Focused ion beam analysis of Cu/low-k metallization structures

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The introduction of Cu metallisation with low-k dielectric materials in the new generations of electronic devices requires the investigation of the properties of these materials during the different application modes of the Focused Ion Beam (FIB) analysis, i.e. cross-section imaging for process development and failure analysis, preparation of specimens for transmission electron microscopy, and device modification. With the decreasing feature sizes the application of dual beam FIB and TEM of FIB prepared samples becomes more and more important.

Cu has a high secondary electron yield during the Ga ion imaging and the ion beam quickly removes the native oxide. Therefore excellent channeling contrast can be obtained and applied to studies of the spontaneous or annealing induced Cu grain growth, via and trench filling, and voltage contrast analysis of shorts in devices. Some examples related to process developments and failure analysis will be discussed.

Different classes of low-k materials can be distinguished, i.e. organic polymers, porous oxides and carbon doped oxides (Si-O-C). The organic low-k materials immediately show a FIB-contrast reversal indicative of the formation of a conductive surface layer by the damage and the Ga introduced by the ion beam (Fig. 1). This behavior, which is of concern for device editing applications, will be examined for some low-k dielectrics.

The FIB milling technique is a major choice for specimen preparation for transmission electron microscopy (TEM) of devices with low-k materials as these are soft and therefore are easily deformed by the conventional preparation procedures for TEM specimens, which involve mechanical polishing techniques. Data on the thickness variations induced by the different sputter rates of the harder and softer materials in the Cu/low-k structures will be discussed (Fig. 2).

For device modifications, the behaviour of the Cu and low-k materials during gas assisted etching, i.e. their selectivities, enhancements, and etch rates are important. Data on some relevant materials will be discussed. The possibility to reveal the layer stack from the sample current will be shown for some multilayer stacks using different gas chemistries (Fig. 3).

Cu shows a severe in-situ corrosion when exposed to I_2, which is the commonly used gas for cutting of Al metal lines. Furthermore, this corrosion has a long memory effect due to I_2 absorbed in the system so that any Cu related FIB work is incompatible with the use of I_2 in the system.

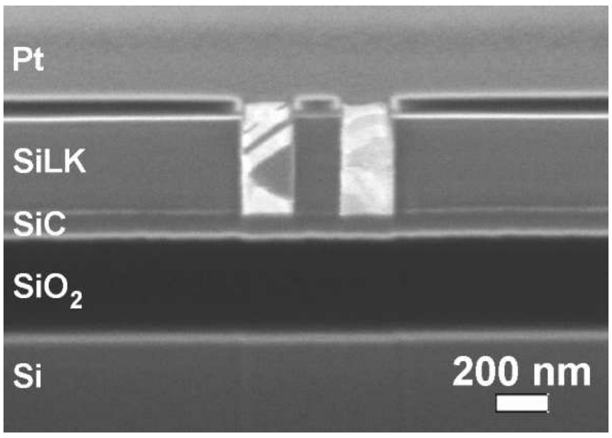

Fig. 1 : FIB cross-section image through a Cu line structure with SiLK^{TM} (organic polymer, Dow Chemical Corporation) and SiO_2 dielectrics. The SiLK and SiC etch stop layer immediately show a gray contrast indicative of a conductive surface induced by the ion milling.

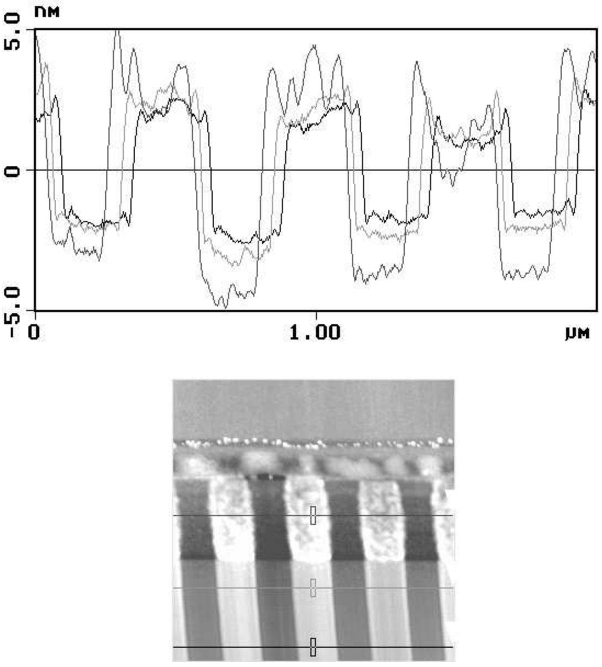

Fig. 2 : AFM linescans over the face of a FIB-prepared TEM specimen prepared of a Cu/porous SiOC structure.

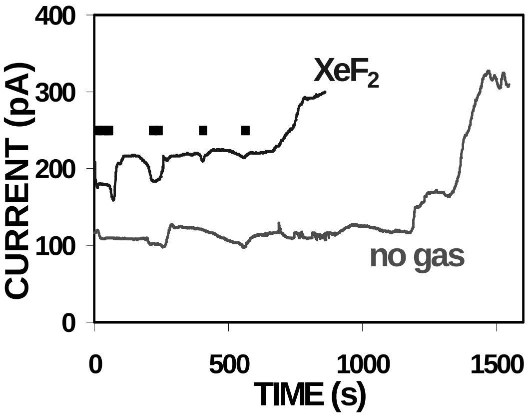

Fig. 3 : Specimen current versus etching time for the milling of a 5x5 µm^2 via through a 6 layer SiO_2/SiLK stack with and without XeF_2. The black boxes mark the position of the resolved oxide layers for the XeF_2 curve. (The curve is shifted by 100 pA for clarity of the figure).