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The Tri-Beam System: Femtosecond Laser Based Tomography in a Dual-Beam FIB

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Acquisition of 3D datasets often requires compromise to strike the balance between resolution, type of data needed, and dataset size. Although many types of 3D tomographic techniques exist, there are still challenges with regard to acquisition rate, resolution, and the amount of material that can be characterized. As such, some material problems are still out of reach of current tomographic techniques. Recently, it was shown by Echlin *et al* [1] that a femtosecond laser can be used to ablate material at 4-5 orders of magnitude faster than traditional serial sectioning techniques [2] (see Table 1). The previously developed femtosecond laser based tomographic technique operates in open atmosphere and therefore is constrained to the collection of optical images and chemical information using laser induced breakdown spectroscopy (LIBS).

Building upon the unique capabilities of the previously developed femtosecond laser based technique, this research addresses the development of a new Tri-beam system. In this technique, we have coupled the femtosecond laser with a dual-beam FIB/SEM, figure 1. As a result, we are able to achieve the high spatial resolutions typical of FIB tomography (20nm) [3] while maintaining the high material removal rate shown by the femtosecond laser based sectioning technique (10^4 – 10^5 $\mu m^3/s$) [1]. Therefore, the Tri-beam system allows the user to address a variety of materials problems ranging from the nm to the mm lengthscale. Furthermore, similar to FIB tomography in [4], the Tri-beam system has been equipped with an electron backscatter diffraction detector (EBSD) and energy dispersive spectroscopy detector (EDS), which allow the collection of precise crystallographic and chemical information. These tools have been successfully combined to enable the fully automated serial sectioning of large volume multi-modal datasets (near mm^3) with high imaging and sectioning resolutions (see Table 1).

References

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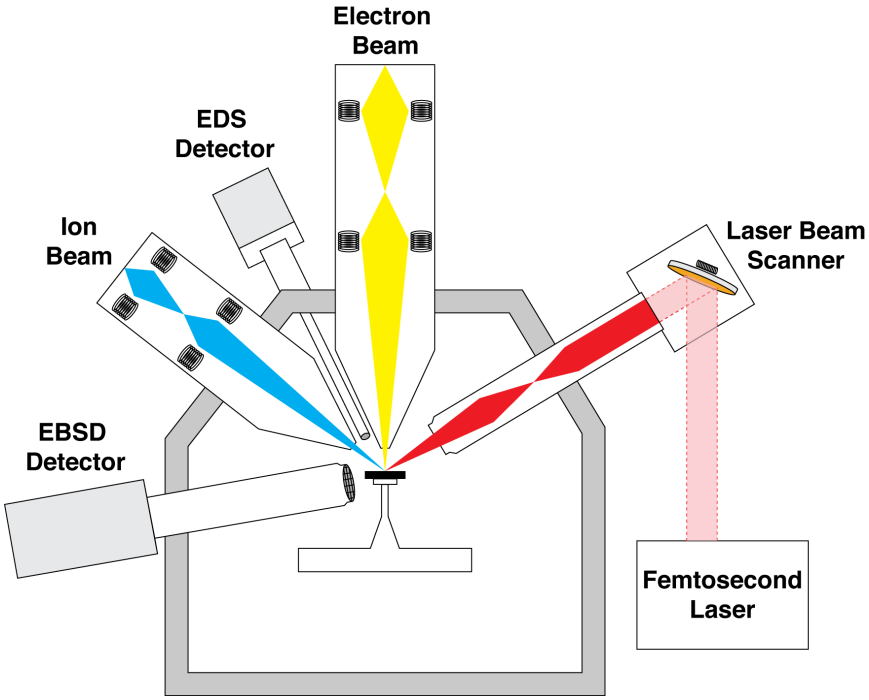

FIGURE 1. Tri-Beam system schematic. A dual-beam FIB modified to introduce a focused femtosecond laser beam into the vacuum chamber. Twin axis Galvonometer scanners are used to scan the laser beam on the sample surface at eucentric electron/ion/laser beam focus.

TABLE 1. Comparison of serial sectioning techniques that use mechanical polishing (Robomet.3D), focused ion beam (FIB-SS), or femtosecond laser (FSL-SS and Tri-beam system) to incrementally remove slices of material.

	Material Removal Rate $\mu m^3/s$	Resolution (X, Y) nm	Resolution (Z) nm	EDS/EBSD Analysis
Robomet 3D	200	250	100 - 2700	No
FIB-SS	0.5	10 - 30	5 - 100	Yes
Optical FSL-SS	10,000 - 100,000	250	20 - 150	No
Tri-beam system	10,000 - 100,000	10 - 30	20 - 150	Yes

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