Enhanced Sample Preparation of Cu Low-k Semiconductors via Mechanical Polishing and Ion Beam Etching

Shane Roberts, Daniel Flatoff
South Bay Technology, Inc.
roberts@southbaytech.com

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Purpose

Modern microelectronics have rapidly decreased in geometry to enhance the speed and processing power of computers. Advanced devices are approaching design rules of sub 0.13 micron in size, and the trend continues at the rate dictated by Moore's Law. Coupled with this reduction in device size, is a change in materials used for producing these devices. Traditional aluminum interconnect metallurgy and oxide dielectric materials are being replaced with copper and low-*k* materials in an effort to continue the trend of shrinking device sizes and higher processing capacities (1).

These changes in materials and device sizes have provided the impetus for alternative methods for producing cross sections. Although focused ion beam instrumentation has been successfully used for preparing cross sections, a combinatorial approach using polishing and argon ion milling has been found to dramatically enhance the ability to produce high quality cross sectional samples in a reasonably short amount of time.

Sample Preparation

SEM cross-section sample preparation is of primary importance to minimize IC production down time. It is most often a cross-section that is needed to expose the identity and source of defects and to reveal the smallest and most critical dimensions of devices and interconnects. Mechanical polishing of cross sections is performed to obtain an area of interest that will be imaged in the scanning electron microscope (SEM). Traditional sample preparation utilized wet etching techniques to delineate specific layers in a cross section or to define specific features of interest for analysis. In recent years, due to the changes in materials used in IC manufacturing, ion beam technology has been used to enhance polished cross section in order to improve the information acquired from the sample. Devices using damascene processing typically contain both copper interconnects and low-*k* dielectric materials. Low-*k* dielectric materials, such as Coral™ and SiLK™, have materials properties that pose difficult problems as they relate to mechanical polishing (2,3).

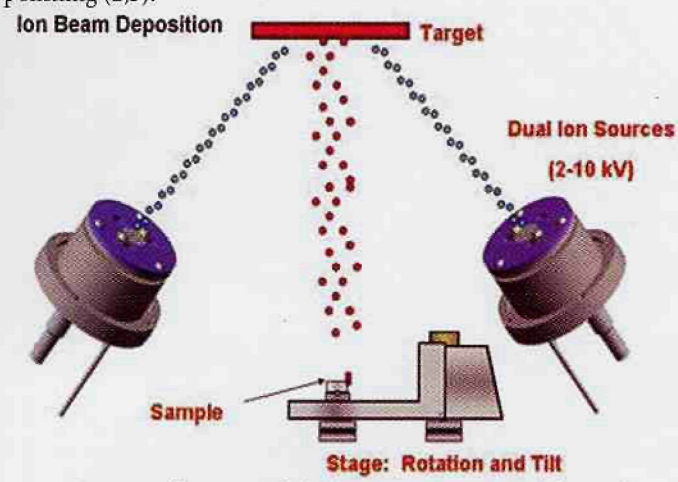

Figure 1: Illustration of the basic arrangement used for ion beam etching and thin conductive film deposition.

IC devices utilizing current copper low-*k* technology were prepared using mechanical cross sectioning techniques. Samples were initially prepared with a glass cover slip epoxy mounted over the device structures to protect the top surface. The sample was then wax mounted onto a polishing stub and then mounted to a Model 590 Tripod Polisher®. Using a series of diamond abrasive lapping films down to 0.5μm in size, the sample was prepared to a general area of contacts observed in an optical microscope. Final polishing was carried out using Rayon™ flocked polishing cloth with 0.1μm diamond suspension. Typical processing times for cross sections such as these is less than 45 minutes, including epoxy curing and adhesive cooling time.

Ion Beam Etching and Conductive Film Deposition

Using an argon ion beam to slowly and controllably remove material from the polished cross section can be utilized to both remove mechanical damage and etch the cross section for layer delineation (4). Ion beam etching utilizes an ion source to generate a relatively focused ion beam directed at the sample to be etched. The ion source consists of a cathode and anode with a common central axis. Applying a high voltage field of 2-10 kV to the anode and subsequently injecting argon gas into the ion source, the high electric field causes the gas to ionize, creating a plasma inside the source region. The ions are then accelerated from the anode region to the exit aperture (cathode) creating a "collimated" ion beam. The resulting ion beam impinges upon the sample, and, via momentum transfer between the ion and the sample, sputters sample material away. Control over the cross section and resulting sample quality is dictated by the anode voltage, ion beam angle of incidence, ion beam current, and the stage motion.

