3D Hollow Cone Nanoprobes for Electric AFM Applications

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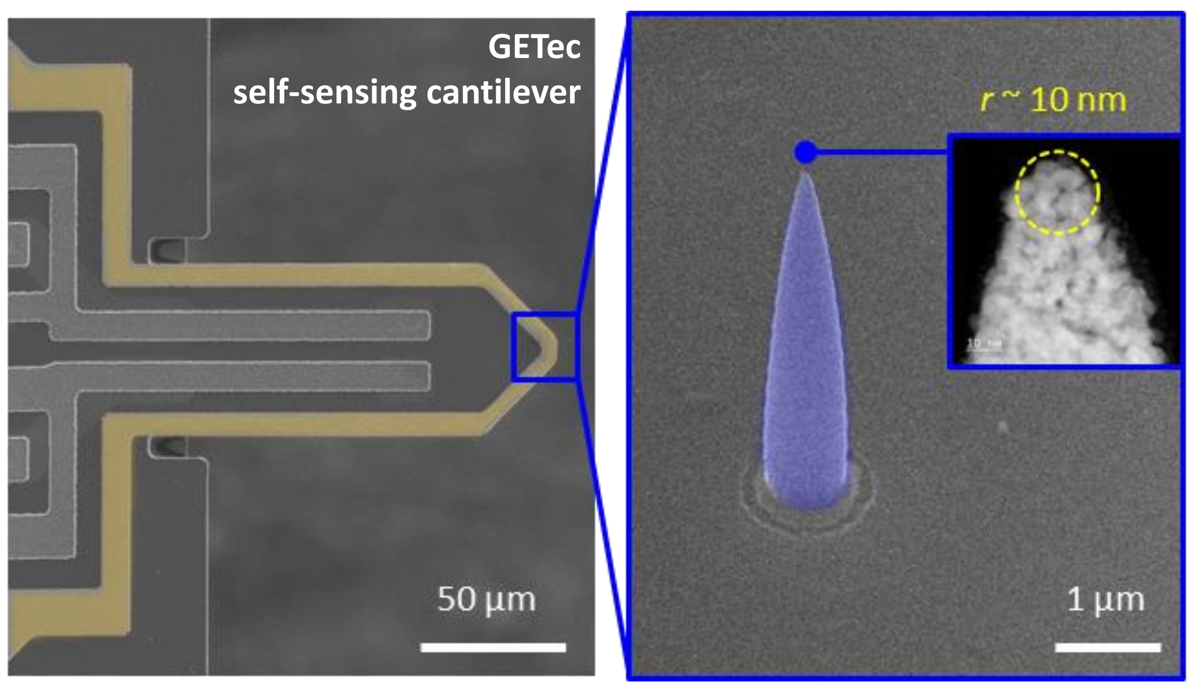
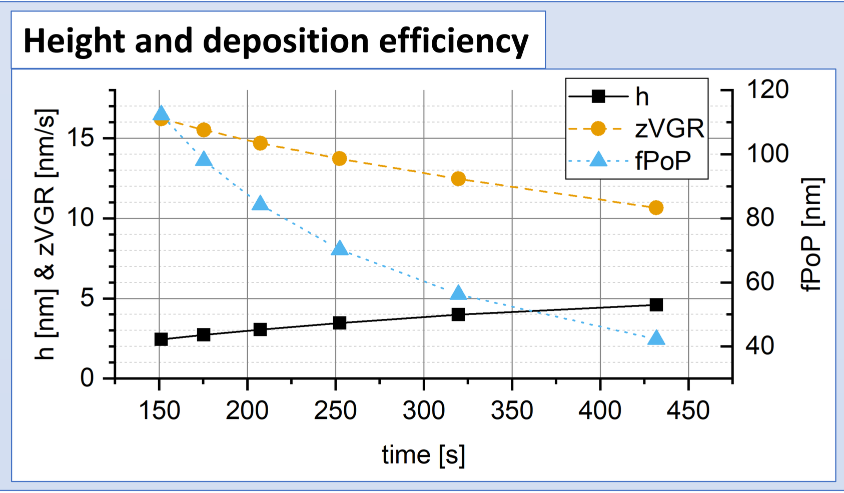
1. Introduction

