In-situ femtosecond pulsed laser ablation for large volume 3D analysis in scanning electron microscope systems

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With the trend to perform 3D “slice and inspect” analysis of increasingly larger samples in scanning electron microscope systems, focused ion beam milling is rapidly becoming the bottleneck to obtain results in a reasonable timeframe. Typical ablation rates for a Ga^+ focused ion beam (FIB) are on the order of 20 $\mu m^3/s$, while that for a Xe^+ plasma focused ion beam (PFIB) are up to 400 $\mu m^3/s$. Ultrashort pulsed laser (UPL) ablation in the femtosecond regime can achieve material removal rates of up to 10^5 $\mu m^3/s$. A benefit of using a femtosecond pulsed beam rather than a picosecond or nanosecond pulsed beam is that the thermal transient experienced adjacent the ablation site is minimal.

We have previously reported results using an early prototype of a combined Ga^+ FIB and UPL system [1]. Our latest TripleBeam prototype tool combines a Xe^+ plasma focused ion beam (PFIB) DualBeam scanning electron microscope (SEM) with an UPL beam at 1030 or 515 nm. The UPL beam is introduced into the DualBeam chamber using a custom designed port such that the beam is focused at the tool eucentric point. This configuration allows rapid electron beam inspection of UPL ablated surfaces without moving the sample, providing straightforward incorporation into automated slice-and-inspect workflows such as large volume 3D electron backscatter diffraction (EBSD).

In this contribution we will present our latest results from UPL processing of samples for 3D analysis using our TripleBeam prototype tool. Volumes of material at the mm^3-scale can be processed, as shown in Figure 1, due to the large field of view of the optics and beam scanning system. Targeted features have also been identified and analyzed by extracting large volumes of material, such as in Figure 2. Here a subsurface cross-section face beneath a solder bump was revealed in tens of minutes, permitting subsequent cross-section SEM analysis and transmission electron microscopy (TEM) sample lift-out. Reconstruction of 3D metallic grain structures by electron backscatter diffraction (EBSD) are shown in Figure 3, accessible due to the fast UPL material removal rate and minimal damage due to the ablation process.

[1] M. P. Echlin *et al.*, Materials Characterization 100 (2015) 1—12.

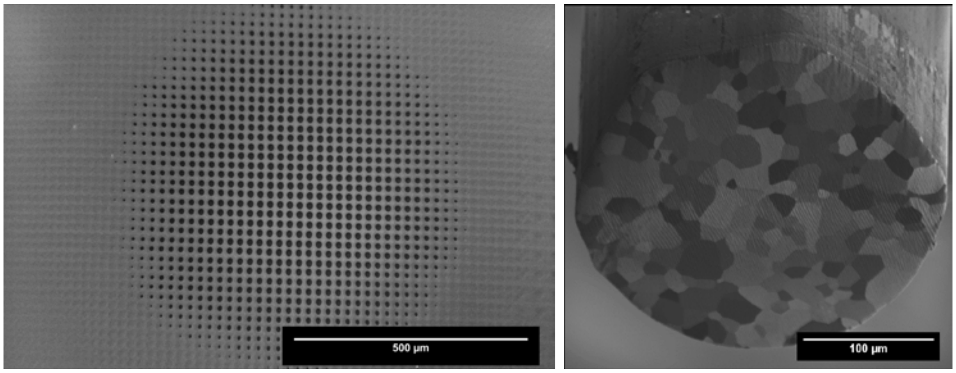

Figure 1: (Left) Scan field single shot array in silicon, showing the large range of beam steering available for material ablation without distorting the focused spot shape and without moving the sample stage. (Right) Platinum wire cut in less than a minute with UPL, as-ablated (no post-laser cleanup), imaged with Xe^{+} PFIB.

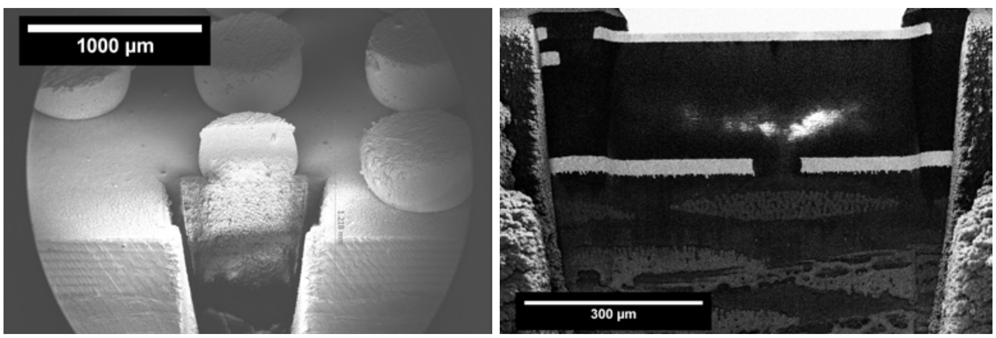

Figure 2: Cross-section face beneath a solder bump within an Nvidia GPU package. Left image shows initial UPL cut, right image shows first cross-section (UPL only, without FIB polish). This demonstrates targeting of buried features in materials for subsequent SEM or TEM analysis. HFW on left is 2.81 mm, depth of cut is over a millimeter.

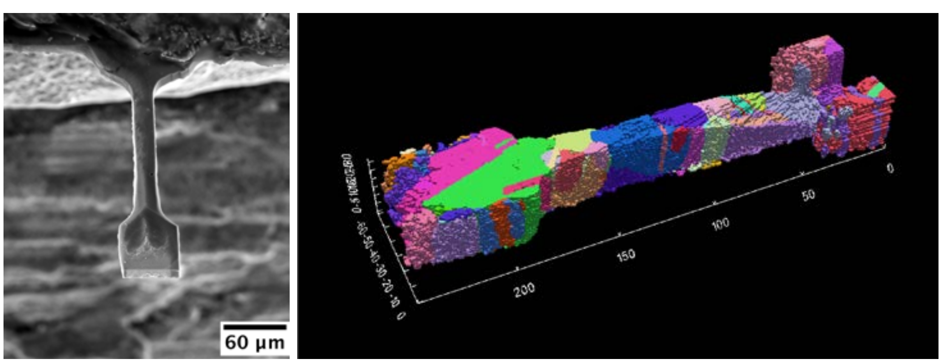

Figure 3: Reconstruction of 3D metallic grain structures by electron backscatter diffraction (EBSD) in a micro-tensile test sample, accessible due to the fast UPL material removal rate and minimal damage due to the ablation process. In most materials the surface quality and damage to the ablated surface is low, permitting EBSD mapping without additional ion beam polishing.