Nanoscale Science and Technology
Room 114 - Session NS2-TuM

Novel Imaging Techniques at the Nanoscale

Moderator: Adina Luican-Mayer, University of Ottawa, Canada

11:30am **NS2-TuM-15 Silicon-Containing Poly(Phthalaldehyde) Resists for Nanofrazor Applications – Direct Patterning of Hard Mask Materials by Thermal Scanning Probe Lithography***, **Nicholas Hendricks**, E. Çağin,* Heidelberg Instruments Nano AG, Switzerland

Thermal scanning probe lithography (t-SPL), enabled by the NanoFrazor technology, is establishing itself as a mature and reliable direct-write nanolithography technique for generating nanoscale structures [1-5]. The NanoFrazor technology offers an alternative or complementary process for conventional lithography techniques of electron-beam lithography (EBL) or focused-ion beam (FIB). t-SPL generates patterns by scanning an ultrasharp tip over a sample surface to induce local changes with a thermal stimulus. By using thermal energy as the stimulus, it is possible to perform various modifications to the sample via removal, conversion, or addition of/to the sample surface. Along with an ultrasharp tip, the t-SPL cantilever contains several other important functions such as an integrated thermal height sensor and an integrated heating element both of which are advantageous for fabricating devices for nanoelectronics, photonics, molecular sensing, and quantum computing.

The main thermal imaging resists used in t-SPL are poly(phthalaldehyde) (PPA) based materials that are commercially available from Allresist or Polymer Solutions. PPA is an all-organic based resist capable of undergoing direct sublimation when exposed to temperatures greater than the decomposition temperature, ~180°C, by a localized endothermic depolymerization reaction. With such characteristics, PPA has been able to produce sub-10 nm lateral dimensions while providing sub-nm vertical resolution and having an etch selectivity of 3 to 1 for a trifluoromethane-based reactive ion etch of silicon dioxide, a standard hard mask material. With a flexible synthesis, PPA can undergo an efficient and effective copolymerization to allow for the direct incorporation of silicon-containing functionalities into the thermal imaging resist. Such a strategy allows for the direct patterning of the silicon-containing hard mask for high-resolution and grayscale patterning with a simplified film stack.

Within this presentation, the background and workings of t-SPL will be introduced as well as the nanolithography and processing capabilities of silicon-containing PPA will be shown. There will be a focus on patterning high-resolution, e.g. sub-40 nm features, from a bi-layer stack of silicon-containing PPA and organic transfer layer (OTL) into a silicon substrate.

[1] S. Howell et al., Microsystems & Nanoengineering, 6, 21 (2020)

[2] V. Levati et al., Adv. Mater. Technol. 8, 2300166 (2023)

[3] O. J. Barker et al., Appl. Phys. Lett., 124, 112411 (2024)

[4] B. Erbas et al., Microsystems & Nanoengineering, 10, 28 (2024)

[5] L. Shani et al., Nanotechnology, 35, 255302 (2024)

11:45am **NS2-TuM-16 Atomic Force Microscopy-Based Nanoscale Mechanics as a Function of Temperature***, **Gheorghe Stan**,* National Institute for Science and Technology (NIST)*; C. Ciobanu,* Colorado School of Mines

In the last decades, Atomic Force Microscopy (AFM)-based nanoscale mechanics underwent significant developments in terms of measurements and analytics.The measured relative contrast between stiff and compliant materials can now be resolved quantitatively through either relevant models or numerical modeling to reveal the true mechanical properties of materials and structures tested. In comparison, the temperature dependence of the mechanical response has not been sufficiently investigated. The AFM modules for thermomechanical applications are just starting to be added on commercial instruments and the theoretical framework for such measurements is still in its infancy. In this work, we analyze AFM-based quasistatic and dynamic measurements from room temperature up to 250 C on few test materials to probe the reliability of these measurements for nanoscale mechanical properties. The temperature dependence of the tip-sample contact mechanics in these measurements was analyzed both analytically and numerically. This analysis consistently reproduced the experimental response and was used to extract the temperature dependence of the elastic modulus of materials tested.

12:00pm **NS2-TuM-17 Cryogenic Scattering Near-Field Optical Microscopy for Probing Optical Properties with 20nm Spatial Resolution at Temperatures < 10k***, **Tobias Gokus**,* attocube systems AG, Germany*; A. Danilov,* attocube systems AG*; R. Hentrich, A. Huber,* attocube systems AG, Germany

Near-field microscopy and spectroscopy has matured as a key technology for modern optics, combining the resolving power of atomic force (AFM) based measurements with the analytical capabilities of optical microscopy and spectroscopy.

Scattering-type near-field microscopy (s-SNOM) has already proven itself vital for probing local optical material properties of modern nanomaterials by enabling applications such as chemical identification [1], free-carrier profiling [2], or the direct mapping and measurement of the dispersion relation of propagating plasmon [3,4], phonon [5], and exciton polaritons [6] in layered materials.

Transferring these near-field measurement capabilities to cryogenic temperatures opens up new avenues for nanoscale-resolved optical characterization of novel materials and their fundamental properties. Until recently, cryogenic s-SNOM measurements were only available to a few experts utilizing home-built microscopes [7].

By integrating a scattering-type near-field optical microscope (s-SNOM) into an ultra-stable, vibrationally damped and automated closed-cycle cryostat system we developed the first commercial cryogenic s-SNOM microscope. It uniquely supports near-field amplitude and phase resolved imaging and spectroscopy in the visible to THZ spectral range and operates in a variable temperature range between < 10K to room temperature. We will demonstrate infrared and visiblenear-fieldimaging with deep subwavelength spatial resolution, visualizing phonon polariton modes in hBNand exciton polariton waveguide modes in MoS_2 at temperatures < 10K.

Furthermore, we will present recent researchresults onspatially resolved measurements of the spectral response of a2D electron gas and its impact on the surface phonon polariton of $LaAlO_3/SrTiO_3$ heterostructure systems by utilizing s-SNOM based mid-infrared spectroscopy at variable temperatures [8,9].

1. I. Amenabar et al., *Nat. Commun.* **8** (2017), p. 14402. https://doi.org/10.1038/ncomms14402

2. J. M. Stiegler et al., *Nano Lett.* **10** (2010), p. 1387. https://doi.org/10.1021/nl100145d

3. J. Chen et al., *Nature* **487** (2012), p. 77. https://doi.org/10.1038/nature11254

4. Z. Fei et al., *Nature* **487** (2012), p. 82. https://doi.org/10.1038/nature11253

5. E. Yoxall et al., *Nat. Photon.* **9** (2015), p. 674. https://doi.org/10.1038/nphoton.2015.166

6. F. Hu et al., *Nat. Photon.* **11** (2017), p. 356. https://doi.org/10.1038/nphoton.2017.65

7. A. S. McLeod et al., *Nat. Phys.* **13** (2017), p. 80. https://doi.org/10.1038/nphys3882.

8. Y. Zhou et al., *Nat. Commun.* **14** (2023), p. 7686. https://doi.org/10.1038/s41467-023-43464-z

9. J. Barnett et al., *arXiv:2311.08354* (2024). https://doi.org/10.48550/arXiv.2311.07354

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