Atomic Force Microscopy is a powerful microscopy technique that has brought great insights into many areas of research. First, nanosharp probes enable topographic surface investigations down to the lowest nanoscale and even below. Moreover, functionalized probes allow simultaneous mapping of materials properties at unprecedented resolution. Due to resolution and design flexibility 3D-nanoprinting via FEBID is well suited to fabricate functionalized AFM probes, like the here presented *Hollow Cone* concept[1]. Post-growth purification in the presence of water vapor minimizes the carbon content in the as-grown deposit[2,3]. While materials properties can be deliberately tuned, the overall shape and morphological aspects like the apex radius are preserved allowing for high-resolution AFM operation in combination with advanced probe functionalities.



2. Initial Fabrication Aspects

Height and deposition efficiency

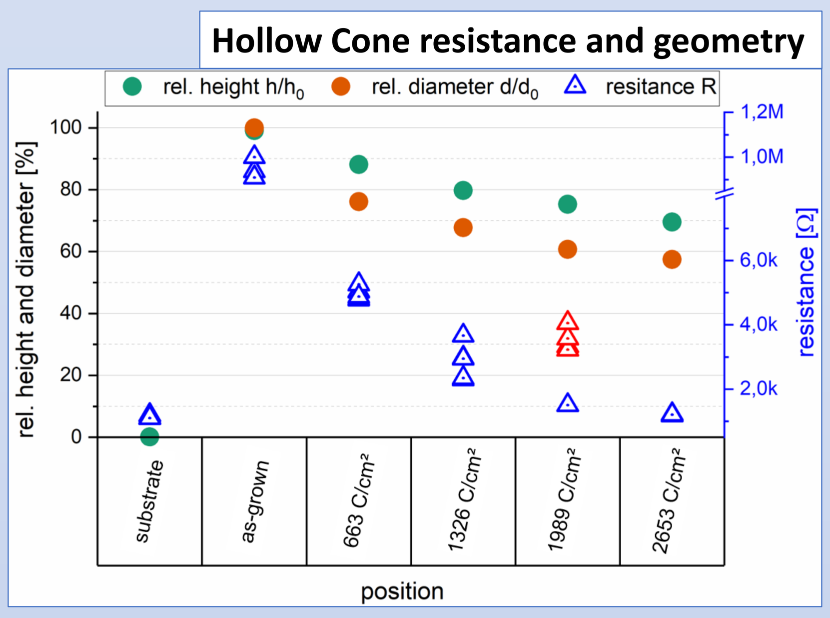


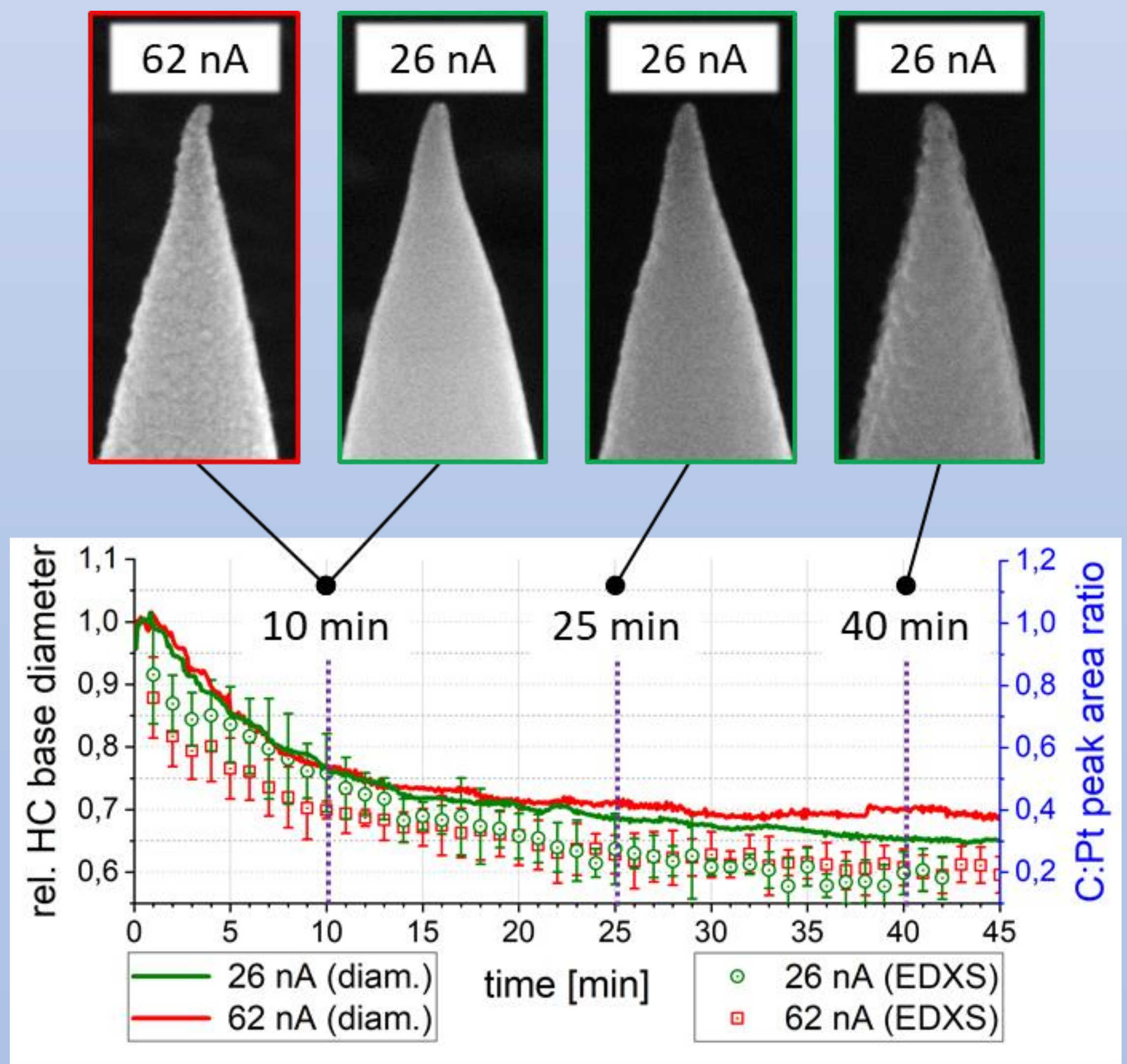
The *Hollow Cone* design combines a resilient base terminated with sub-10 nm apexes. Extensive studies were done to identify ideal beam and patterning parameters to achieve *(1)* symmetric tip regions with *(2)* sharp apex radii and *(3)* smooth side walls and *(4)* high mechanical stability to fulfill AFM related demands for reliable operation.

