# Advanced substrates for measurements of nanomaterials

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## INTRODUCTION

The dimensions of nanoparticles render them comparable to the surface details of many available substrates. Repeatable measurement of nanoparticles requires a stable, reliable substrate that does not interfere with the measurement of the specimen in any quantity [1]. For topography, that would be realized by surface roughness appropriately smaller than nanoparticle dimensions, etc. The realization of substrates has to simultaneously allow for measurement with microscopic tools and therefore enlarge the contact area of nanoparticles.

We present a series of substrates with surface features prepared specifically for the measurement of nanowires (NWs). Features characterize an elevation of about 500 nm above the substrate, an electrical resistivity of $11 \cdot 10^{-8}$ μΩ, and a thermal conductivity of $1{,}6 \cdot 10^{3}$ W/K. Details allow for direct placement of NWs, electrical connection, and measurement of a given quantity. They are prepared in a more condensed, less accessible form, which has to be accessed with nanomanipulators (e.g., Kleindiek MM3A-EM) or more loosely with electrical connections leading out of the sample, allowing for measurement of mechano-electro-thermal properties.

## NANOPARTICLES INTEGRATION

- Transfer to desired location
- Bonding with material deposited with focused electron beam
- Novel devices development


Figure 2. The process of transferring and mounting nanowires onto a substrate. Visible transport of the nanowire with manipulator and focused electron beam-induced deposition (FEBID) deposited mounting pads

## TWO-POINT RESISTANCE MEASUREMENT

- Nanowire deposited between two contacted metal pads
- Contacting with nanomanipulators or measurement probes
- Still imperfect wire-substrate interface

