State-of-the-art Nanofabrication
Fundamentals and Advanced Applications

Wyndham Rio Mar Beach Resort and Spa
Tuesday, May 29, 2018
8:30 am – 3:30 pm

The popular EIPBN Short Courses will take place on Tuesday, May 29th, 2018. This all-day event features 6 lectures given by leading authorities in each field. This is a perfect opportunity to further your knowledge of nanofabrication processes and applications while interacting in a classroom setting with experts in their field.

Space is limited! Please register early to secure your spot!

Continental breakfast and lunch will be provided

Session Chairs:
Stefano Cabrini, Lawrence Berkeley National Laboratory
Aaron Stein, Brookhaven National Laboratory
Erika Penzo, Lawrence Berkeley National Laboratory

8:30 am – 8:40 am
Welcome and Introduction

8:40 am
Scanning Probes in Nanostructure Fabrication, Ivo W. Rangelow, Institute of Micro- and Nanoelectronics, Ilmenau University of Technology

Scanning probe microscopes are capable to image, characterize, measure, and manipulate at atomic scale being an irreplaceable tool in a wide variety of nanofabrication, positioning, and characterization methods. The use of atomically-sharp tips enables an ultimately localized interaction at atomic resolution. Often, this technology is called tip-based nanofabrication. With respect to the interaction mechanism, tip-based nanofabrication can be divided into two groups: (i) mechanical or thermo-mechanical interaction and (b) voltage-driven additive or ablative physical-chemical interaction. Tip-based nanofabrication can generate features in the so called “bottom-up” regime. In this case, atoms or molecules are assembled. Tip-based nanofabrication works also in the “top-down” regime, in which features are created into a bulk material. This course provides a broad description on the development of atomic force microscopy (AFM) nano-structuring and fabrication at the nanometer scale. Attention is paid to the scanning probe techniques and processes that offer high-resolution lithography capabilities for the fabrication of “beyond

CMOS” semiconductor devices. It also reviews the so called active probes, which have an integrated bending-sensor and actuator.

9:30 am
The Dawn of Superconducting Quantum Processors, Irfan Siddiqi, University of California at Berkley, Lawrence Berkeley National Laboratory

Quantum coherence can now be observed for longer than 100 microseconds in superconducting chips containing tens of physical qubits comprised of Josephson tunnel junctions embedded in resonant microwave circuitry. Such advances leverage advanced fabrication techniques which mitigate surface, interfacial, and radiative losses which are naturally introduced when processing bulk superconducting materials into patterned devices. Combining long-lived coherence with quantum-noise-limited, broadband detection of weak microwave signals has enabled the realization of nascent quantum processors suitable for executing shallow-circuit quantum algorithms with modest gate counts and minimal error mitigation. As an example, I will describe the implementation of a hybrid quantum-classical variational eigensolver with superconducting transmon qubits to determine the ground and excited states of simple molecules with near-chemical accuracy. I will also discuss plans for scaling to larger numbers of qubits, particularly focusing on the growth and suppression of different types of errors.

10:20 am
COFFEE BREAK

10:35 am
Electron Beam Lithography, Don Tennant, Cornell NanoScale Science and Technology Facility (CNF)

Electron Beam Lithography is an enabling technology for both prototyping of nanostructures and the commercial production of photomasks. This lecture will provide an overview of the instruments, the technologies that have allowed them to progress, the processes and methods employed by practitioners, and the applications that have been made possible. The course should help you understand the difference between SEM based lithography and that performed with a dedicated EBL system and how to exploit its enabling capabilities.

11:25 am
Technology and Recent Improvements of LMIS for FIB patterning and FIB nanofabrication,
Jacques Gierak, Centre de Nanosciences et de Nanotechnologies and Sven Bauerdick, Raith GmbH