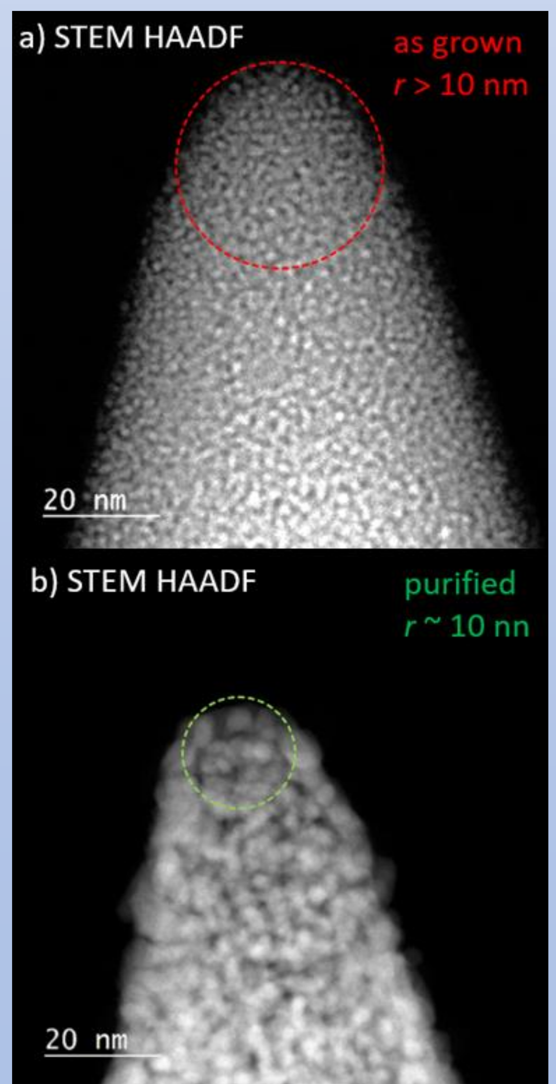
3. Purification Aspects

In the as-grown state, fine Pt-grains are dispersed in a carbon matrix and a large electric resistance is present, preventing electrical applications. Electron irradiation in conjunction with water vapor removes carbon from the deposit and thereby improves the resistance by orders of magnitude. Though carbon removal is accompanied by a substantial volume loss, the inherent robustness of the *Hollow Cone* design allows for crack- / pore-free material transfer into pure metals. Parameters were again optimized to fulfil AFM related demands.

