaging the dark shadow of the tip gives access to the tip sample distance, necessary to operate a smooth tip landing on sample surface.

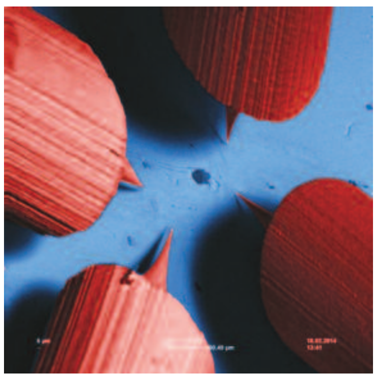


Figure 3. *e-CLIPSE Plus SEM image of the four tips (250 µm diameter) close to the surface (post-processed colors)*

Experimental method

The sample is mounted with a 45° tilt, so that the NWs can be observed by e-CLIPSE Plus SEM and three electrochemically etched tungsten tips can be brought into contact with the same NW as can be seen in figure 4 (the substrate is used as additional fourth contact to the NW allowing for four-point electrical measurements). The first tip contacts the NW at the top in order to inject and measure the electrical current (I) through the NW into the sample. Tips 2 and 3 contact the NW along its length and measure the potential V2 and V3 and thus the voltage drop V23 = V2 – V3 that occurred in between the contact points.

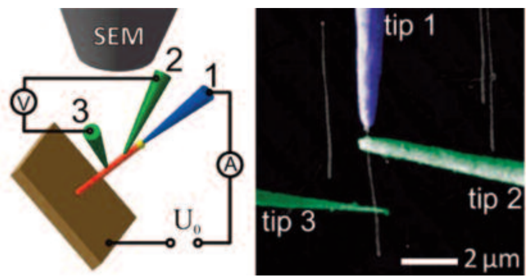


Figure 4. *Schematic view (left) and SEM image with post-processed colors (right) of a four-point measurement using three tungsten tips in contact on a free-standing GaAs NW*

From the slope of the resulting current (I) versus V23 curves, the resistance R23 of the NW segment between the two voltage probes can be calculated by a linear fit. To obtain a resistance profile along the NW (figure 5), the position of tip 3 is moved while tip 2 is always kept at the same position near the NW top. This is why having e-CLIPSE Plus SEM image of the apex location on the sample surface is really important as it gives accurate positions to make precise measurements along the GaAs nanowire. Most of the NW length shows a linear constant resistivity of 12 kW/µm with an increased one at the NW base where the temperature during NW growth is higher. So a constant dopant concentration is assumed on these two regions seen in figure 5.

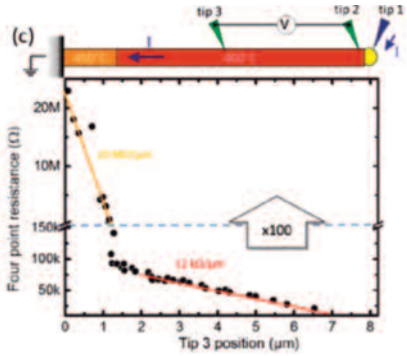


***Figure 5.** Resistance profile along a nanowire obtained with the TetraProbe STM coupled with e-CLIPSE Plus SEM*

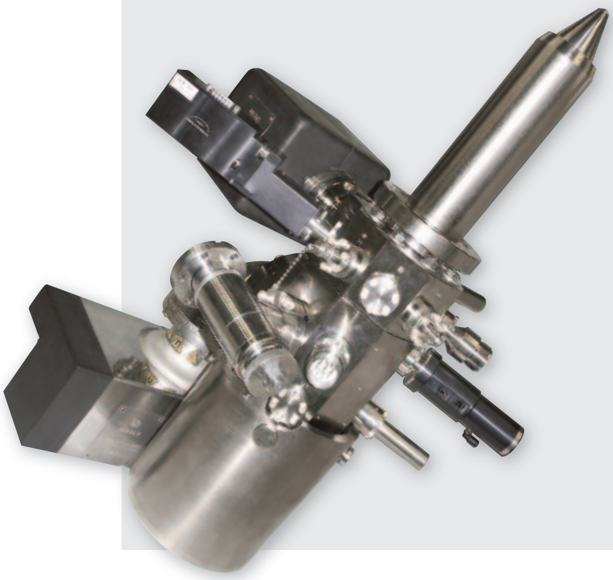
References :

- Korte et al., Resistance and dopant profiling along freestanding GaAs nanowires, J. Appl. Phys. 103, 143104 (2013).
- Peter Grünberg Institut (PGI-3) and JARA-Fundamentals of Future Information Technology, Forschungszentrum Jülich, 52425 Jülich, Germany
- Photovoltaics Group, Institute for Physics, Technische Universität Ilmenau, 98684 Ilmenau, Germany
- CeNIDE (Center for NanoIntegration Duisburg-Essen) and Center for Semiconductor Technology and Optoelectronics, University of Duisburg-Essen, 47057 Duisburg, Germany

.

e-CLIPSE *Plus*

High resolution electron imaging
for all your analysis



- ➔ **Schottky FEG (Field Emission Gun)**
- ➔ **Energy range: 1 -30 keV**
- ➔ **Probe current: 10 pA – 100 nA**
- ➔ **Pneumatic valve for electron isolation**
- ➔ **Purely electrostatic column**
- ➔ **12 movable apertures**
- ➔ **Electrostatic beam blanker + Faraday Cup**
- ➔ **63 CF fitting flange**

UHV
Compatible