Helium Ion Microscopy Focus Topic
Room: 106 - Session HI+AS-TuA

Basics of Helium Ion Microscopy
Moderator: A. Gölzhäuser, University of Bielefeld, Germany, V.S. Smentkowski, GE-GRC

2:00pm **HI+AS-TuA1 Principles of Helium Ion Microscopy**, ***J.A. Notte***, *L. Scipioni, L.A. Stern*, Carl Zeiss NTS **INVITED**

The Helium Ion Microscope (HIM) consists of an interesting blend of long established technologies and recent state of the art engineering designs that enable superior charged particle scanning microscopy capabilities. They are capable of providing sub-nanometer spatial resolution with remarkable surface information and a unique ability to image insulating samples. HIMs share many similarities with Scanning Electron Microscopes (SEMs), but also embody new principles that uniquely differentiate HIM hardware and applications from traditional SEMs.

The most significant hardware difference of the HIM compared to SEM is the ion source. On the macroscopic scale the source appears very similar to a standard electron field emission source. However, the detailed tip geometry allows for much higher electric fields to be produced in the vicinity of the tip than what is found in traditional SEM field emission sources. The higher field enables ionization of the neutral helium gas which surrounds the tip, producing the needed helium ion beam. In addition to the high electric field requirement, it is necessary to keep the tip and surrounding imaging gas at cryogenic temperatures. The implementation of source cryogenics while operating the tip at ~ 35 keV, and also maintaining mechanical motion for both source translation and tilting, introduces significant engineering challenges in the design of a HIM.

Due to fundamental differences between helium ion and electron interactions with the sample under observation, the HIM is capable of producing images that are significantly different from those produced by traditional SEM. Since the entire electron population created due to an incident helium ion is of very low energy, only those electrons near the point of helium incidence are capable of escaping from the sample, resulting in images that are rich with surface information and possess superior spatial resolution. Due to the much higher secondary electron yield associated with helium bombardment of a sample relative to electron bombardment, and the fact that the incoming particles are positively charged, the net charge state of the sample is always positive, unlike the SEM case. Furthermore, due to the strong affinity of a helium ion to capture an electron, the net charge on the sample always exists as a surface charge. The positive surface charge can be easily neutralized with an electron flood gun, thus enabling charge free imaging on highly insulating samples. These various unique imaging principles make the HIM a versatile and unique imaging instrument.

2:40pm **HI+AS-TuA3 Design and Performance of a Near Ultra High Vacuum Helium Ion Microscope**, ***R. van Gastel***, University of Twente, The Netherlands, *L. Barriss, J.A. Notte,* Carl Zeiss NTS, *G. Hlawacek*, University of Twente, The Netherlands, *L. Scipioni, A.P. Merkle, D. Voci*, Carl Zeiss NTS, *C. Fenner,* LVestus Energy Inc., *H. Zandvliet, B. Poelsema*, University of Twente, The Netherlands

The advent of He Ion Microscopy (HIM) as a new technique to image materials and microstructures has enabled a new look at materials that is based on the interaction of swift light ions with matter, as opposed to that of more commonly used high (and low) energy electrons [1]. Initial Carl Zeiss Orion® He Ion Microscope instruments have demonstrated high-resolution imaging, combined with great surface sensitivity, the ability to neutralize charge very efficiently, and with enhanced materials contrast when ion induced secondary electrons are used for imaging. The use of Rutherford backscattered ions to form images has provided a new imaging modality that emphasizes differences in elemental composition and it can also be used to probe samples in-depth.

The HIM provides obvious benefits in terms of novel modes of contrast, surface sensitivity, lateral resolution, depth of field and charge compensation. To achieve ultimate performance, the chamber vacuum of the existing platform may be improved. For instance, carbon deposits due to beam interaction are readily seen due to the surface sensitivity of the technique. At sufficiently high current densities the sharply focused He ion beam may very efficiently decompose or cross-link residual hydrocarbons that are present in the instruments vacuum, more so than an electron beam in a SEM setup. Not only can this obscure a clear view of the sample, thereby negating the benefits of the small spot size, it also limits the available acquisition time for spectroscopic measurements. In addition to this, some materials (Au in particular) have yielded unexpectedly high sputtering rates. On the one hand, this has proven extremely useful in the field of nanopatterning for sensors, plasmonics or other device fabrication applications at the sub-10nm level when operating at high doses. On the other hand, it is undesirable when the instrument is used for materials characterization.

In this presentation we will discuss the basic considerations that went into the design of a Near-UHV (NUHV) Orion Plus® He Ion Microscope. We will detail how the improved vacuum level is anticipated to alter those processes that are directly relevant to the imaging performance of the instrument such as beam interaction in the surface region and the emission of secondary electrons. First applications that the instrument was used for will be highlighted and its impact in the areas of surface physics, notably catalysis, corrosion, and other research areas that require increased imaging sensitivity, both laterally and in depth, will be discussed.