Hollow Cone resistance and geometry

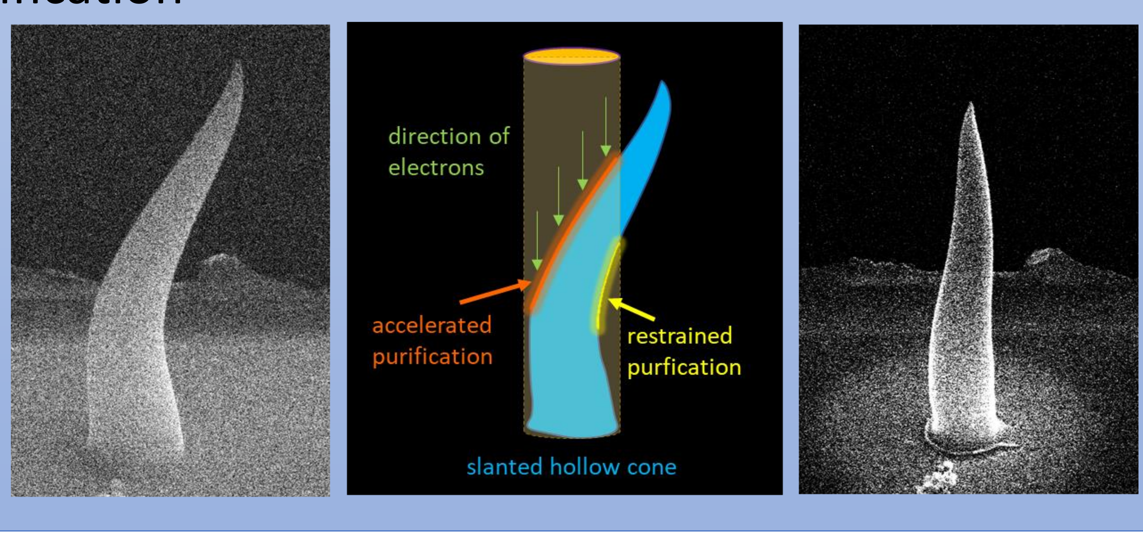




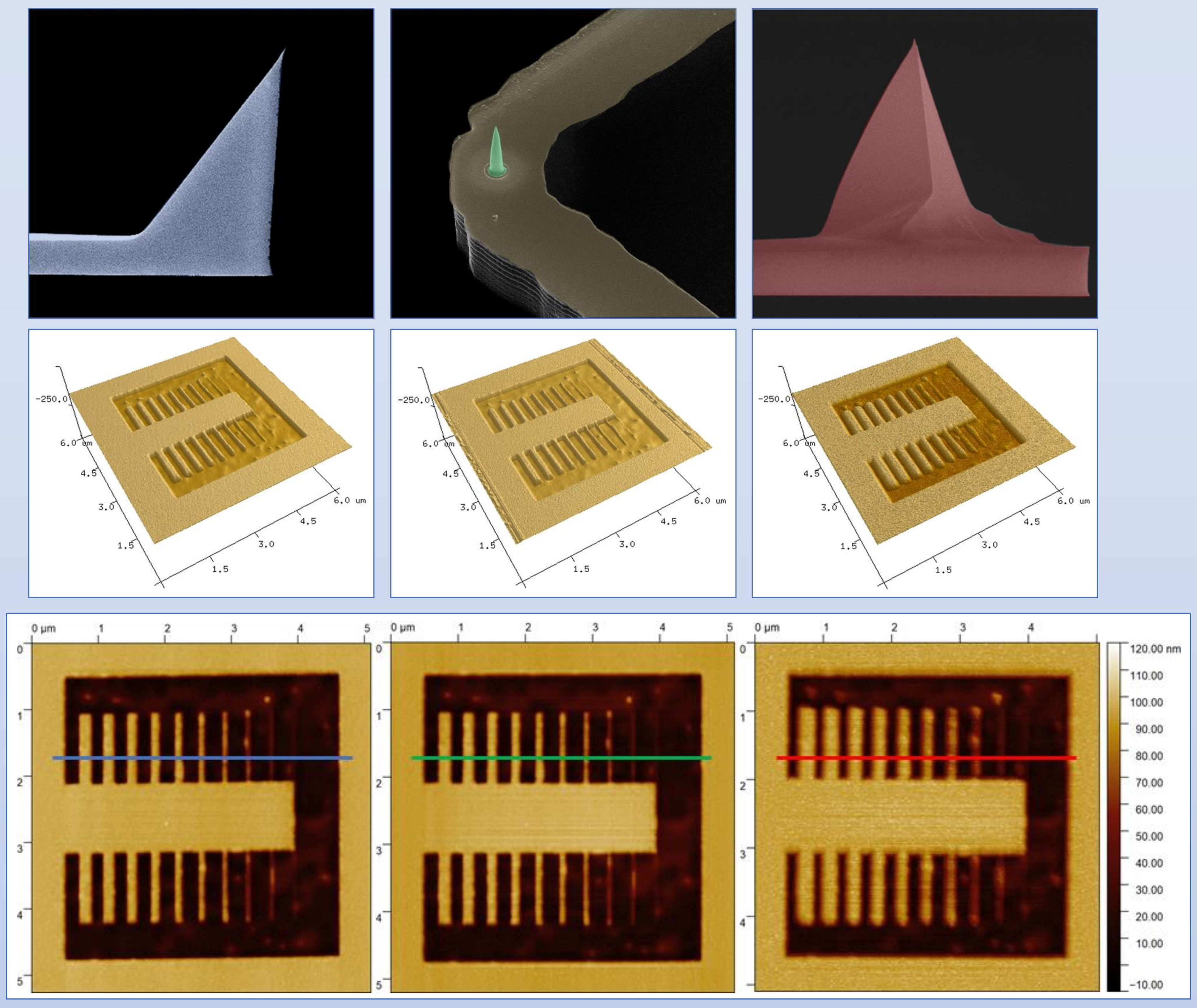


4. Self-Alignment during Purification

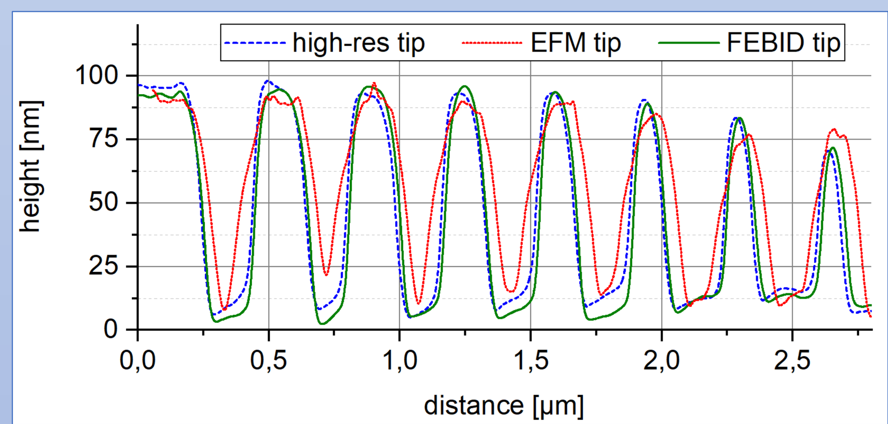
Drift issues can cause a slanted Hollow Cone shape after deposition. Interestingly, the dynamics of the purification process enable a self-alignment, which can compensate non-perfect initial shapes. While a dramatic example is shown here, typical deviations are entirely compensated.



