Delayering of Microelectronic Devices Using an Adjustable Broad-Beam Ion Source

A C Robins, R R Cerchiara, P E Fischione, M F Boccabella, J M Matesa, L M Marsh and Z Zhang

E. A. Fischione Instruments, Inc., 9003 Corporate Circle, Export, PA 15632 USA

Email: rr_cerchiara@fischione.com

Abstract. Analysis of the integrated circuits of a microelectronic device depends on delayering. Focused ion beam (FIB) or broad ion beam (BIB) milling are effective complementary methods of delayering. FIB provides higher removal rates, but is limited in the effective area that can be revealed per unit time, while BIB provides lower removal rates, but has the advantage with respect to the size of the field of view produced. Microstructural features and the appearance of defects were identified and tracked for two model systems: Cu vias and Cu TSVs (through-silicon vias).

1. Introduction

Analysis of the integrated circuits of a microelectronic device depends on delayering. As the scale of the microstructure has decreased below the 32 nm node, the need for greater precision and planarity of the etched surface has increased. Options for rapid material removal include mechanical, plasma, and ion-based techniques. [1] Mechanical methods require the use of abrasives and lubricants that can produce residual contamination and damage.

Focused ion beam (FIB) or broad ion beam (BIB) milling are effective complementary methods of delayering. FIB provides higher removal rates, but is limited in the effective area (> 10 µm x 10 µm) that can be revealed per unit time. BIB provides lower removal rates, but has the advantage with respect to the size of the field of view (> 1 mm x 1 mm) produced.

2. Materials and methods

2.1. Materials

Dies containing Cu vias and Cu TSVs (through-silicon vias) were produced by proprietary processes.

2.2. Methods

A recently developed ion source technology was applied to the delayering process. [2] Adjusting (expanding) the diameter of the Ar ion beam at a given accelerating voltage (kV) allows areas to be planarized approaching 10 mm x 10 mm. An ion beam diameter of ~ 2 mm was used for the current tests detailed below. Laser detection of sample height permitted sample transfers between the ion milling instrument and the field emission scanning electron microscope (FESEM) without loss of the precise milling geometry. One or more ion sources were tilted to a low incident angle with respect to the plane of the given sample. A time series of FESEM images was acquired to document the
delayering process. Microstructural features and the appearance of defects were identified and tracked for two model systems: Cu vias and Cu TSVs (through-silicon vias).

3. Results and discussion

3.1. Cu vias
Following mechanical preparation, a cross-section was planarized by ion milling with the following parameters: single ion source, 4 kV, 7° incident angle, 45% focus, and ± 70° rocking angle for 45 minutes. 1 µm of Cu overburden was observed (see figure 1). After mounting an identical sample in plan-view, this overlayer was removed using the following optimized parameters: 2 ion sources, 4 kV, 4° incident angle, 45% focus, and 360° rotation for 34 minutes. Further ion milling at 30 seconds or 1 minute iterations with imaging in a field emission scanning electron microscope (FESEM) revealed voids that had been apparent in the cross-section.

![Figure 1. SEM images of Cu vias: Cross-sectional view before (A) and plan-views after (B, C, and D) removal of overburden.](image1)

3.2. Cu TSVs
Following mechanical preparation, a cross-section was planarized by ion milling with the following parameters: single ion source, 4 kV, 7° incident angle, 45% focus, and ± 55° rocking angle for 35 minutes. 2 µm of Cu overburden was observed (see figure 2). After mounting an identical sample in plan-view, the sample was delayered by ion milling with the following parameters: 2 ion sources, 4 kV, 5° incident angle, 45% focus, and 360° rotation. Changes in the microstructure of an individual TSV were tracked and the process terminated once the ion-milled surface was clearly below the terminus of an axial defect.

![Figure 2. SEM images of Cu TSVs: Cross-sectional view before (A) and plan-views after (B, C, and D) after removal of overburden.](image2)

3.3. Delayering plus FIB
After delayering, FIB can be used to create a site-specific cross-section of an individual defect. A typical scenario is presented in figure 3. An *in situ* FIB lift-out sample is obtained. Residual amorphization and implantation due to the interaction of the sample with Ga ions may occur during this process. Post-FIB clean up using the Model 1040 NanoMill® TEM specimen preparation system is the final step prior to imaging in a field emission transmission electron microscope (FETEM) [3].
**Figure 3.** FIB and post-FIB processing of a delayered microelectronic material.

**Summary**

An adjustable broad beam Ar ion source was used to delayer microelectronic materials. Overburden and defects were assessed in cross-section, then iterative ion milling and SEM imaging of Cu vias and TSVs produced corresponding microstructural information as a function of depth. FIB and post-FIB processing of an *in situ* lift-out sample can yield site-specific information concerning individual defects.
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