In this presentation we will review some fundamentals of the Focused Ion Beam (FIB) technique based on scanning finely focused beams emitted from Electro Hydrodynamic Emitters (EHD) to perform direct writing [1]. It is widely assumed that the spatial extension of the phenomena induced by FIB irradiation represents a severe drawback, presumably limiting the use of this method for the realization of highly localized structures. At the light of advanced experiments and analysis techniques we will review these limitations and thus explore FIB for patterning sensitive devices such as III-V heterostructures, thin magnetic layers, artificial defects fabricated onto graphite or graphene, engraving nanopores into thin Si-based and atomically thin suspended graphene membranes. This includes the aspect of short ion penetration ranges and high localization of ion-deposited energy for localized damage generation showing the ultimate potential of this technique with respect to spatial resolution and ion doses. We will introduce the principle and mechanism of liquid metal ion source (LMIS) operation and explain achievements for its performance in particular for Ga. Moreover the technology and range of available ion species of alloy sources (LMAIS) are presented and discussed [2]. We will conclude in presenting the instrumental routes we are exploring aiming at higher resolution, better stability and various ion species as well as turning FIB processing “limitations” into decisive advantages. Such new routes for the fabrication of devices or surface functionalities are urgently required in some emerging nanoscience applications and their developing markets.

12:15 pm
LUNCH (Sponsored by KLA-Tencor)

1:00 pm

Cold Ion Source Technologies: History and Outlook, Adam Steele, *zeroK NanoTech Corporation* and Anne Delobbe, *Tescan-Orsay Holdings*

A new class of ion sources featuring laser-cooled particles have recently been developed that offer enhanced performance and new capabilities for focused ion beam instruments. The first generation of systems using this technology are currently poised for commercial deployment. In this short course we will first compare and contrast the mechanisms of action for these ion sources with the more traditional GFIS, LMIS, and ICP sources. This new class of ion source employs laser-cooling to bring gaseous atoms to very low (micro-Kelvin) temperatures; we will review the physics, history, and limitations of laser-cooling techniques. Subsequently we will show how the application of laser-cooling enables the creation of ion beams of high brightness, low-energy spread, or those that possess other exotic properties. The present and projected performance of prototype systems employing cold-atoms will be reviewed, and followed by a discussions of the anticipated applications where this technology will yield immediate benefits; these include nanomachining, semiconductor circuit edit and failure analysis, lithium battery research, and secondary ion mass spectrometry (SIMS).

1:50 pm
GFIS Technology and Applications, John Notte, Carl Zeiss

The gas field ion source (GFIS) technology is one of the newly developed ion source alternatives to the well-established liquid metal ion source (LMIS). The focused ion beam (FIB) systems equipped with the GFIS can offer a range of ion species such as helium and neon, and at an exploratory level, hydrogen, nitrogen, and xenon. The chief advantage of this technology is the high brightness of the source which allows the beam to be focused to a probe size as small as 0.35 nm. The lighter ion species have demonstrated great virtues in applications such as resist lithography, beam chemistry, and imaging. The heavier species offer advantages of higher sputter yields, and shallower penetration depths for precision sputtering with no gallium residue. More recently, these ion beams are being integrated into secondary ion mass spectrometers (SIMS) to provide high resolution analytical capabilities. This portion of the tutorial will provide a detailed view of the technology, and a survey of the applications.

Speaker Bios:

Sven Bauerdick studied physics at the Universities of Muenster and Tuebingen, Germany. He received his diploma in 2001 as well as a certificate in Medical Physics and Technology at the University of Kaiserslautern. In 2004 he finished his Ph.D in micro and nano technology at the University of Tuebingen. In 2004, Sven Bauerdick joined Raith in Dortmund, Germany, where he contributed to and managed various R&D projects on focused electron and ion beam nanofabrication systems. Since 2009 he is product manager of focused ion beam nanofabrication systems and is responsible for defining and promoting corresponding products as well as developing new applications. Sven Bauerdick is co-author of more than 20 papers in the area of nanotechnology applications and instrument development. Moreover he has co-authored an open access review article entitled “Direct- Write Ion Beam Lithography”.

Anne Delobbe: After a Ph.D. on X-ray absorption and circular dichroïsm spectroscopies (Paris XI), and a year as a teacher (PARIS VI) combined with research on structure and magnetic properties of clusters (Co or Ni in AlN), **Anne Delobbe** has entered Orsay Physics, French company specialised in FIB (Focused Ion Beam) technology in 2000. In this company, she was first manager of the final tests (production department) also in charge of installation of new systems and technical contact with customers. Then she was in charge of application and software teams (R&D department). She is currently head of R&D department in Orsay Physics and Chief Technical officer (CTO) in Tescan Orsay holding. She is the author and co-author of more than 20 articles in international reviews.