5. AFM Operation – High Resolution and Functionalities

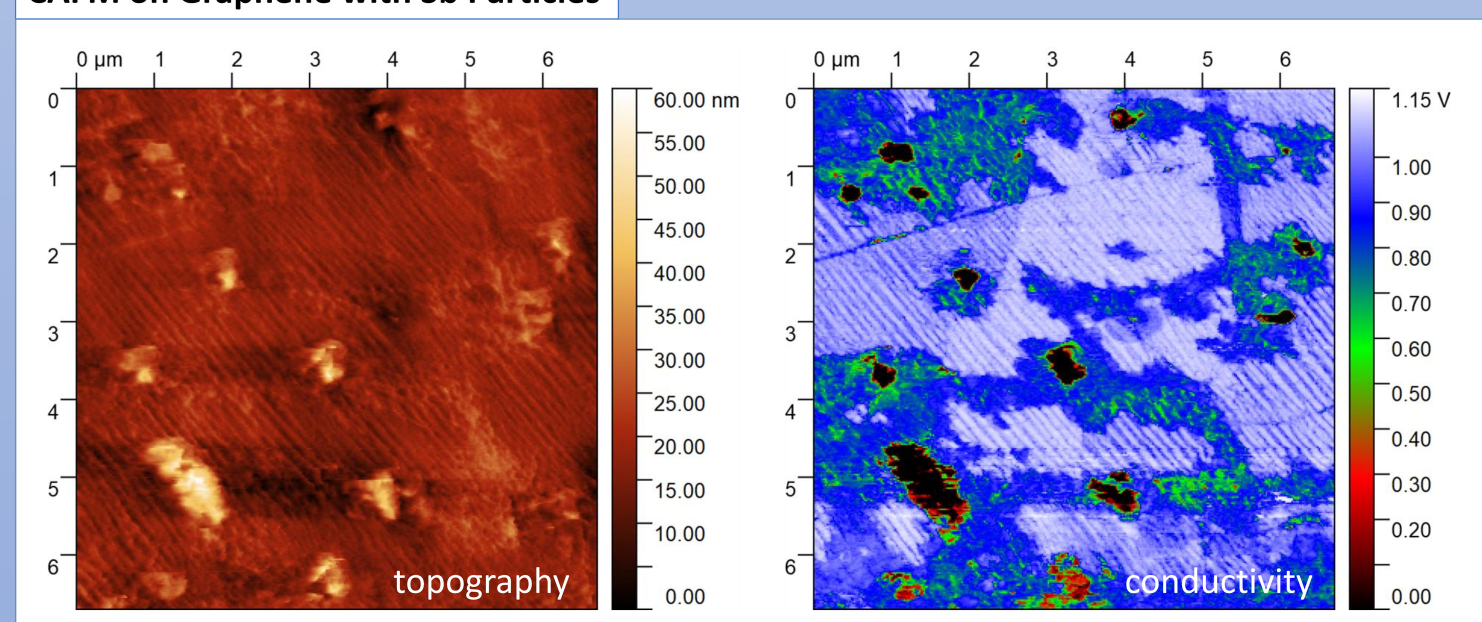


high-resolution tip **FEBID tip** **EFM tip (PtIr coated)**

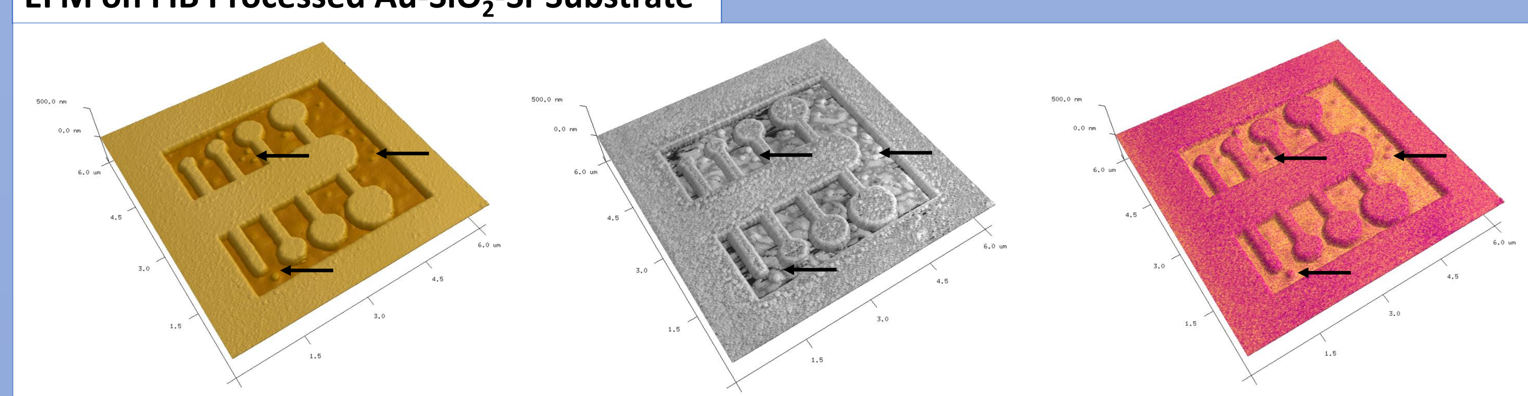


Topographic measurements demonstrate the *Hollow Cone* resolution capabilities, comparable to commercial high-res tips. Further, conductive (**CAFM**) and electrostatic (**EFM**) measurements proved the functionality and resolution. By that, FEBID tips combine the best of both worlds.

CAFM on Graphene with Sb Particles



EFM on FIB Processed Au-SiO$_2$-Si Substrate



3D height (3DH) 3DH & main phase overlay 3DH & EFM overlay

6. Conclusions

- Implementation and optimization of conductive AFM probe fabrication
- Subsequent material transfer via H_2O assisted purification successful
- Comparison to commercial probes underlines resolution and functional capabilities

References

[1] Plank, H. (2022) Multifunctional Nanoprobes for Scanning Probe Microscopy (US 17102900)
[2] B. Geier et al., Journal of Physical Chemistry C (2014)
[3] Z. Warneke et al., Beilstein Journal of Nanotechnology (2018)

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