Advanced Focused Ion Beams Focus Topic
Room Oregon Ballroom 203-204 - Session IB-ThP
Advanced Focused Ion Beams Poster Session

IB-ThP-1 Emission of Multiple Ion Species from a Single Ion Source: Top-Down FIB with LMAIS on a Lithography Platform*, **Torsten Richter**, A. Ost, A. Nadzeyka, P. Mazarov, L. Bruchhaus, F. Meyer,* Raith GmbH, Germany

Focused Ion Beams (FIB) technologies are broadly used in nanoscale science related applications, and they are inherently applied for direct nano-patterning, resist based processes [1] as well as ion microscopy [2]. FIB patterning has become a direct, versatile, and precise fabrication method of smallest features at high reproducibility. Therefore, high demands are made on the FIB in terms of beam stability, but also the sample stage requires a high degree of stability, accuracy and automation for nanoscale patterning and imaging.

The Liquid Metal Alloy Ion Source (LMAIS) is a versatile FIB source technology able to emit various ion species [3] at high stability. Light and heavy ions such as Silicon and Gold or Lithium and Bismuth are emitted simultaneously from a single ion source (AuGeSi or GaBiLi) [4] and separated using a downstream Wien filter. This source technology allows the optimization of lateral resolution as well as depth resolution, sputter yield or avoiding sample contamination by selecting the most suitable ion species. Combining the LMAIS with a high-precision laser interferometer stage, the Raith VELION FIB-SEM offers new process pathways reaching from nm-sized feature to wafer-scale patterning.

Besides nanofabrication, novel 3D ion microscopy imaging workflows have become possible thanks to the top-down FIB geometry on the VELION, becoming thus a powerful ion microscope for sample 3D reconstruction. Milling with bismuth allows a fast and homogeneous surface sputtering at highest depth resolution, while switching to Lithium ions enables 2D imaging at high lateral resolution (down to 1.5 nm).

In this contribution, we present the latest advances in LMAIS source technology along with related applications such as resist based ion beam lithography and introduce 3D ion microscopy using both light and heavy ions from LMAIS.

[1] Lei Zhang et al., Nanotechnology 31 325301 (2020)

[2] N. Klingner et al., Beilstein J. Nanotechnology. 11, 1742 (2020)

[3] L. Bischoff et al., Appl. Phys. Rev. 3, 021101 (2016)

[4] W. Pilz et al., JVSTB 37, 021802 (2019)

IB-ThP-2 Roadmap for Focused Ion Beam Technologies*, K. Höflich,* Ferdinand Braun Institut, Germany*; G. Hobler,* TU Wien, Austria*; F. Allen,* University of California at Berkeley*; T. Wirtz,* LIST, Luxembourg*; G. Rius,* Institut de Microelectrònica de Barcelona, Spain*; **Gregor Hlawacek**,* Helmholtz Zentrum Dresden-Rossendorf, Germany

This roadmap document comprises a review of the current state-of-the-art of advanced focused ion beam (FIB) processing and technology followed by an outlook on required future developments curated by a diverse group of stakeholders.

FIBs play an important role in scientific research in fields ranging from health and biology to quantum technology and nuclear fusion research. However, usually FIBs are perceived as tools for the preparation of samples for other methods such as transmission electron microscopy or atom probe tomography. The intention of this document is to show that this is a clear underestimation of the method by showcasing current and past applications as well as providing a guideline for academia, industry and funding agencies on necessary future developments.

The roadmap starts with presenting the state-of-the-art of the FIB technology and instrumentation. The working principle of the FIB is described and an overview of additional instrumentation and detectors who widen the applicability of the method is given. In the second section the available instruments for the simulation and prediction of the focused ion implantation and milling process is given. This includes advanced simulation techniques such as DFT and MD but also computational efficient methods like BCA which can be used in the every day lab work by FIB users. The core part of the review describes the various applications which go beyond the preparation of TEM samples and include in addition to the above mentioned applications also the fields of spintronic and magnonics, super conductivity, photonics, micromechanics, MEMS/NEMS and many more.

