CDE4301 Proposal : Fabrication and characterization of electron and ion microscope 3D resolution standards

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Proposer details

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Motivation:

Microscopes are crucial tools in imaging minute features across diverse research fields such as physics, materials science, and engineering. Modern charged particle microscopes, including scanning electron microscopes (SEMs) and ion microscopes, can achieve resolutions below 1 nanometer. Attaining such a high resolution necessitates precise calibration of the microscope, which involves focusing and adjusting brightness and contrast.

Yet, commercial calibration standards face significant limitations at sub-100nm resolutions due to imprecise edges, poor surface roughness, and substantial edge slope issues.[1] Existing standards often lack the vertical sidewalls necessary for precise measurements. For example, current proton beam applications increasingly demand nano dimensional resolution measurements, requiring standards with "a high degree of side-wall straightness" that many commercial options cannot provide. [2]

There are several promising lithography approaches that could create more precise sub-100nm structures. Proton beam writing (PBW) shows particular promise as one solution. As a direct 3D writing lithographic technique, PBW utilizes fast and focused MeV proton beams to pattern photoresists and form sub-100 nm features with exceptional precision.[3] Unlike current electron beam lithography, PBW benefits from the higher mass of protons (approximately 1800 times that of electrons), resulting in minimal lateral spread of secondary electrons in photoresists—less than 2 nm within 5 μm thick PMMA. This leads to minimized proximity effects coupled with straight and deep proton trajectories, making PBW uniquely capable of fabricating high aspect ratio sub-100 nm structures.[3,4]

Additionally, direct laser writing lithography has demonstrated success in creating ultra-small features with well-defined edges, fabricating structures as small as 1 μm with smooth boundaries that minimize the impact of etching damage.[5] Two-photon lithography through direct laser writing offers even more sophisticated capabilities, enabling the creation of high-aspect-ratio 3D microstructures with micron resolution.[6] This technique has been successfully applied to produce complex 3D microelectrode arrays and biomimetic structures, demonstrating exceptional control over geometrical features at the microscale.

This gap in reliable nanoscale calibration standards exists because traditional fabrication methods cannot achieve sufficient precision below 100 nm. Advanced lithography techniques could overcome these limitations but have primarily been developed for semiconductor manufacturing rather than metrology applications. Despite their unique ability to address the challenges of creating vertical sidewalls and precise edges at the nanoscale, they have not been systematically investigated for the development of resolution standards for electron and ion microscopy.[3]

Objective:

The project aims to create reliable reference structures that ensure consistent calibration across different microscopes, ultimately improving the accuracy and reproducibility of nanoscale imaging in scientific research and engineering applications. Creating 3D structures that can be used as reference objects (resolution standards) for calibration, ensuring different microscopes deliver consistent results and standardizing equipment performance.

Scope:

To fabricate resolution standards using various lithography techniques, such as laser writing and proton beam writing, to create a fine grid. This process is followed by metallization to produce a metal grid.
Additionally, optimization steps will be incorporated, culminating in a published protocol aimed at facilitating future mass fabrication of resolution standards for fast ion and electron beams.

Deliverables:

1. Creating physical resolution standards for microscope calibration below 1 nanometer
2. Optimizing and documenting fabrication methodology, with aims for future mass production

Reference

[1] F. Zhang, J. A. van Kan, S. Y. Chiam, and F. Watt, “Fabrication of free standing resolution standards using proton beam writing,” Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, vol. 260, no. 1, pp. 474–478, Jul. 2007. doi:10.1016/j.nimb.2007.02.065

[2] Y. Guan and M. Tortonese, “Metrology standards for Semiconductor Manufacturing,” Proceedings. 7th International Conference on Solid-State and Integrated Circuits Technology, 2004., 2004. doi:10.1109/icsict.2004.1435075

[3] J. A. Kan et al., “Proton Beam writing: A progress review,” International Journal of Nanotechnology, vol. 1, no. 4, p. 464, 2004. doi:10.1504/ijnt.2004.005980

[4] X. Xu et al., “Design considerations for a compact proton beam writing system aiming for fast sub-10 NM direct write lithography,” Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, vol. 404, pp. 243–249, Aug. 2017. doi:10.1016/j.nimb.2016.12.031

[5] L. Yu et al., “Ultra-small size (1–20 μ m) blue and green micro-leds fabricated by laser direct writing lithography,” Applied Physics Letters, vol. 121, no. 4, Jul. 2022. doi:10.1063/5.0099642

[6] M. A. Brown et al., “Direct laser writing of 3D electrodes on flexible substrates,” Nature Communications, vol. 14, no. 1, Jun. 2023. doi:10.1038/s41467-023-39152-7