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Advances in Sample Preparation of Semiconductor Devices for Electron Microscopy

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In recent years, many advances have been made in conventional sample preparation and focused ion beam (FIB) preparation for electron microscopy. Improvements include the preparation quality, the accuracy of site-specific preparation, and the preparation time. The preparation time plays an important role in the semiconductor industry. The FIB technique ensures a target preparation of a semiconductor structure for TEM examination within 1 to 4 hours [1]. The main advantages of this method are the high accuracy and the very low preparation time compared to conventional ion milling techniques. Nevertheless, FIB also has some disadvantages especially due to the heavy Ga ions used for the milling process. The interaction between the incident Ga ions and the sample material leads to surface amorphization of about 20 nm on each side [2],[3]. This makes preparation of high quality HRTEM samples very difficult. To solve the problem, FIB users are looking for a method to reduce the damaged area as well as lamella thickness. One possible way is the combination of FIB processing with conventional low energy, broad beam, ion milling. The conventional milling reduces the damaged surface areas. However, the additional milling generates contamination due to the "H" geometry created by the FIB processing. To overcome this problem we have developed a special method based on broad beam ion milling that can be fully automated. An alternating milling of both sides of the sample with the same ion gun suppresses the contamination even for the "H" geometry. We are able to reduce the thickness of both the damaged surface area and the lamella. Ion energy, milling angle, frequency of changing the direction of ion incidence and milling time can be preset and depend on the sample to be prepared. The method can be carried out with the RES 100 using the programming mode, and different parameter sets can be saved as recipes. The process is time-saving, reproducible, and does not necessitate operator intervention.

Another preparation technique that we have developed involves the use of the wire-shadowing method [4],[5] to achieve site-specific cross-sectional TEM samples of semiconductor material in a short period that is free of damage. To facilitate the technique we used mechanically pre-prepared samples with a thickness range between 10 μm and 20 μm. A wire or fiber was glued on the top of the sample above the structure of interest. The wire and the uncovered sections were then removed during milling. We milled the samples with perpendicular ion incidence with respect to the sample surface until the wire almost disappeared. The sample becomes highly electron-transparent directly under the remnant wire and tapers off slightly, below this point down to the depth of the milled section. The sample was oscillated during the milling to avoid preferred milling structures and minimize shadowing effects. To control the progress of milling we used a combination of a conventional milling system with a SEM [6]. This allows *in-situ* monitoring of the preparation process and ensures termination at the appropriate time. Fig. 1 shows *in-situ* cross-sectional SEM images of a sample with the wire on the top and the exposed structures of interest. The finished sample is shown in Fig. 2 and 3. It is a wedge with an electron transparent area of a few hundred microns in length. We could achieve very clean and sharply wedged samples in a milling time between 1 and 1.5 hours. Due to the nearly parallel ion incidence the milled surfaces are almost free of damage.

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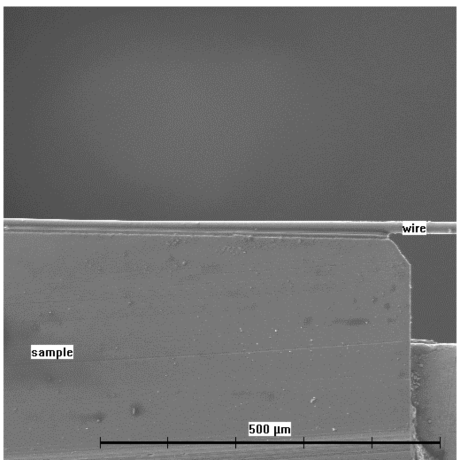

FIG.1a

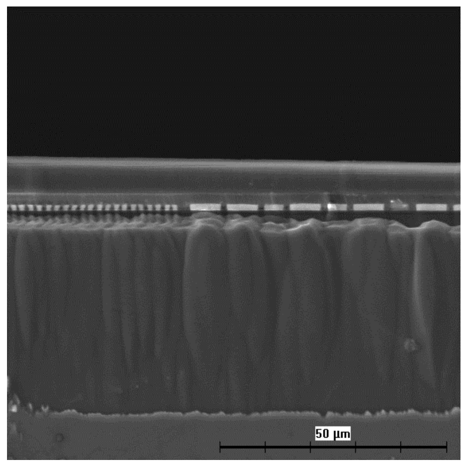

FIG1b

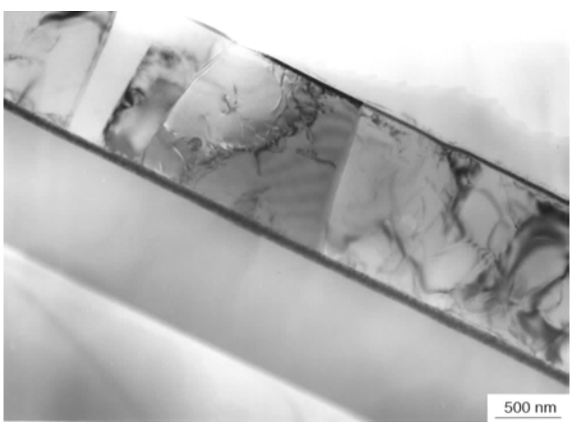

FIG.2

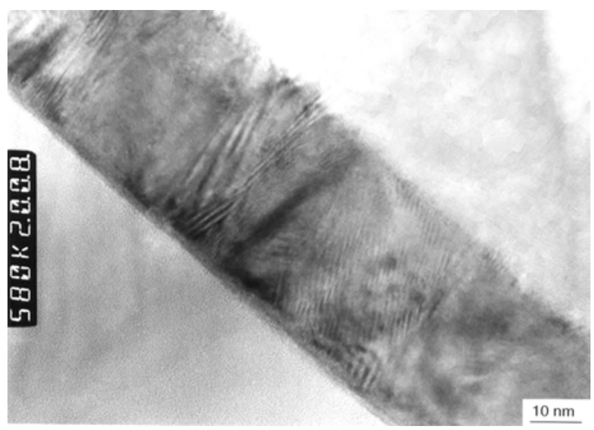

FIG.3

FIG. 1. In-situ SEM images of a sample protected with a wire on top before (FIG. 1a) and during the preparation (FIG. 1b with exposed structure) using the wire-shadowing method
FIG. 2. TEM cross-sectional image of the completely prepared sample
FIG. 3. TEM cross-sectional image of the lower intermediate layer

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