HIGH THROUGHPUT FIB IN-SITU TEM SAMPLE PREPARATION

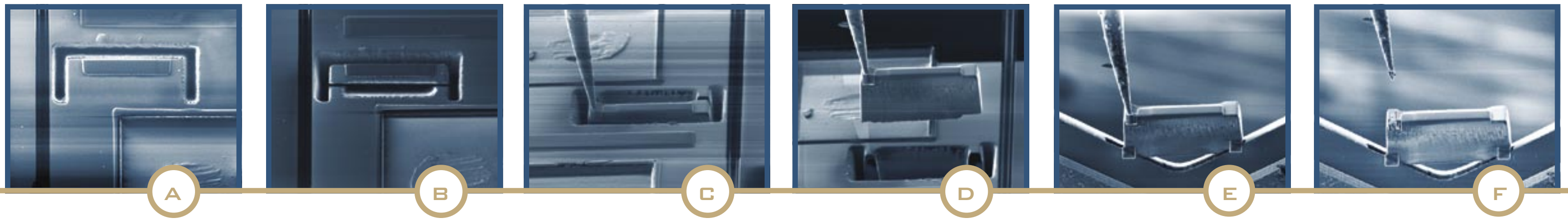

FIG.1 Typical steps of in-situ lift-out with the Total Release™ method. A) first cut; B) release cut; C) tip attach; D) extraction; E) holder attach; F) and tip separation.

In 1965, Gordon Moore forecast that the microprocessor industry would continually scale to smaller feature sizes and the number of transistors would double every 18 months. Scaling below the 100nm node, combined with the implementation of copper and low dielectric constant insulators to reduce the RC time delay, has produced the situation in which SEM inspection no longer offers suitable resolution to image key artifacts and structures. The transmission electron microscope (TEM), once considered more of a development tool, is now in the forefront for process control and failure analysis, especially for measurements such as the thickness of non-planar barrier and seed layers.

The use of focused ion beam (FIB) microscopes has become the method of choice for site-specific TEM sample preparation. Originally, the FIB was used as a final thinning step for mechanically prepared ribbons of semiconductor material adhered to a modified TEM grids, known as the "H-Bar" method. More recently, Omniprobe's Total Release™ method was introduced for performing the entire TEM sample preparation process within the FIB. This method is known as "in-situ lift-out" and is based on the use of Omniprobe's AutoProbe™ 200 chamber-mounted nanomanipulator and beam-induced material deposition. The use of the Total Release™ method in the FIB offers advantages over conventional mechanical TEM sample preparation.

The AutoProbe™ 200 nanomanipulator system offers excellent mechanical stability and motion control, programmable movements and adopts the X-Y-Z frame of reference of the FIB stage. The dual-beam FIB offers the ability to locate the lift-out site with SEM resolution and then use the ion beam to excise the sample without sacrificing the wafer, followed by thinning the extracted sample to the thickness required for TEM inspection. This is especially attractive for 300mm processing where the value of each wafer in the flow can exceed $100,000. In-situ lift-out also enables the return of the mostly abandoned practice of including informative test die on product wafers.

Omniprobe's Total Release™ method for in-situ lift-out is designed to maximize throughput of a TEM sample preparation process. The method can be simplified into three successive steps (see Figure 1). [1,2] The first is is the excision of the lift-out sample using FIB milling and extraction of the sample from its trench with two rapid ion milling steps, or "cuts". The first cut is "U"-shaped and partially surrounds the target. The second is a straight cut that intersects the first cut beneath the target and produces a wedge-shaped sample. Then the probe is fixed to the released sample, typically with ion-beam metal deposition, and the sample is removed from the wafer by the nanomanipulator. The second step is the "holder-attach" step, during which the wedge is translated on the probe tip to a custom Omniprobe TEM sample holder, called a "lift-out grid". Then the sample is attached to the lift-out grid (again, typically with ion beam-induced metal deposition) and later detached from the probe tip point using FIB milling. The third and final step is the thinning of the wedge into an electron-transparent thin section using FIB milling.

The Total Release™ method has several attractive features for a high-throughput TEM sample preparation process. It requires a minimum of ion milling to excise the sample and provides reliable and protected transport of the sample. It allows for instant and definitive indication that the sample release procedure has been completed successfully, thus saving time. If pressure is applied by the probe tip to the sample during the final milling procedure, a change in mechanical load measured by a sensitive strain gauge inside the Omniprobe's AutoSense™ probe shaft can be used to indicate that the sample release procedure has been successfully completed. The AutoSense™ probe shaft can also be used to detect contact between the tip of the probe and the sample in an automated process. Such a detection method is independent of electrical continuity effects and functions efficiently with a fine probe tip on any type of sample surface. Since the probe tip is not attached to the sample prior to total release, a premature lift-out attempt can be avoided, and re-deposition in the initial stage of the lift-out process can be more easily cleared without having to detach the probe tip.

The throughput advantages of the Total Release™ method can be augmented by an improvement in sample handling that eliminates the need for the holder attach step. A significant portion of the total time is involved in completing this step. The relative amount of time involved depends on the amount of time required to mechanically isolate the lift-out sample from the initial bulk sample (material-dependent ion beam milling rate), and will vary between 30% to 60% of the total time for TEM sample preparation. However, Omniprobe's Short-Cut™ system provides direct mechanical conversion of the lift-out sample to TEM sample holder. This method eliminates the holder-attach step and provides several key throughput and resource advantages (The Short-Cut™ system is demonstrated in Figures 2 through 5). For example, the semiconductor wafer can be returned to the process flow immediately after lift-out. Thinning of the sample can be performed immediately, or later in an off-line FIB. The use of the off-line FIB for final thinning reduces the load on the critical in-line (clean room) FIB and is well suited for an automated sample preparation procedure. Omniprobe's Short-Cut™ system provides rapid, low cost and robust bonding of the probe tip point to the standard 3mm TEM holder. Coupons are available for both top-side and back-side thinning of the TEM sample.

As more semiconductor products migrate to sub-100nm geometries, the need for low- cost, high-throughput and site-specific TEM sample preparation will increase in importance. Omniprobe's Total Release™ method for TEM sample preparation provides an effective solution, and the Short-Cut™ system offers additional throughput advantages. This approach is particularly effective for high-throughput applications such as in-line process control, and maximizes the use of FIB resources in a process in which an in-line large-wafer dual-beam FIB is used to extract the lift-out samples, and an off-line small dual-beam FIB is used for final thinning of the TEM sample. In addition, Omniprobe's OmniGIS™ automated multi-gas injection system with feedback control adds a critical component for high-throughput process control.

[1] T.M. Moore et al., U.S. Patent 6420722.
[2] T.M. Moore, U.S. Patent 6570170.

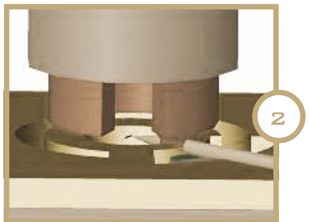

FIG.2 - A schematic of the press for mechanical conversion, the TEM holder coupon and the probe tip with sample attached.

FIG.3 - A schematic of the press for mechanical conversion, the TEM holder coupon & sample attached.

FIG.4 - Transfer of the FIB cassette with a lift-out sample to the mechanical conversion anvil.

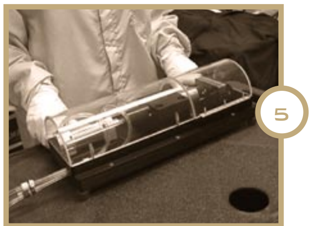

FIG.5 - Mechanical conversion of the lift-out sample to TEM sample.