Dual-beam Focused Ion Beam: A Multifunctional Tool for Nanotechnology

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New materials are now being fabricated with greater geometric complexity and smaller feature sizes. Such complexity is inherent to most biomaterials and their synthetic analogues, as well as to nanotechnology. Beyond complexity, phenomena occurring on even smaller length scales often adversely affect performance and reliability. Foremost among these phenomena are interface properties within the composite materials, resulting in chemical and structural gradients. Understanding and improving the performance and durability of these systems requires high-resolution structural, chemical and geometric analysis of cross sections through the layers. The ability to perform such analysis on precisely located cross sections is one of the key attributes of the dual beam focused ion beam (FIB). This FIB system has been developed to combine the imaging capabilities of a typical scanning electron microscope (SEM) with the imaging and fabrication capabilities of a highly focused ion beam. As focused ion beam technology has advanced, focused ion beam systems have been gaining more attention as an alternative method for micro- and nano-scale machining and fabrication. Presently, the preparation of sections by mechanical polishing, dimpling and ion milling is either excessively time consuming or possible only with highly trained metrology experts or, in some cases, totally impossible. In other cases, the compliance of the constituents prevents the formation of undamaged/undistorted cross sections: certain shell-like biological structures exemplify this problem. The FIB system obviates these problems and also provides unique high precision etching and deposition for micromanipulation as well as imaging and analysis. This instrument provides unique capabilities for advanced materials research connected to nanoscale, biological, photonic and multifunctional materials.

The dual beam FIB offers unprecedented capability when new understanding requires that imaging be performed on cross sections made at precise geometric locations. This is essential at sites where failures are known to originate**.** Additionally, it may be used to cross-section through the exact center of an impression, or along planes parallel to a set of microstructural features. Standard methods are incapable of preparing cross sections with the requisite spatial precision. A number of novel imaging capabilities, recently developed for the SEM, may be used on cross sections created by the FIB to locate and identify the defects and microstructural features of interest. These imaging modes include Electron Beam Induced Current (EBIC), Orientation Imaging Microscopy (OIM) and Cathodoluminescence (CL). Each of these capabilities can be interfaced with the imaging column of the dual-beam FIB system.

The use of FIB technology has seen much application in research but its practical use in industry is yet to be determined. Challenges arise when the FIB is applied on the large scale because of the high doses that would be required and the relatively long fabrication times compared to equivalent lithography techniques. Efforts have been made to further develop FIB technology beyond current limitations to increase the usable resolution of the instrument so that work may be done around the 10 nm range reproducibly [1]. Investigations into its inspection, metrology, and failure analysis functions demonstrate its capability to self-diagnosis [1,2]. The direct write capability of the FIB has been applied using several different methods and compounds in order to cause deposition onto the surface [3,4]. Deposition using the FIB occurs through the introduction—by a gas feed system—of a cloud of atoms directly above the surface of the sample in the region of ion bombardment, a process know as chemical vapor deposition (CVD). Ion interaction volumes in the sample surface are similar to those of electrons and are important to understanding how the surface morphology can be modified by impacting ions and the energy thus imparted. While the energy of the incoming ion beam could cause the sputtering of atoms from the surface, it could also be used to "push" atoms, near the sample surface, onto the surface, creating a deposited feature. Direct-write capabilities and more precise and accurate FIBs offer the possibility of creating usable nano-scale structures controllably and reproducibly. This paper presents some of the potential of the dual beam FIB as well as of the FIB as a general, multifunctional tool.

References

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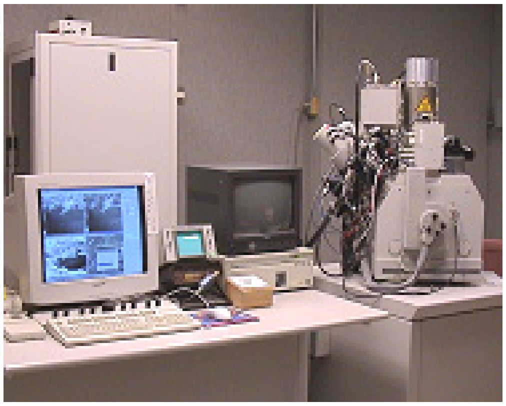

FIG. 1. The FEI Strata^{TM} DB 235 at the Princeton Materials Institute incorporates both a focused gallium ion beam as well as a scanning electron microscope. The SEM column is above the chamber while the ion beam column is attached towards the side at 52° angle. The precision provided by the exactness of the ion beam machining and the high resolution imaging of the SEM provide the ability to prepare various samples and to perform *in situ* fabrication with observation.