Figure 2: Image of the Model IBS/e combined ion beam etching and thin film deposition system. This instrument combines the use of ion beam etching and ion beam deposition of thin films into a single system for a wide variety of electron microscope operations.

Following ion beam etching of the cross section, the deposition of a thin, conductive film is required to help eliminate problems associated with charge build-up in the SEM. Charging can have a drastic effect on image resolution and can often be problematic in materials such as low-*k* dielectric semiconductors. For deposition, two ion sources are directed at a target material and sputtering of the material occurs onto the sample. Figure 1 shows a schematic illustration of the ion beam etching and deposition geometry.

Ion beam sputtered films are very low in energy, do not heat the sample, and are precisely controllable to 5 angstroms or more. Continuous tilting at user-defined angles, combined with sample rotation, creates very uniformly distributed films over the surface of the sample. A combined system for both ion beam etching and ion beam deposition is ideal for semiconductor applications where image resolution, sample quality, and throughput are of primary concern. Figure 2 is an example of the IBS/e system that combines these features into a single instrument manufactured by South Bay Technology, Inc.

For this report, samples were ion beam deposited with thin films of platinum to serve as a protective layer as well as to provide sufficient charge dissipation during imaging in the SEM. Platinum is a good metal to utilize for deposition due to its minimal structure seen at

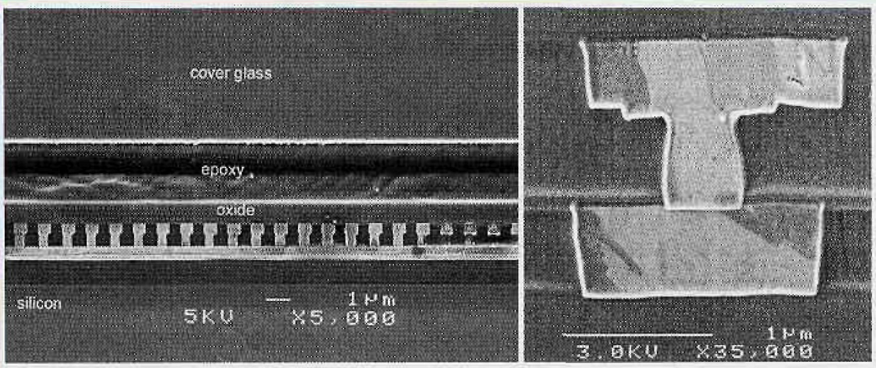

Figure 3 (left), 4 (right): Examples of cross sectional integrated circuit samples prepared via mechanical polishing and ion beam etching.

high magnification, high film quality, and fine deposition thicknesses. Depositions were performed for 5 minutes at a voltage of 8kV and gun current of 6mA. Samples were rotated and continuously tilted at 45° at a pressure of 5×10^{-6} torr.

Sample Results

Two microelectronic samples were processed using these mechanical polishing, ion beam etching, and ion beam film deposition techniques. In Figure 3, the sample shows improved results from ion beam etching, exhibiting the grain structure in the copper contact metallization. The low-*k* dielectric material remains intact and the diffusion barrier metal is clearly observed. Figure 4 shows the optimized conditions for ion beam etching where the copper grain structure is clearly visible in the contact and lower metal interconnects. The barrier metal is also clearly delineated with the low-*k* dielectric material observable as well. No damage to the ILD materials is visible and a possible void in the contact metallization is observed.

Conclusion

Mechanical polishing cross sectional samples has been a long standing technique utilized in a wide variety of materials analysis laboratories. This technique is still viable for advanced materials such as modern microelectronic materials, where a wide range of materials properties is present within a single sample. The use of ion beam etching technology to enhance the cross sectional samples has been shown to provide a large benefit to standard preparation methods. The ion beam can be tailored to specific sample materials and, when used under the proper operating conditions, can improve the quality of the cross section as well as enhance the information available to the analyst. Combined with the ability to produce ultra thin, high resolution thin film coatings to the sample *in situ*, ion beam etching is a valuable method to enhance the cross section process and eliminates the use of wet chemicals for cross section enhancement. Samples of modern microelectronic materials can be cross section polished, ion beam etched and conductive film coated in less than 1 hour. This throughput combined with the information obtainable from the sample makes this combinatorial sample preparation method a valuable technique to the analyst. ■

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