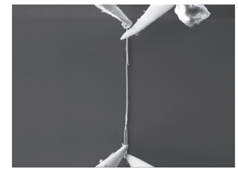
Electrical in-situ Characterization of Au/Ni/Au-Nanowires with Nanomanipulators

René Sewcz, Saskia F. Fischer,
Electronic Materials and Nanoelectronics, Ruhr-University Bochum, Germany
Kornelius Nielsch, University of Hamburg, Germany
Axel Rudzinski, Frank Nouvertné, Michael Kahl, Raith GmbH, Germany



Ruhr-University Bochum

Introduction

Electrical characterization of nanowires with usual probing stations requires metal electrodes with a size of several microns. Different methods have been applied to contact electrodes and nanowires, each of them having their own advantages and disadvantages [1]. Deposition of nanowires on a substrate with prepatterned electrodes can be obtained either by a) random distribution of nanowires using drop casting or by b) controlled placement with nanomanipulators. The latter requires a dedicated procedure for picking up and dropping down the wires. Sample preparation for the former is faster, but searching by SEM inspection for nanowires on electrodes that are suitable for measurement is elaborate. An additional method is c) contacting selected nanowires by lift-off technique, which is a flexible but even more time consuming process, and which is not hundred percent fail-safe, either. Finally, d) ion and electron beam induced deposition can be used to produce the contacts. Although these two methods allow pre-process selection of nanowires and the processes are fast compared to lift-off, there are also disadvantages like the currently limited number of available metal precursor gases and the comparably high resistivity of the deposit.

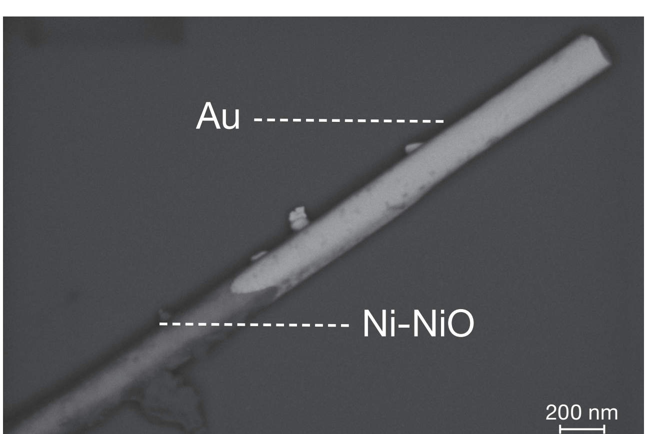


Figure 1: ESB detector image of a nanowire, Ruhr-University Bochum, University of Hamburg

In the unique application described here, only the combination of eLINE key features working together - four nanomanipulators used as nanoprobers, accurate motion with the high precision laserinterferometer stage, metrology software functionality and the SEM monitoring mode - make it possible to directly contact and measure the electrical conductivity of Au/Ni/Au-nanowires under visual inspection.

By applying an in-situ electrical measurement, immediate feedback is obtained regarding suitable ohmic contacts, which can eventually be further optimized by additional fine movement of the nanomanipulators. Moreover, SEM live imaging gives additional information on the selected nanowire that might help to understand unexpected results of the electrical measurement. For example, melting of nanowires by supplying big currents can instantly be monitored. This application note describes the process steps that are carried out for this “view & measure” approach for electrical characterization of nanowires in-situ - a method, which is much more efficient and less time consumimg as compared to any other process described in a) to d).

Nanowire Inspection

Nickel nanowires are of high interest regarding their properties with respect to anisotropic magnetoresistivity effect, a good electrical contact being an important prerequisite for reliable experiments. The nickel nanowires have a length of about 20 µm and a diameter of about 200 nm. Nickel has a natural surface oxide of more than 10 nm. In order to realize ohmic contacts on the wire, gold-contacts are deposited electrochemically in-situ as part of the forming-process at both ends of the nanowire. The length of the gold-ends is in the range of 1 to 2 µm.

Figure 1 shows the gold end of a nanowire in a SEM image using an inlens energy selective backscattered detector (ESB), which is a unique option for the eLINE system. As the ESB is providing excellent material contrast the gold-ending is clearly visible.

