Introduction to Direct Write Lithography Workshop Agenda

Friday, August 12th

Building 8600, C-152

Agenda

8:30 AM	Brief Opening Remarks and update on Helium Ion Microscope user capabilities, Adam Rondinone
8:35 AM	Three–Dimensional Focused Electron Beam-Induced Deposition, Jason D. Fowlkes
9:15 AM	Laser-Assisted Focused Electron and Ion Beam Induced Processing, Philip D. Rack
10 :00 AM	Scanning Transmission Electron Microscope Based Lithography: Approaching Atomic Scale Assembly, Stephen Jesse
10:30 – 10:45	Break
10:45 - noon	Direct Laser Write Based on Two-Photon Polymerization: From 3D CAD to Function, Nick Lavrik
	Lunch on Own
1 PM - TBD	Hands-on Practical Demonstration of two-photon lithography

Three–Dimensional Focused Electron Beam-Induced Deposition

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A three–dimensional focused electron beam induced deposition (FEBID) simulation will be presented. The FEBID simulation was created as a predictive tool geared toward the design of 3D micro- and nanoscale deposits. In the past, our team has focused on executing simulations for determining unknown FEBID related parameters or for unravelling the evolution of the electron–precursor–solid interaction. The ultimate goal of the current simulation is to predict the primary electron beam coordinates and beam dwell times required for experimental 3D FEBID. This goal was achieved for the 3D FEBID of objects as complex as truncated icosahedrons. The 3D constructs are deposited as mesh objects as opposed to a solid object model using conventional multi–level raster scanning.

The presentation will cover the initial phase of development where the FEBID simulation was calibrated based on experiments. The convergence of experiments and simulations was observed for a simple set of 3D mesh objects following calibration. A computer aided design (CAD) program was then created in order to design more complex 3D geometries specific to FEBID. The CAD program output is a data set including beam spatial coordinates and beam dwell times which are necessary to generate the prescribed 3D mesh. Robustness of the approach was evaluated by executing 3D FEBID using two different electron microscopes. 3D objects including rings, frames, cubes and icosahedron geometries, predicted by simulation, were successfully replicated on both microscopes.

