APPLICATIONOTE

Microelectronic device delayering using an adjustable broad-beam ion source

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: copper vias and copper through-silicon vias.

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.

Materials and methods

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

The Fischione Instruments Model 1060 SEM Mill was applied to the delayering process. [2] Adjusting (expanding) the diameter of the argon (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.

Results and discussion

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. A Cu overburden of 1 µm was observed (Figure 1). After mounting an identical sample in plan view, this overlayer was removed using the following optimized parameters: two 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

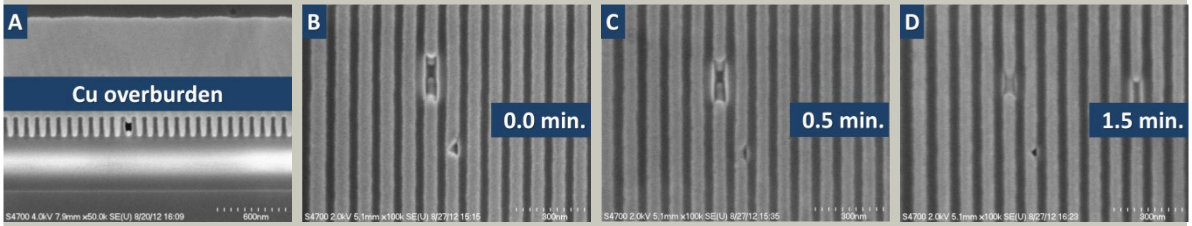

Figure 1. FESEM images of Cu vias: Cross-sectional view (A) before and plan views (B, C, and D) after removal of overburden.

electron microscope (FESEM) revealed voids that had been apparent in the cross section.

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. A Cu overburden of 2 µm was observed (Figure 2). After mounting an identical sample in plan view, the sample was delayered by ion milling with the following parameters: two 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.

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 gallium ions may occur during this process. Post-FIB clean up using the Fischione Instruments Model 1040 NanoMill® TEM specimen preparation system is the final step prior to imaging in a field emission transmission electron microscope (FETEM) [3].

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.

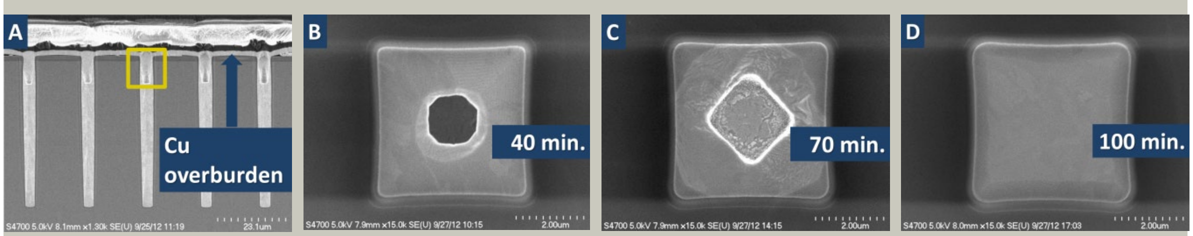

Figure 2. FESEM images of Cu TSVs: Cross-sectional view before (A) and plan views (B, C, and D) after removal of overburden.

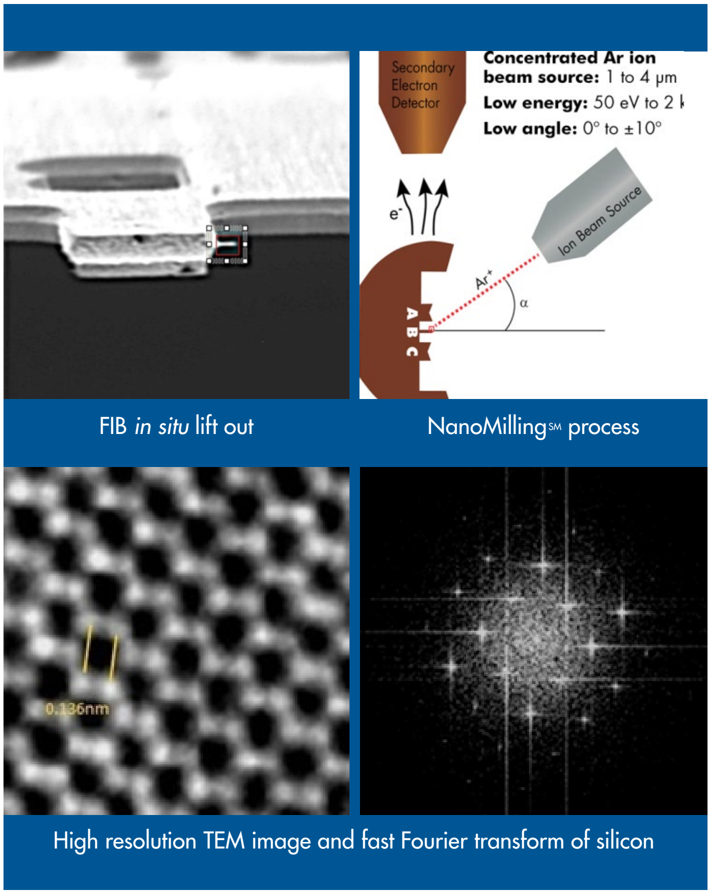

Figure 3. FIB and post-FIB processing of delayered microelectronic material.

Acknowledgements

The high resolution transmission electron microscope (TEM) image and fast Fourier transform of silicon are courtesy of Angus Kirkland and Crispin Hetherington, University of Oxford, UK.

References

[1] Torrance R, James D. Reverse Engineering in the Semiconductor Industry. In: CICC '07. Proceedings of the Custom Integrated Circuits Conference; 2007 Sep 16-19; San Jose. Los Alamitos (CA): IEEE; 2007. p. 429-436. doi:10.1109/CICC.2007.4405767

[2] Cerchiara R, Fischione P, Lange J, Woods P, Matesa J, Boccabella M, Robins A. Preparation of Materials for EBSD using an Adjustable Broad Beam Ion Source. Microsc Microanal. 2011;17 Suppl 2:390-391. doi:10.1017/S1431927611002820

[3] Cerchiara R, Fischione P, Liu J, Matesa J, Robins A, Fraser H, Genc A. Raising the Standard of Specimen Preparation for Aberration-Corrected TEM and STEM. Micros Today. 2011;19(1):16-19. doi:10.1017/S1551929510001197

E.A. Fischione Instruments, Inc.
9003 Corporate Circle
Export, PA 15632 USA
Tel: +1 724.325.5444
Fax: +1 724.325.5443
info@fischione.com
www.fischione.com

Document Number AN004 Revision 00 09/2013