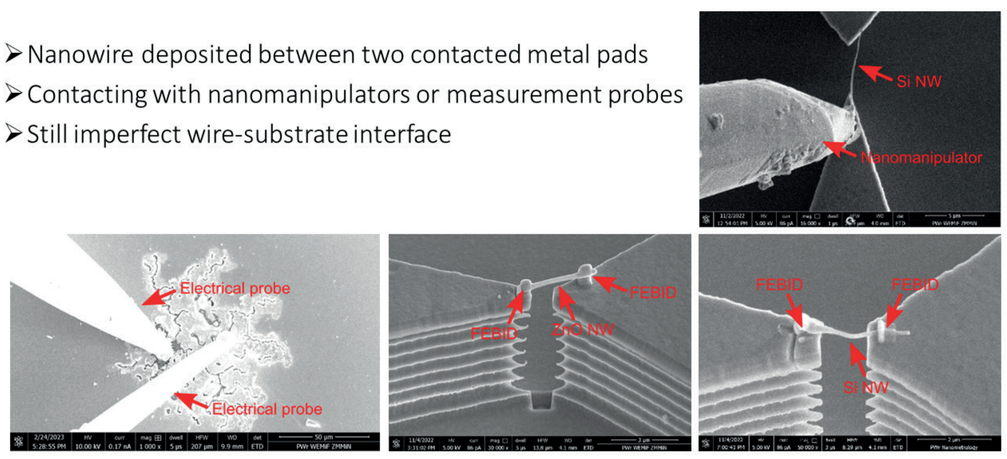



Figure 4. Realisation of the two-point resistance measurement

## SUBSTRATES FOR NANOWIRES

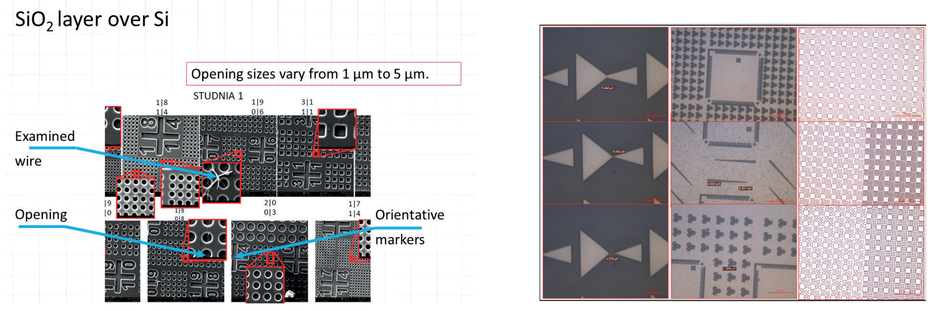
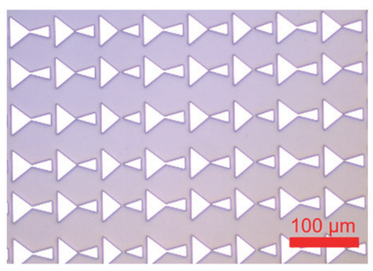



Figure 1. Different substrates with orientation patterns and various openings

## SUBSTRATES FOR IMPROVED CURRENT MEASUREMENTS




- Fine details for nanowires placement
- Metal over oxide on silicon
- Gaps as narrow as 500 nm
- Substrates 10 by 10 fields of 12 by 12 structures

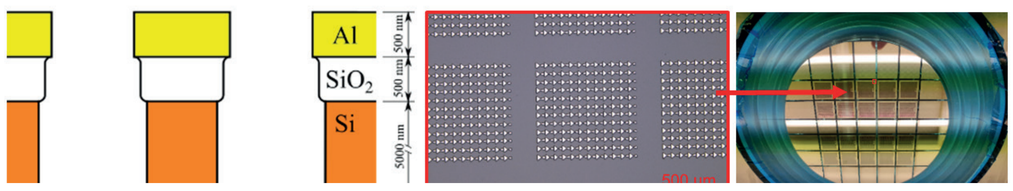
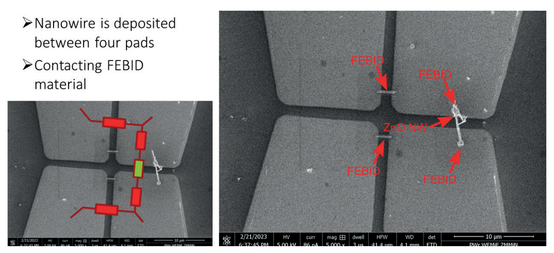



Figure 3. Substrates for measurement of nanoparticles: matrix of separated electrically and thermally islands for measurement of nanoparticles imaged with optical microscope

## FOUR-POINT RESISTANCE MEASUREMENT

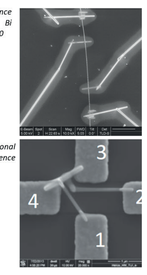
- Nanowire is deposited between four pads
- Contacting FEBID material

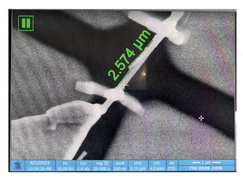



Why four point?

- Irrelevant probe and contacts resistance
- Hardly realised by SPM
- Allows for mechanoelectrical measurements

Cronin et al., *4-Point Resistance Measurements of Individual Bi Nanowires. MRS Proceedings, 2000*




Koopset et al. *30th International Vacuum Nanoelectronics Conference (IVNC) 2017*

Figure 5. Single section of electrically connected setup with nanowire placed imaged with scanning electron microscope.

## SUMMARY

- A new line of substrates for NW will allow for correlative microscopy of their thermal, mechanical, and electrical properties.
- Simultaneous measurement of various phenomena is a necessity in determining transducing properties such as thermoelectricity, piezoelectricity, or thermal expansion.
- In further development, substrates will incorporate active structures, enabling the determination of even more parameters.

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https://www.ptb.de/empir2020/nanowires/home/

## REFERENCES

[1.] Wielgoszewski, G., Jóźwiak, G., Babij, M., Baraniecki, T., Geer, R., & Gotszalk, T. (2014). Investigation of thermal effects in through-silicon vias using scanning thermal microscopy. Micron, 66, 63-68.