Helium Ion Microscopy Focus Topic
Room: 19 - Session HI+AS+BI+NS-ThM

Imaging and Lithography with the Helium Ion Microscope
Moderator: A. Gölzhäuser, University of Bielefeld, Germany, V.S. Smentkowski, General Electric Global Research Center

8:40am **HI+AS+BI+NS-ThM3 Helium Ion Microscopy of Photonic Structures in Biological Systems**, ***S.A. Boden***, *A. Asadollahbaik, H.N. Rutt, D.M. Bagnall*, University of Southampton, UK **INVITED**

The natural world is replete with examples of biological systems that have developed complex micro- and nano-scale structures to interact with light. Such structures, which include thin film multilayers, diffraction gratings, graded index layers and 2D and 3D photonic crystals, acting alone or in combination, allow the realization of a range of optical effects that would be impossible through the use of pigmentation alone. These effects range from the vivid iridescence observed on the skin of some species of bird, through the vibrant metallic sheen of some beetle species, to the dramatic interference patterns seen on the transparent wings of some species of fly. Lepidoptera (an order of insects that includes butterflies and moths) also provides a rich seam of examples of structural color ranging from the antireflective nipple arrays found on the eyes and wings of some species of moth to the photonic crystal structures producing vivid coloration on the wings of some butterfly species.

As these optical effects are a result of the scale of these structures being at or below that of visible light wavelengths, scanning electron microscopy (SEM) is often used to explore their form and to offer insights into their function. Recently, helium ion microscopy (HIM) has emerged as a surface imaging technique, similar to SEM but with the benefits of higher resolution and a larger depth of field. Here, HIM is used to probe the structures responsible for a number of optical effects observed in Lepidopterans. Images will be presented showing the fine details of the ribs and cross-ribs found on the highly-absorbing black ground wing scales of *Papilio ulysses* (Blue Mountain Butterfly) and the complex gyroid 3D photonic crystal structure observed underneath the top lamina on vividly green wing scales from *Parides sesostris* (Emerald-patched Cattleheart). Other examples will include the antireflective close-packed nipple array on the wings of *Cephonodes hylas* (Pellucid Hawk Moth), and cross-sections of the multilayer structures that make up the various colored wing scales of *Chrysiridia rhipheus* (Madagascan Sunset Moth).

The integrated electron flood gun on the helium ion microscope is employed to neutralize charge build-up, allowing samples to be imaged without the need of a conductive coating. This ensures that the natural surface itself is imaged at high resolution and details are not obscured by coating artefacts. In addition, by taking advantage of the large depth of field available with HIM, stereo pairs are generated to extract information on the three-dimensional nature of these structures.

9:20am **HI+AS+BI+NS-ThM5 Imaging of Carbon Nanomembranes (CNM) and Graphene with Helium Ion Microscopy**, ***H. Vieker***, *A. Beyer, A. Polina, A. Willunat, N.-E. Weber, M. Büenfeld, A. Winter, X. Zhang, M. Ai, A. Turchanin, A. Gölzhäuser*, Bielefeld University, Germany

We present a Helium Ion Microscopy (HIM) study of carbon nanomembranes (CNMs). CNMs are extremely thin (~1 nm) nanolayers consisting only of surface. They are made via cross-linking of self-assembled monolayers (SAMs) with large-area exposures of electrons, photons or helium ions and a subsequent transfer to suitable substrates. Patterned radiation exposures allow the fabrication of perforated nanomembranes, e.g., nanosieves. After annealing at temperatures above 800K, CNMs become conductive and eventually transform into graphene. HIM images of CNMs with different precursor molecules are shown, and images of graphene from SAMs are compared with the CVD grown graphene. Capabilities of the HIM imaging of freestanding CNMs and graphene will be discussed.