In the last part the authors comprising the relevant stake holders give an overview of the required future development which will enable FIB technology to stay at the forefront of research in the discussed fields. This outlook part is partly based on a survey conducted within the European COST Action CA19140 FIT4NANO which unites more than 200 users, developers and manufacturers of FIB technology. The intention of this part is to act as a guideline for academic and commercial developers as well as funding agencies to steer the future developments in a direction agreed upon by the community.

It is this aim supported by the divers group of contributors to the review which makes this roadmap relevant and timely for many fields of research.

IB-ThP-3 A Multi-Scale Understanding of the Three-Dimensional Microstructure of the Cornea Using Oxygen Plasma Focused Ion Beam, Scanning Transmission Electron Microscopy and Micro-CT Techniques*, **Valerie Brogden**, M. Scanagatta-Long, H. Uehara, A. Lin,* University of Oregon **INVITED**

The cornea is a transparent tissue of the eye which is used to focus light and consists of multiple layers including the epithelium, stroma, and endothelium.In certain genetic conditions, the endothelium deteriorates, leading to loss of pumping function and the formation of excrescences of collagen known as guttata. This condition describes Fuchs' endothelial corneal dystrophy (FECD), an inheritable disease which causes corneal fluid accumulation and eventual clouded vision. Since human corneal endothelial cells do not proliferate in vivo, the only treatment for advanced FECD is corneal transplantation. A shortage of donor corneas necessitates a new therapy for FECD.

Currently, the structural nature of guttata formation is not well understood. With a better understanding of guttata structure, new therapeutic methods may be developed. In order to investigate the three-dimensional structure of the endothelial layer on multiple length scales, we utilized Plasma Focused Ion Beam Scanning Electron Microscopy (PFIB-SEM) tomography in conjunction with Scanning Transmission Electron Microscopy (STEM) and Microcomputed Tomography (μ-CT).

While xenon is the most commonly used PFIB species in materials sciences, oxygen is proving to be particularly useful for creating artifact-free cuts into biological tissue. Researchers have found that oxygen PFIB can be used to remove curtaining artifacts in organic samples significantly faster than xenon PFIB.

The above reasons make oxygen PFIB the ideal technique for understanding 3D volumes of biological structures where sub-micron resolution is necessary. However, due to the novelty of this technique, it has yet to be popularized. To demonstrate oxygen PFIB application to biological samples, a normal mouse cornea (C57BL6J) and an FECD mouse cornea ($Col8a2^{Q455K}$) were examined as test samples.

Upon investigation of the 3D renderings of PFIB SnV data, we noted that the diseased cornea appears more topographical than the healthy cornea and the nanostructure of the guttata can be observed. This suggests that oxygen PFIB SnV with 3D rendering is a powerful technique for understanding the microstructure of the corneal endothelium. Paired with μ-CT and STEM imaging, a correlative, three-dimensional, multiscale understanding of the cornea is possible.

IB-ThP-5 Focused Ion Beam Implantation by Deceleration*, M. Titze,* Sandia National Laboratory*; J. Poplawsky,* Oak Ridge Natinal Laboratory*; E. Bielejec,* Sandia National Laboratory*; **Alex Belianinov**,* Sandia National Laboratories

Ion implantation is a key capability for a growing number of scientific and industrial areas, including quantum information sciences, and the semiconductor industry. As devices become smaller, new materials and processes are introduced and quantum technologies transition to being mainstream, traditional implantation methods may fall short in terms of energy, species, and positional precision. In this talk we will show data demonstrating Au implants into Si at energies 10 eV– 450eV in a Raith Velion focused ion beam system by decelerating ions using bias and keeping the beam focused. The implants were validated using atom probe tomography. Our data reveal that standard implant modeling approaches fail to agree with experimentally measured depths, potentially due to surface sputtering and lattice enrichment. Finally, we discuss how our results pave a way to much lower implantation energies, while maintaining high spatial resolution.

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