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In-situ Low Energy Argon Ion Milling of Nanoelectronic Structures Using a Triple Beam System

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Sample preparation is a critical step in TEM that significantly determines the quality of structural characterization and chemical analysis of the smallest and most critical structures in semiconductor manufacturing. In recent years, the accuracy requirements for the preparation of TEM cross-sections of nanoelectronic structures have drastically increased, and the rapid advance in TEM technology has demanded the highest standards of sample quality. Combination of a focused low-energy Ar ion beam column with a FIB and a SEM column in a triple beam instrument provides precise positioning as well as minimum thickness, surface damage and roughness of a lamella.

Two beam SEM/FIB instruments offer high quality site specific TEM sample preparation with high throughput and precision [1]. However, using high-energy (typically 30kV) Ga ions modifies the specimen by implanting Ga, and by structurally altering the material in a layer that extends up to 30nm beneath the surface. As the damage layer thickness is in the same range as the maximum specimen thickness required for high resolution TEM [2], TEM image quality and analysis sensitivity are degraded. The Ga contaminated damage layer can be reduced to some extent in a final milling step using the focused Ga ion beam at low voltage (2-5kV), but it can be completely removed and the specimen be further thinned using low-energy (<2kV) Ar ion polishing [3]. While Ar polishing has typically been done using a broad Ar ion beam in a dedicated preparation tool, the system used here combines SEM and FIB with a small diameter low energy scanning Ar ion beam (500-1000V, 10nA, diameter ≈100µm) within a single instrument. The three beams are coincident on the sample surface so that the polishing process can be precisely controlled by real time SEM imaging (Fig. 1).

Optimum process parameters for preparing TEM samples of advanced CMOS devices, like milling rates and their dependency on the Ar incidence angle, were determined for the triple beam system within a long-term collaboration project between the equipment manufacturer and semiconductor industry. In this study, we show at cross-sections of TEM lamellas that the 20nm thick damage layer in Si after 30kv Ga ion milling is reduced to <3nm applying in-situ Ar polishing (Fig. 2). High resolution TEM image quality is greatly improved and provides, e.g., more precise characterization of ultrathin films and interfaces in high-k metal oxide/metal gate layer stacks. AES depth profiling shows the reduction of Ga contamination by Ar ion polishing. Thus, in-situ Ar polishing provides the TEM lamella quality that is needed for metrology and failure analysis of nanoelectronic products manufactured in future technology nodes. Further possible applications of such a system include, e.g., delineation etching of cross-sections under visual control for SEM imaging.

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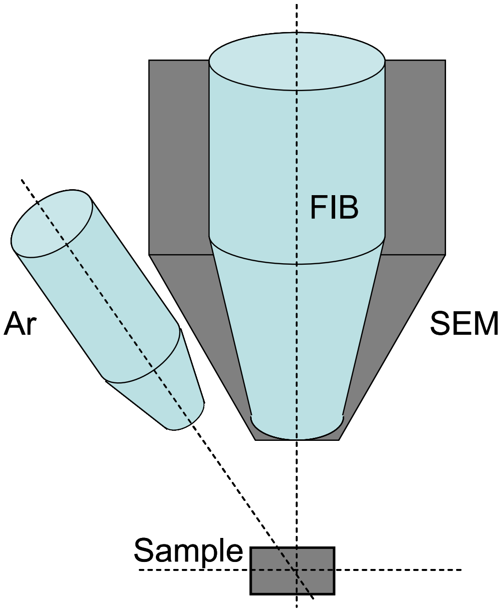

Fig. 1. Coincidence geometry of the triple beam system.

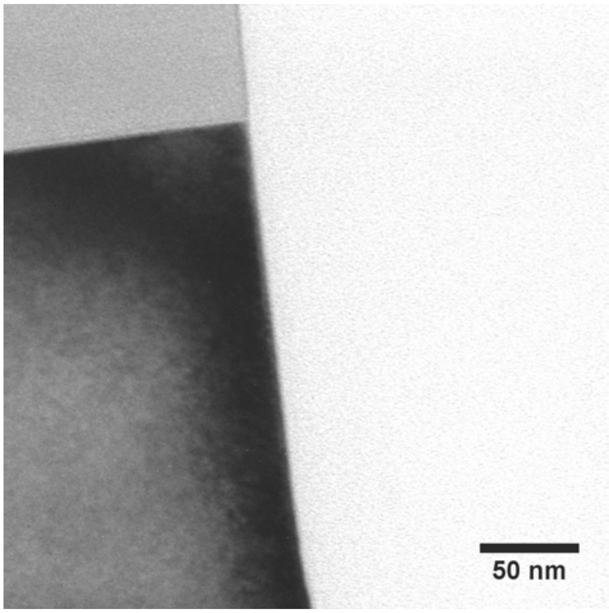

Fig. 2. TEM brightfield image of a cross-section of a TEM lamella (dark area to the left: Si, bright area top left: SiO2 cap layer) polished with 1kV Ar+ ions at 3° incidence to the lamella surface. No significant amorphization zone is visible at the surface.