

Non-Contact Mechanical Characterization of FEBID Nanopillars through Resonance Frequency Analysis and Automated Geometry Reconstruction

Alexander Bauer,^a Elena Unterleutner,^a Harald Plank,^{a,b} Robert Winkler^{*a}

^a *Institute of Electron Microscopy and Nanoanalysis, Graz University of Technology, 8010 Graz, Austria*

^b *Graz Centre for Electron Microscopy, 8010 Graz, Austria*

Mechanical characterization is essential for the design and optimization of FEBID-fabricated three-dimensional nanostructures used in functional nanodevices such as MEMS/NEMS, sensors, and microrobots [1]. Several experimental techniques have been developed to characterize the mechanical properties, including static bending (using AFM cantilevers or micromanipulators), nanoindentation, and buckling analysis of high-aspect-ratio pillars [1]. Resonance frequency analysis based on thermally excited vibrations provides a unique, completely non-contact approach for mechanical characterization. The vibrations of the nanopillar modulate the secondary electron signal when the electron beam is positioned in spot mode at the pillar edge (Fig. 1). Frequency-domain analysis of these signal fluctuations enables determination of the fundamental resonance frequency directly inside a SEM or STEM [2,3,4]. While resonance frequency analysis provides an attractive route for mechanical characterization, accurate determination of the Young's modulus-to-density ratio (E/ρ) requires both precise reconstruction of the nanopillar geometry and appropriate mechanical modelling [1].

In this contribution we present an integrated SEM-based characterization workflow for the non-contact determination of the mechanical properties of FEBID nanostructures. The workflow combines resonance frequency analysis, automated geometry reconstruction from SEM images, and mechanical finite element simulations to determine the material-specific E/ρ . The proposed workflow enables rapid, reproducible, and operator-independent mechanical characterization while substantially reducing uncertainties associated with manual geometry measurements and simplified geometric assumptions. By integrating automated image analysis, resonance frequency analysis, and mechanical modelling into a single workflow, the presented approach provides a robust platform for the non-contact mechanical characterization of FEBID nanostructures and supplies reliable material parameters for the design and optimization of future functional nanodevices.

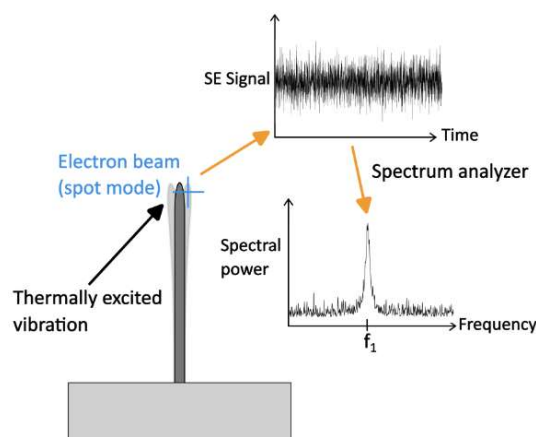


Figure 1. Schematic representation of the thermal vibration measurement.

References

- [1] Ivo Utke et al., *Micromachines*, 11(4), 397 (2020).
- [2] Vinzenz Friedli et al., *Nanotechnology*, 20(38), 385304 (2009).
- [3] Kazuhiro Nonaka et al., *Japanese Journal of Applied Physics*, 48, 06FG07 (2009).
- [4] Georg Arnold et al., *Advanced Functional Materials*, 28(19), 1707387 (2018).

* Corresponding author: robert.winkler@felmi-zfe.at; phone +43 316 873-8324