Jacques Gierak: My current interests are in inventing, experimentally developing and analytically understanding non-conventional “Focused Ion Beams” solutions capable of pushing the frontiers in nanofabrication and materials science. I am an experimentalist at heart and in practice. I am passionate about hands-on work – both my own and that of my collaborators and my students. When I approach problems analytically, it is important for me to verify the adequacy of formulations and hypothesis through experimental results. I have introduced the concept of nanofabrication using Focused Ion Beams with numerous applications in technological and materials science. I hold patents on these technologies and have published pertinent results in journals and conferences. As an individual with an insatiable curiosity, deep and persistent interest for learning, and a fervent desire to share what I have learnt with others, I will continue to explore new areas – some of which may have no immediate application but which are intellectually appealing to me, challenging and, very importantly, motivating.

John Notte received his undergraduate physics degree from Case Western Reserve University (Cleveland, Ohio), and his physics Ph.D. from U.C. Berkeley. He has worked for a number of instrumentation companies such as AMRAY, KLA-Tencor, and FEI, where he worked on imaging systems, detectors, and electron optics. He was one of the founding scientists of the startup company, ALIS, where he worked to mature the gas field ion source (GFIS) to a point where it was commercially viable. This technology became the ion source for the original ORION Helium Ion Microscope (HIM) instruments. Acquired by Zeiss in 2006, the product has diversified to be a versatile instrument with many nanofabrication and analysis capabilities. Presently, John serves as chief scientist for business development and “technology evangelist” at Carl Zeiss in Peabody, Massachusetts. John has over 30 journal publications, and is named in over 100 patents around the globe.

Ivo W. Rangelow received the M.S. and Ph.D. degrees in electronics from the University of Wroclaw in 1983. He was as post-doc at the University of Muenster, where his research was focused on the development of ion and electron beam techniques. In 1985, he joined the Fraunhofer-Institute in Berlin, where he worked on X-ray lithography. In 1986, he joined the University of Kassel, where he was focused on the development of force sensors, microresonators, and novel fabrication techniques for MEMS and CMOS. In 2005, he joined the Ilmenau University of Technology. He was a Guest Professor with the University of Vienna, Wroclaw University of Technology, and the University of Berkeley. He has authored or co-authored over 300 scientific papers and holds 48 patents. Actually he is working on scanning probe lithography and single ion implantation for single electron and quantum devices. He is currently the Director of the Institute of Micro- and Nanoelectronics at the Ilmenau University of Technology.

Irfan Siddiqi is a Professor in the Department of Physics at the University of California at Berkley and a Faculty Scientist at the Lawrence Berkeley National Laboratory. Siddiqi and his research group, the Quantum Nanoelectronics Laboratory, focus on the development of advanced superconducting circuits for quantum information processing, including computation and metrology. Siddiqi is also the founding director of the interdisciplinary Center for Quantum Coherent Science at Berkeley. Siddiqi received his A.B. in chemistry & physics from Harvard University and Ph.D. in applied physics from Yale University. Siddiqi is the recipient of many awards, including the APS George E. Valley Prize and the Berkeley Distinguished Teaching Award.

Adam V. Steele is co-founder of zeroK NanoTech, a startup that aims to commercialize new ion source technology based on laser-cooled atoms. He has expertise in atomic physics and the development of ion sources for focused ion beam applications. He is also the author of numerous publications and inventor of several patents, including zeroK's core technology. He holds a B.S. in physics and computer science from Carnegie-Mellon University (2002) and a PhD in physics from Georgia Tech (2008).

Don Tennant serves as Director of Operations of the Cornell NanoScale Science and Technology Facility (CNF) after long career at Bell Labs where he was a Distinguished Member of Technical Staff and managed the Advanced Lithography Group. His work in the nanofabrication field has had significant impact on a wide range of disciplines, including: soft x-ray imaging, high precision grating production for optical network components, extreme ultraviolet lithography (EUVL), and gate technologies for high performance devices and circuits. He has authored or co-authored over 200 articles in these fields, organized major conferences and has been awarded 11 U.S. patents. Don currently serves on the Advisory Committee for the International Conference of Electron, Ion, and Photon Beams and Nanotechnology (EIPBN). He is a past chairman of the Nanoscale Science and Technology Division of the AVS and was named a Fellow of the Society in 2010.