Contacting Nanowires

The tungsten tips that are used for measurement have a tip-radius of less than 800 nm. The tips are clamped into steel-sleeves which were connected via shielded coax cables to triax feed-throughs. This dedicated wiring set-up enables low noise electrical measurements with a current resolution down to only a few hundred fA. A ceramic holder isolates the steel-sleeve from the Nano-manipulator. Figure 2 shows the tungsten tips at their start position 1 mm above the sample surface.

The approach of the tips to the nanowire is shown in figures 3 and 4. Manipulator movement is performed by applying and navigating in an intuitive cartesian coordinate system. There are two movement modes for all directions: Coarse positioning mode has a travel range of several centimetres; in fine positioning mode, the manipulators are moved with an accuracy of 5 nm per step within a range of 4 µm.

Using simple features of the comprehensive eLINE metrology functionality, the tips can be pre-arranged above the SiO_2 surface according to the observed nanowire configuration (figure 3) without “interference”. In the critical step, the high nanometer-range accuracy of the laserinterferometer controlled stage (LIS) is used for final approach. The LIS is moved laterally under visual control (imaging mode switched on), so that the nanowire is placed precisely below the tips. Finally the stage is moved up in order to press the nanowire into contact with the tips (figure 4). No impact has been observed on nanowire conductivity properties regarding potential contamination by the electron beam.

The beam current meter readout gives instant feedback when an ohmic contact has been obtained. Insufficient contacts can immediately be optimized by independent small movement of single nanomanipulators.

Although there are no arrays of identical objects in this experiment, it should be worth to mention here that this method is basically also suitable for semi-automated step-and-repeat measurements in arrays of identical objects due to the high positioning accuracy of the laser-interferometer-stage.

Measurements

Two-point and four-point measurements were realized with a Keithley 2182A Nanovoltmeter and a Keithley 6221 DC-Current-Source.