References

[1] B. *Ward*, J. *Notte*, and N. Economou, *J. Vac. Sci. Technol.* 24, 2871 (2006).

3:00pm **HI+AS-TuA4 Sub-10 nm Scanning Helium Ion Beam Lithography**, *K. van Langen, E.W.J.M. van der Drift,* Delft University of Technology, Netherlands, *E. van Veldhoven, D.J. Maas*, TNO, Netherlands, ***P.F.A. Alkemade***, Delft University of Technology, Netherlands

Since the launch of the novel sub-nanometer helium ion microscope by Zeiss / Alis in 2006 nanofabrication with this tool has gained a lot of interest [1]. Key characteristic in this matter is the directional interaction of the helium ion with matter with negligible backscattering. In ion milling it enables very steep structuring when compared to the Ga^+ ion equivalent [2]. In a similar comparison helium ion beam-induced deposition in a precursor gas ambient yields tall and smooth nanostructures [3], partially also because the sputtering by helium ions is at least an order of magnitude lower than by gallium ions.

The present contribution deals with scanning helium ion beam lithography (SHIBL). Thusfar two initial SHIBL studies on hydrogensylsesquioxane (HSQ) resist were reported [4,5]. In the present work performance of SHIBL is compared with state-of-the-art electron beam lithography (EBL). As resist materials we explored HSQ, polymethylmethacrylate (PMMA), and the inorganic resist of aluminumoxide. The latter material choice is motivated by the need for enhanced mask selectivity in pattern transfer in the sub-10-nm area.

The results for HSQ and PMMA can be summarized as:

- smallest feature size of 5 nm, equivalent to the best EBL performance [6]

- clear pattern densities up to 10 nm full-pitch, which is better than in EBL

- sensitivity 1-2 orders of magnitude better than in EBL.

As for the inorganic resist, 5-nm features have been realized.

In a semi-quantitative and comparative approach the results will be explained and future prospects will be outlined.

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5 D. Winston, B.M. Cord, B. Ming, D.C. Bell, W.F. DiNatale, L.A. Stern, A.E. Vladar, M.T. Postek, M.K. Mondol, J.K.W. Yang, K.K. Berggren, J. Vac. Sci. Technol. B (2009) 27: 2702

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4:00pm **HI+AS-TuA7 Contrast Performance in Helium Ion Microscopy**, ***D.C. Bell***, Harvard University **INVITED**

In order to achieve ultra high resolution imaging with secondary electron imaging, it is critical that the electric potential of the specimen surface is well controlled. For electrically conductive samples this can be achieved by simply grounding the specimen. However, imaging of electrically insulating specimens can provide challenging or impossible to image due to uncompensated charge resulting from the electron or ion beam interaction with the specimen surface. The main reason for the uncompensated charge is that the insulating specimen has insufficient conductivity through mobility of either electrons or holes to quickly restore the neutrality of the scanned area. The buildup charge causes significant deflection and distortion of the ion or electron beam. Which is more appropriate, to use charge compensation with high kV helium Ions or employ a low kV SEM image to obtain the required surface information? This paper will present a systematic examination of the surface information provided by both techniques, including SEM charge compensation mechanisms.

One key advantage of the Helium Ion Microscope technology in the case of imaging highly charging specimens is the electron flood gun can be utilized to neutralize the positive charge buildup and facilitate high-resolution imaging. A flood gun is used to charge the surface to a negative potential (using electrons as the neutralizing particles). When utilizing the electron flood gun, the electron beam and He ion beam are synchronized and adjusted with respect to one another, so that the low energy electrons are not interfering with the secondary electron imaging.

Some of our research from the past year has been surprising and may provide a foundation for a change in analysis techniques of different materials. The nature of the Helium ion beam interactions with the sample shows enhanced edge contrast which is especially useful for critical dimension measurements; one particularly interesting development is the imaging of non-conducting materials showing a contrast due to three apparent mechanisms simultaneously - atomic number, channeling contrast and a possible enhanced edge contrast. The advantages of Helium ion microscopy is still being investigated and still are proving some exciting results.

5:00pm **HI+AS-TuA10 Helium Ion Beam Induced Deposition Examined using a 3D Monte Carlo Simulation**, ***D.A. Smith***, *P.D. Rack*, University of Tennessee Knoxville, *P.F.A. Alkemade, H. Miro*, Delft University of Technology, The Netherlands

The growth of nanostructures has traditionally been dominated by electron beam induced deposition (EBID) or gallium ion beam induced deposition (Ga-IBID). While EBID provides smooth sidewalls and good resolution for nanopillar growth, the cross-section for dissociation is low and etching is difficult as sputtering is negligible. Ga-IBID is a relatively faster method of producing nanostructures, however it suffers from lower resolution, alters deposited materials, and leaves an etching residue. A new tool in this field has been recently explored: the helium ion beam microscope. This tool has been modified to perform IBID using high energy helium ions. It has been found that He-IBID combines the high resolution of EBID with the speed of Ga-IBID. Moreover, there is less implantation damage and minimal sputtering compared to Ga beams.

