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Circumferential FIB Milling for Lift-Out Specimens

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Ex-situ and in-situ lift-out specimens prepared by FIB milling have been subsequently analyzed via SEM, , STEM, SIMS, Auger, XPS, TEM, atom probe, and other methods [1-3]. The basic FIB milling techniques and methods for lift-out procedures have not changed very much since their first inception. Ways to increase specimen preparation throughput, efficiency, quality, and success rates are to (i) use a higher current density FIB source, or (ii) use different FIB milling algorithms. We will focus on the latter in this study.

An understanding of ion-solid interactions can be used to maximize FIB milling results [4]. For example, it is well known that the ion sputter yield increases as the incident angle increases. Thus, for a given target, the sputter rate, and therefore specimen preparation throughput, will increase when FIB milling with the ion beam close to parallel to a specimen edge rather than FIB milling with the beam perpendicular to a target surface. This fact is the basis for the so called "cleaning cross-section" FIB milling algorithm that is standard on FEI FIB and DualBeam systems. We can therefore extend this type of milling behavior by scripting a set of circular FIB cuts such that each beam position overlaps a previous edge position extending from the outer diameter to an inner diameter toward the region of interest using just one aperture setting (i.e., 20 nA) [5]. Since the ion beam always mills on an edge or specimen sidewall, this increases the sputter yield (i.e., throughput) and yields a deeper trench toward the region of interest (e.g., see Fig. 1,2). This type of first cut also reduces redeposition artifacts that may cause sputtered material to re-attach to the specimen or to close up trenches or holes already FIB milled. For this first cut, any series of circumferential cuts could be made such that any shape (e.g., circle, oval, square, triangle, octagon, freeform, or polygon) could be left standing.

A 2nd FIB mill cut is then made at an angle to undercut the freestanding sample by totally releasing it from the bulk material as also shown in Fig. 1 and Fig. 2. Depending on the depth of the 1st cut and its outer diameter, the 2nd cut can be started either outside or inside the original cut as shown in either Fig. 1 or Fig. 2 respectively. The resulting combination of the pillar and bowl structure reduces the chance of the sample falling over or out of the cut area when it is released. Once the sample is cut free, it can be lifted-out and manipulated using e.g., the conventional Omniprobe in-situ lift-out techniques. Fig. 3 shows the lift-out sample after manipulation to a TEM grid. For an ex-situ lift-out sample, the 1st circular cut can be performed, then the center portion of the specimen can be polished or FIB milled to a desired shape or thickness. Then the sample can be tilted and undercut free, and/or it can be removed from the chamber system to an ex-situ manipulator station where the specimen can be lifted-out and manipulated for future analysis as necessary.

References

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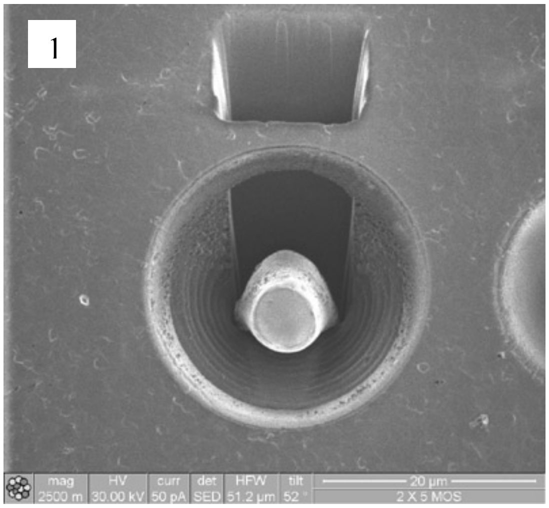

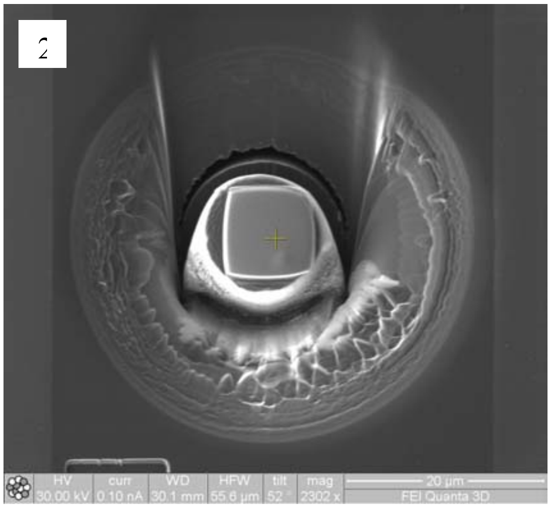

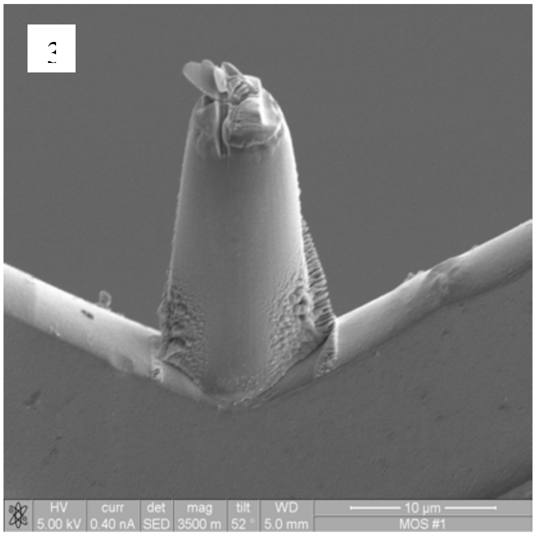

Fig. 1. Circumferential FIB milling example showing initial cut and release cut outside of outer diameter.
Fig. 2. Circumferential FIB milling example showing initial cut and release cut inside of outer diameter.
Fig. 3. In-situ lift-out sample after manipulated to a grid.