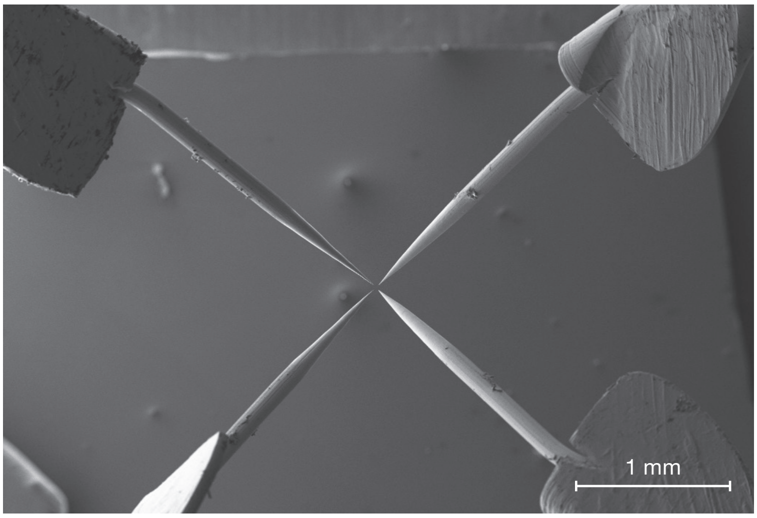


Figure 2: Overview

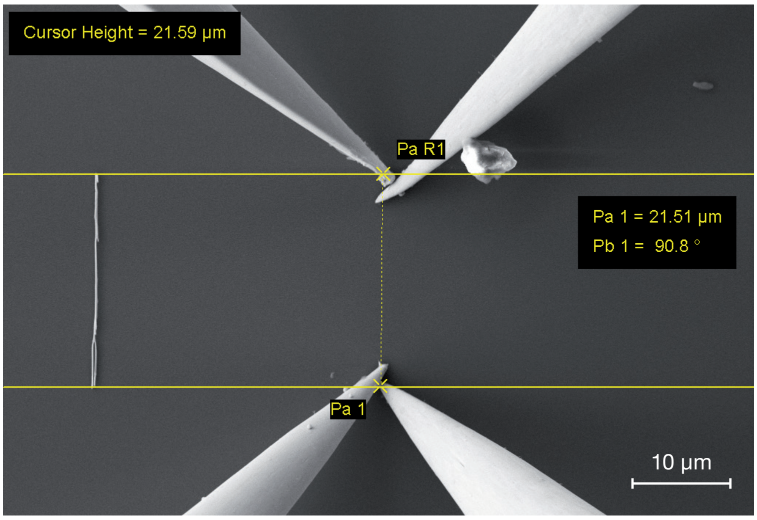


Figure 3: Positioning the tips

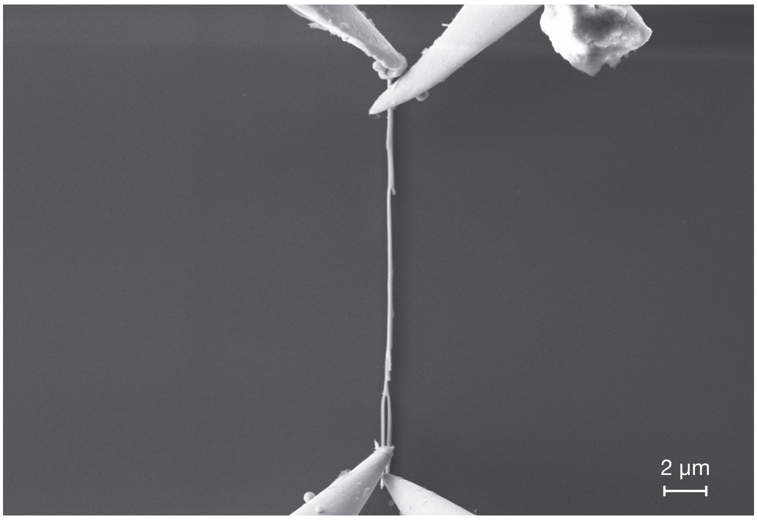


Figure 4: In contact with the nanowire

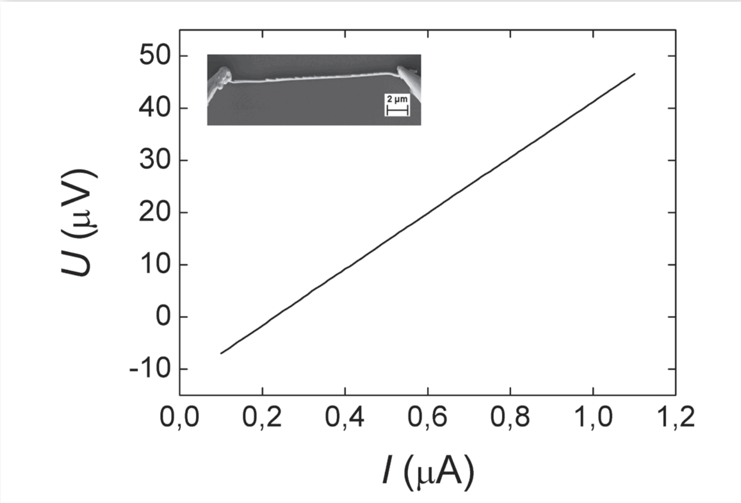


Figure 5: IV-characteristic by two-point-measurement

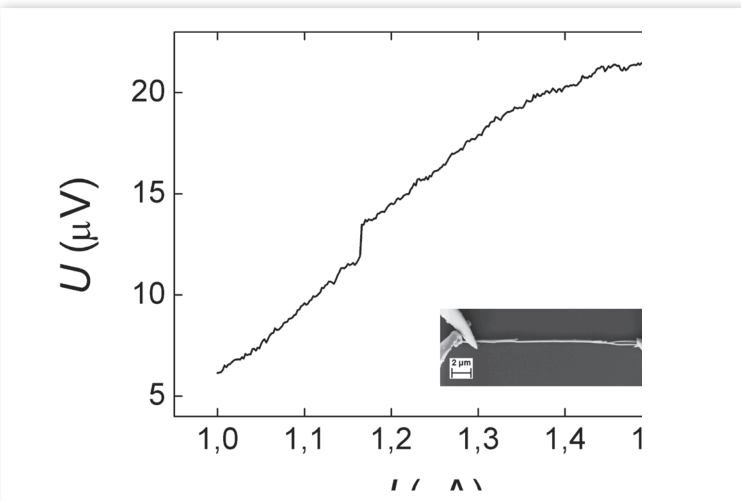


Figure 6: IV-characteristic by four-point measurement

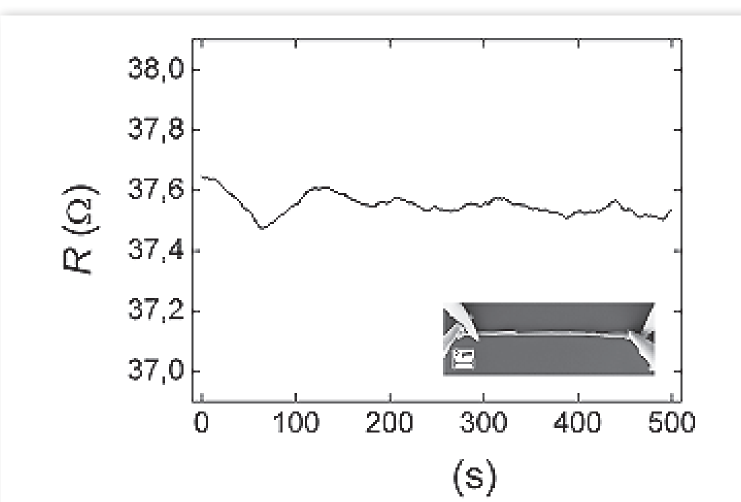


Figure 7: Resistance over time in Delta-Mode measurement

Figure 5 shows the IV-characteristic of a nanowire with a length of 18 µm and an average diameter of 180 nm achieved by a two-point measurement (only two tips contact the nanowire). The resistance, which is the slope of the curve, is R = 53.5 Ω. Compared to the resistance of bulk nickel of the same physical dimensions, the measured value is 9 Ω higher than predicted by theory. This offset is comparable to the observed resistance of a gold pad and can therefore be explained by additional feed cable- and contact-resistances in the measurement setup.

Figure 6 shows an IV-characteristic achieved by a four-point measurement of a nanowire with a length of 18.5 µm and an average diameter of 210 nm. A current is applied to the nanowire by the outer two tips and the potential is measured by the inner two tips. In this measurement setup the feed cable- and contact-resistances do not contribute to the measured value, which is R = 34.1 ± 0.4 Ω in figure 6. Only the contact resistance of the Au to Ni transition needs to be considered for the used four-point measurement setup, since all