To examine this process, a 3-dimensional Monte Carlo simulator has been designed based ion-solid-precursor interactions. This simulation system, named EnvisION, can provide useful knowledge of how user-controlled parameters can be optimized for highly efficient growth of nanostructures using this tool. In this work, an in-depth explanation of the simulation will be presented, including an example of its use examining the growth efficiencies of nanopillars grown on a silicon substrate using the (CH3)3Pt(CpCH3) precursor via He-IBID. Furthermore we compare how the morphology changes with dwell times, refresh time, precursor coverage and surface diffusion in order to span the range of growth regimes from mass-transport limited to reaction-rate limited deposition. The simulated morphologies predicted using the EnvisION simulator are compared to experimentally grown pillars to validate the simulation.

5:20pm **HI+AS-TuA11 TEM Specimen Preparation with Light Ions**, ***L. Giannuzzi***, L.A. Giannuzzi & Associates LLC

Much research with light energetic ions such as He^+ and Ne^+ from gas field ionization sources has focused on imaging and nano-machining. It is a natural progression to question to the viability of TEM specimen preparation using these light ions. Of vital importance for TEM specimen preparation quality is the understanding of surface ion implantation and amorphization damage. Theoretical calculations using SRIM indicate that there may be a damage trade off between vacancy formation, ion range, and dose. That is, the range of light ions is much greater than conventional heavy ions (e.g., Ga+), and can indeed penetrate directly through a TEM specimen. While this may indicate the possibility of light ions damaging the entire TEM specimen thickness, light ions produce far less vacancies per ion compared to heavy ions for the same dose. However, since the sputter yield of light ions is smaller than heavy ions, a larger dose of light ions may be necessary to achieve sufficient material sputtering. This theory will be supplemented with experimental results.

5:40pm **HI+AS-TuA12 The Possibilities of the HIM for Imaging and Nanopatterning of EUVL Masks**, *D.J. Maas, E. van Veldhoven,* ***N.B. Koster***, TNO, Netherlands, *P.F.A. Alkemade, E.W.J.M. van der Drift*, Delft University of Technology, Netherlands

Although Helium Ion Microscopy (HIM) was introduced only a few years ago [1], many new application fields are emerging. Key issue is the directional interaction of the primary helium ion beam with the sample at and just below its surface with negligible backscattering. The sub-nanometer sized probe of the 10-35 keV ion beam generates Secondary Electrons (SEs) that have a typical energy between 0 and 20 eV. Taking all together the SE signal stems from an area that is very well localized around the point of incidence of the primary beam. This makes the HIM well-suited for both high-resolution imaging as well as high resolution nanofabrication [2]. We explore the possibilities to use the HIM simultaneously for imaging and nano patterning of EUVL masks.

The HIM is a high-resolution surface imaging tool. In practice, the optimum dose for imaging is a balance between maximizing S/N ratio, while minimizing sample damage. Imaging work at TNO van Leeuwenhoek Laboratory (VLL) [3] focuses at sensitive materials such as e.g. DUV and EUV resists and EUV masks, which are difficult to image in a SEM due to their charging behavior. An electron flood gun in the HIM offers effective charge cancellation, which enables high-resolution imaging of insulation structures and for pin pointing defects on a EUV reticle. In this presentation we will show images of particles down to 5 nm on reticles.

Furthermore, to explore the possibilities of the helium ion microscope as a nanofabrication tool, the HIM at the TNO VLL is equipped with a pattern generator and a gas injection system (GIS). This presentation will show our latest nano structuring results made with Helium Ion Beam Induced Processes: deposition and etching. It is expected that the unique capabilities of the HIM in combination with the GIS are suited for EUV mask repair. These capabilities offer the possibility of circuit repair in the latest and smallest semiconductor technology nodes (beyond 22 nm). In both cases sub-surface damage due to scattered He ions is a matter of concern and topic of investigation. At this moment we are capable of etching 13 nm lines with 25 nm spacing on a EUV dummy mask with approximately 80 nm of TaN absorber. Furthermore we demonstrate Pt deposited lines of 13 nm width at a 16 nm spacing.

References

[1] J. Morgan, J. Notte, R. Hill, and B. Ward, Microscopy Today 14, (2006) 24

[2] D.J. Maas et al., Proc. SPIE Vol. 7638, 763614 (2010) 1-8

[3] http://www.vanleeuwenhoeklab.com/

Authors Index

Bold page numbers indicate the presenter