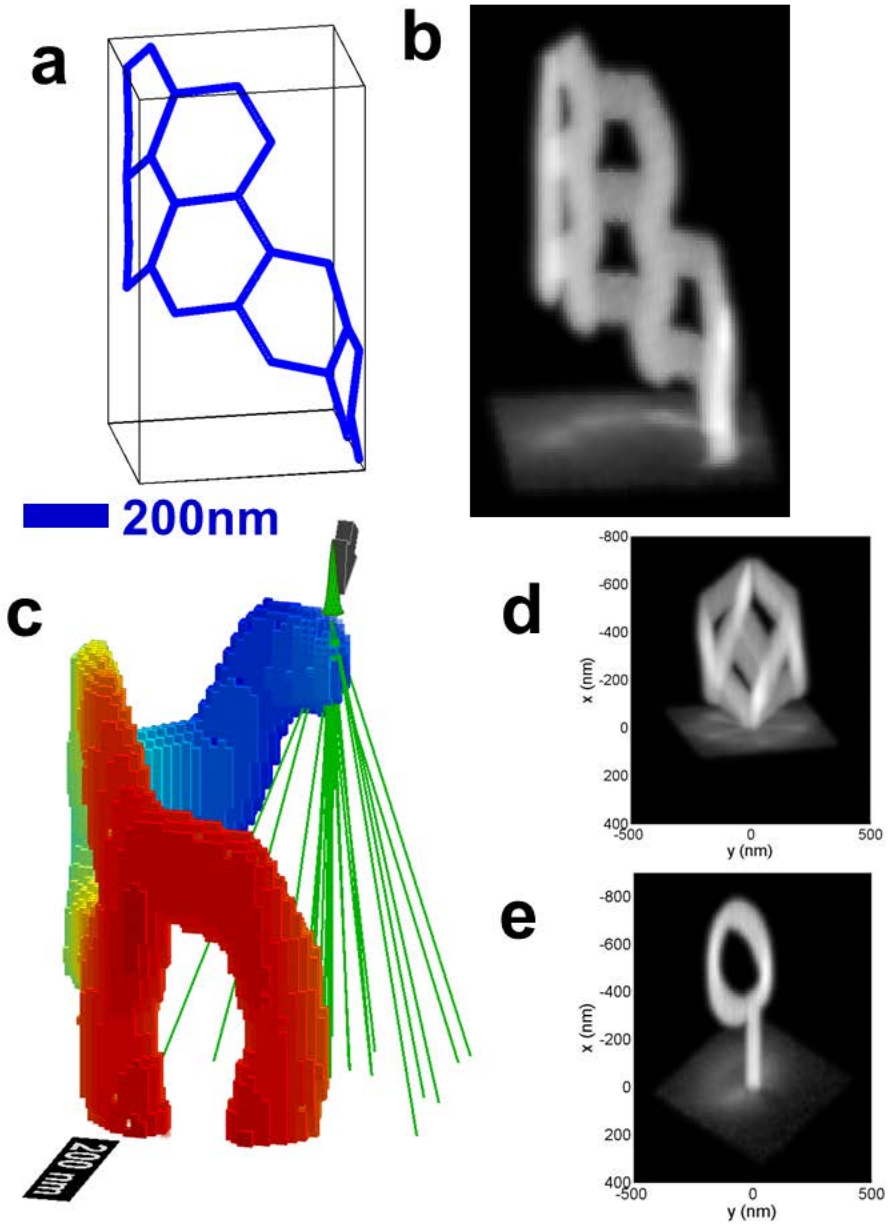

Figure 1 (a) A 3D object design for focused electron beam induced deposition (FEBID). (b) A virtual scanning electron microscope (SEM) image of the 3D FEBID simulation result for $Me_3Cp(Pt^{IV})Me$ deposition at 30keV and 21pA. (c) The deposit surface in cubic voxels midway through the FEBID simulation. The beam impact point is indicated by the green Gaussian pulse and select electron trajectories are superimposed on the object as green paths. The precursor gas flux vector is shown as the grey arrow. The surface voxel color shading changes with depth into the page. Additional objects simulated include (d) a 3D icosahedron and (e) a suspended ring.

Laser-Assisted Focused Electron and Ion Beam Induced Processing

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Focused electron and ion beam induced processing are direct-write nanoscale synthesis techniques that use focused charged particle beams to deposit and etch materials via directed chemical reactions at a substrate/precursor/electron or ion intersection. One major obstacle is that the typical organometallic precursors are not fully dissociated by the beam and unwanted carbon ligands are incorporated into the deposit. In the first part of the presentation we will overview our recent research using laser and post-electron exposure to purify electron beam induced deposits using the *MeCpPt(IV)Me$_3$* precursor. Next, we will overview or recent He^+ and Ne^+ ion beam induced nanoscale processing research. The He+/Ne+ gas field ion source has been extensively studied as an alternative ion source to the standard liquid Ga^+ source. While superior imaging and nanomachining resolution has been achieved, perhaps the Achilles heel of higher exposure dose nanomachining operations is the cumulative damage that occurs beneath the region of interest. To this end, we have developed a laser-assisted focused He^+ and Ne^+ beam induced process in which a pulsed laser photothermally facilitates the helium diffusion, and for instance silicon interstitial/vacancy recombination, and thus inhibits the amorphization and the nanobubble formation. Futhermore, we have recently studied gas-assisted and laser-gas(XeF_2)-assisted He^+ etching and have realized both reduced swelling as well as enhanced etch rates for titanium thin films. We will overview the processing parameters and the ion/photon/reactive gas fluxes that lead to both damage mitigation as well as laser- and gas-assisted etching.

Scanning Transmission Electron Microscope Based Lithography: Approaching Atomic Scale Assembly

Stephen Jesse

Aberration Corrected Scanning Transmission Electron Microscopy (STEM) has enabled angstrom resolution imaging and spectroscopy of materials revealing the real space configuration of atomic structure. In these instruments, the scanned electron beam is focused to a region smaller than the spacing between atoms with electron energies on the order of 100 keV. While such intense beams offer unprecedented imaging capabilities, they can also induce transformations within materials under observation. These transformations are usually unwanted, and microscopists typically go to great lengths to avoid such 'damage'. Here I will present some recent work into exploring ways to use beam induced transformations to our advantage. That is, as a means to modify material in a desired way to create structures at the atomic scale. I will show examples of atomic layer-by-layer control of crystallization fronts, creation of single atom defects in 2D material, beam induced motion of dopant atoms, and focused electron beam induced deposition from liquid precursors using in-situ environmental STEM. An important aspect of this approach is that we can see transformation at the atomic scale while they are occurring. This therefore offers not only a pathway towards establishing feedback loops to tightly control material transformations, but also a new window into the mechanisms of material transformation at their fundamental length scales to yield a deeper understanding of material dynamics during phase and chemical changes.

Direct Laser Write Based on Two Photon Polymerization: From 3D CAD to Function

Nick Lavrik

Oak Ridge National Laboratory

Over the last decade, the direct laser write (DLW) techniques based on 2-photon polymerization have matured into user friendly commercially available tools that extend the concept of additive manufacturing into the nanoscale. Examples of such tools include a Photonic Professional GT system (Nanoscribe GmbH) that enables a researcher with facile and flexible means of fabricating arbitrary complex 3D elements with submicron fidelity.

The tutorial will present the main principles behind direct write fabrication using 2-photon polymerization while also demonstrating the step-by-step process of creating intricate 3D elements with various targeted functionalities. The workshop will demonstrate how to implement several types of functional elements starting with their 3D models compiled and evaluated in COMSOL. The participants will have an opportunity to follow a step-by-step process of compiling a 3D CAD model, preparing the CAD files for DLW and implementing them using the Photonic Professional GT tool.

We will also discuss the different direct write technologies available within the nanofabrication research lab focusing on their integration with more conventional wafer level processing. Participants are encouraged to prepare and bring COMSOL or STL files of their choice.

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