four nanomanipulator probes are in contact with gold. The comparison to the theoretical value for bulk nickel yields a contact-resistance of $R_{Au\text{-}Ni}$ = 1 Ω for each transition. Concerning the discontinuity of the IV-characteristic, we can only speculate about its origin; it might be explained by a small mechanical movement of the tip relative to the nanowire during the measurement or perhaps by a small filament melting away.

Figure 7 shows a measurement verifying the resistance value achieved by the slope of the IV-characteristic. Current pulses of 1 µA are applied to the nanowire, and the resulting voltage is averaged over 50 measurement points by a moving filter. In this so called Delta-Mode [2], designed for low noise DC-measurements, a constant resistance of R = 37.6 ± 0.1 Ω has been measured during the complete time of measurement which has been 500 sec.

Final Measurement Control by Imaging

Applying a large current can destroy the contacted nanowire. Figure 8 shows a nanowire that has been melt purposely by an induced current of 10 µA. In this case the SE image revealed a double wire which has been approached with the tungsten tips, but only the left one had been in contact and therefore destroyed.

This kind of SEM monitoring can be used to observe a burn-out of the wire or bad contact with the tips and thus help to control or explain the result of a measurement. A melted nanowire can be the reason for a huge resistivity as is obvious and well visible in figure 8. With a conventional probing station possible reasons for bad measurement results can only be guessed.