10:40am **HI+AS+BI+NS-ThM9 Dopant Contrast in Helium Ion Microscopy**, *Y. Chen, H. Zhang,* ***D. Fox***, *C.C. Faulkner, J. Wang, J. Boland, J. Donegan*, Trinity College, Ireland **INVITED**

Innovation in metrology is crucial to the future of semiconductor industry, since the miniaturization of transistors demands novel characterization technologies at and beyond the nanometre scale. Recent research has demonstrated that dopant contrast in the Helium-ion Microscope (HIM) is plausible and the HIM is a competitive platform for quantitative secondary-electron (SE) dopant mapping in terms of throughput, sensitivity, and resolution. However, the contrast mechanism of SE imaging is still debatable and it hinders further development of the technique. In this research, quantitative HIM dopant contrast of gallium-doped silicon samples has been investigated and compared with the contrast observed in a scanning electron microscope (SEM). Beam-sample interaction, signal general, as well as detection configuration have been considered via using a range of detectors in the two microscopes. It has been found that the Everhart-Thornley (E-T) secondary electron detector attached to HIM provides similar contrast to the images acquired from the InLens detector attached to SEM, while contrast reversal is observed with the SEM E-T detector. The contrast reversal also depends on the Dwell time. We have confirmed that the HIM is more sensitive to type-I SEs and a capacitance model based on charging effect has been proposed to explain the contrast reversal. Our results indicate that quantitative dopant contrast in the HIM is promising, while charging effect and imaging conditions must be carefully considered.

11:20am **HI+AS+BI+NS-ThM11 High Resolution Patterning of Carbon Nanomembranes and Graphene via Extreme UV Interference Lithography: A Helium Ion Microscopy Study**, ***A. Winter***, *A. Willunat, A. Beyer*, University of Bielefeld, Germany, *Y. Ekinci*, Paul Scherrer Institute, Switzerland, *A. Gölzhäuser, A. Turchanin*, University of Bielefeld, Germany

Two-dimensional (2D) carbon materials like graphene, graphene oxide, carbon nanomembranes (CNMs) or ultrathin polymeric films have recently attracted enormous interest due to their potential use in electronics, chemical and biological sensors, nanofilters, hybrid materials, etc. Most of these applications require lithographic patterning of these 2D carbon materials with the nanoscale resolution. In this respect, Extreme UV Interference Lithography (EUV-IL) provides both large-scale pattering and high resolution with an ultimate limit in the sub-10 nm range. We employ EUV-IL to generate nanopatterns in ~1 nm thick CNMs and graphene. We characterise these nanopatterns with a Helium Ion Microscope (HIM). Its high surface sensitivity and lateral resolution provide excellent conditions for imaging of the topographic and chemical features in CNMs and graphene. The possibility to routinely fabricate and characterize the nanopatterns via EUV-IL and HIM on various technologically relevant insulating substrates (e.g., oxidized silicon wafers, glass, and quartz) and with the resolution below 20 nm shows high potential of both techniques for applications in carbon-based nanotechnology.

11:40am **HI+AS+BI+NS-ThM12 Application of Helium Ion Microscope on Processing and Characterization of Nano Wires**, ***H.X. Guo***, *S. Nagano, K. Onishi, D. Fujita*, National Institute for Materials Science (NIMS), Japan

Scanning helium ion microscope (SHIM) is advanced in high resolution and high focal depth of secondary electron imaging and Rutherford backscattered ion imaging.[1] It also employed in the nano pattern or fabrication on surface and other various structures, such as 2D materials, graphene.[2] It is an excellent candidate for the naon processing of 1D nano structures, such as nanowires and nanotubes.

Rhenium trioxide (ReO3) is an unusual transition metal oxide with high electrical conductivity close to that of metals. It is well investigated for the applications of photovoltaics[3], catalyst[4],and tip for scanning tunneling microscope[5]. Various ReO3 nano structures such as nano paticles[3,6], nano wires[7], and core-shell structures have been synthesized and characterized by different methods.

In this research, ReO3 nanowires were synthesized by a physical vapor deposition method. Etched by the helium ion beam, the diameter of part of the nanowire was decreased. During this processing, the structure and transport properties of the ReO3 nanowire were modified with a controllable method. In this presentation, we will show the structure and properties characterization of the etched nanowires by using scanning probe microscope (SPM) , transmission electron microscope (TEM) and other methods. An *in-situ* transport properties measurement system with SHIM will also be introduced in the presentation.

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