Usefulness of low voltage ion milling in the preparation of TEM lamellae in microelectronic industry

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Transmission electron microscopy is widely used in the microelectronics field to achieve precise physical and chemical characterization, and to identify the root cause of electrical failures [1,2]. Regarding TEM experiment, the object under study requires to be thinned enough so as to be transparent to the electron waves. In microelectronics fields, TEM samples are usually thinned via Focus Ion Beam technique (FIB). This way, 100 nm thick TEM lamellae can be prepared. Nevertheless, some artefacts mainly ruled by ions implantation can modify the structural order by inducing some phase transition from a crystalline compound to an amorphous one. Due to the energy of FIB instrument, depending on the tension applied, ions bombardments usually promote collision cascade, mixing and recoils implantation [3]. This leads to the creation of lacuna, interstitials, and disorder at higher doses. While amorphization usually occurs on lamellae surfaces, this can induce imaging artefacts such as some blurred interfaces. Furthermore, ions implantation induced by FIB can generate locally an increase of the temperature distribution [4]. In the case of materials crystallizing in metastable phases, FIB effect could provoke phase transition. Consequently, damages promoted by FIB process can alter the material and thus limit the characterization or even induce inaccurate results. To overcome this problem, the use of low energy voltage could hence reduce damage. New FIB system gives the possibility to clean TEM lamellae using low voltages down to 500 eV. However, for certain sensitive materials such as indium or tellurium, sample preparation requires a specific study to overcome any damages. Another way would consist of using light element ions at low voltage [5]. In this study, we demonstrate that the use of argon ion as ion milling accelerated at low voltage, typically 300 eV, significantly reduces amorphization induced by FIB. TEM micrograph of backend region, illustrated in figure 1a, shows some sharp interfaces between SiO/SiN layers for a TEM lamella. This blurred effect is actually related to surface amorphization during FIB sample preparation. However, the use of argon ion milling post FIB, as seen in figure 1b, enhances the image quality and allows to distinguish clearer interfaces. This improvement is related to the cleaning of amorphous layers owing to argon ion milling. Finally, this Ar cleaning enables accurate measurements of this specimen (Fig 1b). Other experiments indicate that the use of argon milling at low voltage improves the thinning at the interface of W contact with TiN barrier. Indeed, as seen in figure 2, EELS analysis of TiN barrier does not identify any nitrogen content post FIB preparation. Certainly, this is mainly ruled by relief transfer artefacts. However, as illustrated in figure 2b, using low voltage argon enables to thin this area. First of all, the STEM image appears cleaner, and the TiN layer is clearly identified. Moreover, this thinning allows to point out a nitrogen content, as displayed on Fig2 b at nitrogen edge. Others experiments (not shown here), revealed that argon ion milling post FIB enables to prevent any structural damages by conserving metastable phase of TiSi. Furthermore, GeSbTe sample preparation using FIB and cleaned by argon ion milling evidenced a clear conservation of the structural order.

Therefore, we reported here the improvement of TEM lamellae cleaned by argon ion milling, leading to the improvement of characterization of thin interfaces and the significant utility to thin any sensitive material by preventing from any amorphization and thus conserving the local structural order.

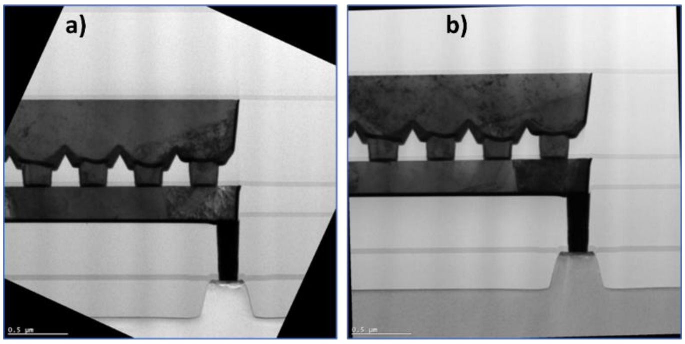

Figure 1a) Backend TEM micrograph prepared by 16 keV FIB, B) TEM micrograph of the sample cleaned by Ar ion milling

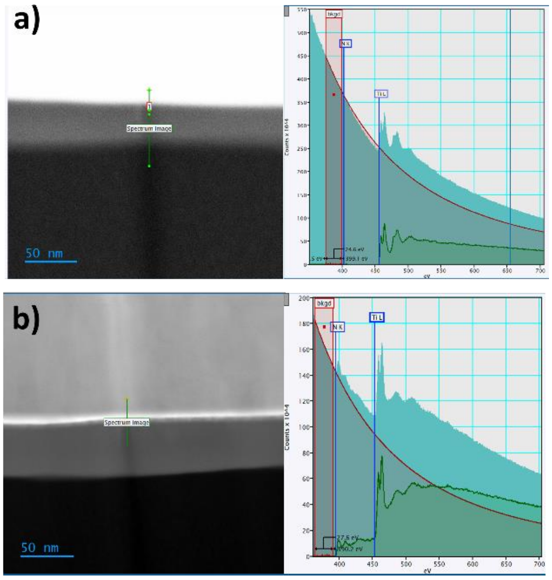

Figure 2 1a) STEM mircograph prepared by 16 keV FIB and its associated EELS spectra at nitrogen k and Ti L2,3 edges B) STEM micrograph of the sample cleaning by Ar ion milling and its EELS spectra of TiN interfaces

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