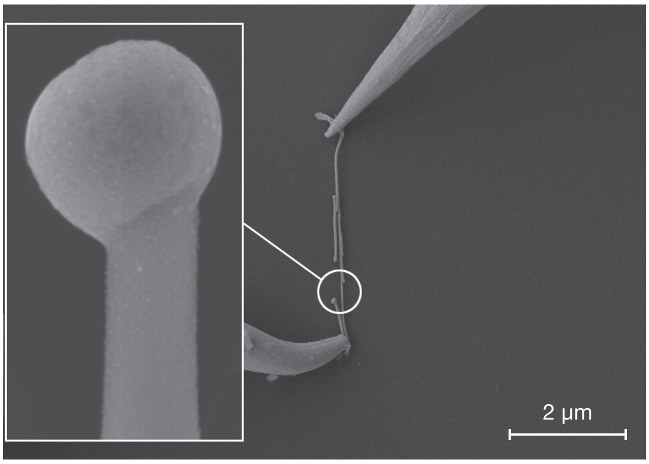


Figure 8: Melted nanowire

Summary

Electrical characterization of nanowires can be a demanding application. For measurements with a conventional probing station a sequence of time consuming process steps might be required to prepare a substrate with metal contact pads that are connected to the nanowires. As an alternative to nanowire contacting by EBID [3] only the eLINE nanoengineering workbench allows direct contacting of the nanowires with tungsten tips in-situ, both in a two- and four-point measurement setup. For this experiment, the ultra high positioning accuracy of eLINE´s laserinterferometerstage in the order of a few nm only in conjunction with four high precision nanomanipulators under visual electron microscopic control has been exploited. Positioning accuracies of conventional SEM stages (typically >1µm) would be far too low in order to achieve the required precision during critical fine approach. Measurement results of Ni-nanowires show low-ohmic resistances in the range of theoretically calculated values. This indicates a low-ohmic contact resistance from W-tips to Au-nanowire-ends. Advantages of direct probing with nanomanipulators are a saving of measurement time, no additional resistivity from wiring between nanowire and contact pad, and the possibility for an in-situ optimization and control of the measurement setup under visual control using the SEM monitoring mode of the eLINE system.

References

[1] R. M. Langford, T. .-X. Wang, M. Thornton, A. Heidelberg, J. G. Sheridan, W. Blau, and R. Leahy, “Comparison of different methods to contact to nanowires,”, J. Vac. Sci. Technol. B, vol. 24, iss. 5, pp. 2306–2311, 2006.

[2] Keithley Instruments, Inc., „Nanotechnology Measurement Handbook – A Guide to Electrical Measurements for Nanoscience Applications”, pp. 3-28, 2007.

[3] S. Bauerdick, A. Linden, C. Stampfer, T. Helbling, and C. Hierold, „Direct wiring of carbon nanotubes for integration in nanoelectromechanical systems,“ J. Vac. Sci. Technol. B, vol. 24, iss. 6, pp. 3144–3147, 2006.

Raith GmbH, Konrad-Adenauer-Allee 8, PHOENIX West, 44263 Dortmund, Germany
phone +49 231 / 95004 - 0, fax +49 231 / 95004 - 460, e-mail: sales@raith.com, website: www.raith.com

Raith America Inc., 1377 Long Island Motor Parkway, Suite 101, Islandia, New York 11749, USA
phone +1 631 738 9500, fax +1 631 738 2055, e-mail: sales@raithamerica.com

Raith Asia Ltd., Two Chinachem Exchange Square, No. 338 King‘s Road, Floor 11, Unit 03, North Point, Hong Kong
phone +852 2887 6828, fax +852 2887 6122, e-mail: sales@raithasia.com

Raith China Ltd., Room 1409, Tower B, Techart Plaza, No.30 Xue Yuan Road, Haidian District, 100083 Beijing, P.R.China
phone: +86 10 828679 20/21/22, fax: +86 10 828679 19, e-mail: sales@raithchina.com

Raith India Pvt. Ltd., Sri Krishna Complex, No 36, 2nd Floor, Opposite Mother Theresa School, M. E. S. Ring Road, Bangalore 560054, India
phone +91 80 2838 4949, Fax +91 80 2838 4949, e-mail: sales@raithindia.com