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Cross-sectional TEM Specimens Preparation of Precisely Selected Regions of Semiconductor Devices using Focused Ion Beam Milling

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Abstract A procedure for preparing cross-sectional specimens for transmission electron microscopy (TEM) by focused ion beam(FIB) milling of specific regions of semiconductor devices is outlined. This technique enables TEM specimens to be prepared at precisely preselected area. In-situ W thin film deposition on the top surface of desired site is complementally used to secure the TEM specimens to be less wedge shaped, which is main shortcoming of previous FIB-assisted TEM sample preparation technique. This technique is quite useful for the TEM sample preparation for fault finding and the characterization of fabrication process associated with submicron contact technologies.

As the lateral dimension and layer thickness of semiconductor device structure are continually being reduced, the detailed information on a submicron scale becomes increasingly important for process characterization and failure analysis. For that purpose, the cross-sectional transmission electron microscopy(TEM) is the most useful analytical technique with sufficient resolution.

The standard TEM specimens are usually formed by sandwiching a sample taken from the material under investigation in a support structure, and thinned by slicing, polishing and ion milling.(1) Although the wide-spread introduction of conventional ion milling technique plays a big role in preparing the TEM specimen of complex devices, it requires repeated ion mill / observe cycles since the probability of obtaining TEM specimens at precisely selected regions of semiconductor devices is negligibly small.

A new technique using focused ion beam milling has been developed for preparing the TEM specimens from prespecified location although it still has some shortcoming, i.e., the specimens are strong wedge shaped, making it difficult to examine the wide vertical section of semiconductor devices.(2,3)

In this contribution an attempt was made to overcome these problems by a complementary technique for the capability of obtaining the large, thin TEM sample, thus providing comprehensive informations of complex device structure. In-situ W thin film deposition on the specimen top surface was complementally used to secure the TEM specimen to be less wedge shaped. Some TEM observations at various submicron contacts are presented.

The first stage in specimen preparation for TEM is to select the area of interest on the wafer or chip using in-situ scanning ion microscopy in the FIB machine(SEIKO SMI 8300). Schematically shown in Fig.1 is the procedure of the sample preparation for TEM observation. Some holes around the prespecified location are formed by irradiating focused Ga^+ ions of 30KeV for a position monitoring during the sample thinning. A slice containing the selected area for analysis is then cut from the wafer using a low speed diamond saw. The slice is a few mm long and 100~300μm wide. Before microsectioning, FIB-induced deposition of W thin film (~2000Å thickness) using $W(CO)_6$ as source gas is employed on the prespecified area. This is desirable for protecting the top surface of the sample from the Ga^+ ion damage and furthermore preventing the sample to be strong wedge shaped since W has higher sputtering resistance as compared to Si, SiO_2 and Al that are most materials used in semiconductor devices.

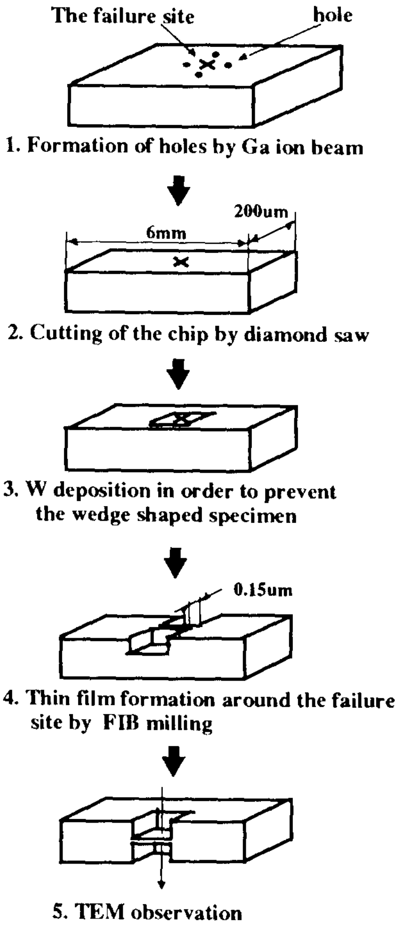

Fig. 1. Schematic diagrams showing cross-sectional TEM sample preparation procedure using focused ion beam milling.

Two trenches are then cut by a beam of 30KeV Ga^+ ions, focused to a spot with a typical beam diameter of 500Å, inward from both edges of the slice to within a few microns on either side of the selected region. A rough milling with high ion beam current of 4.8nA is performed for high throughput at this stage. A final, fine sputtering with low ion beam current of 110pA is carried out in order to reduce the width of thin wall thus ensuring a region of electron transparent material being left. The TEM observation was done in a JEM-2000FX II transmission electron microscope at an accelerating voltage of 200KV.

Fig. 2. shows a scanning electron micrograph showing the tilted view of sample prepared by focused ion beam. The film thickness is about 1500 Å, thin enough for electron transparency.

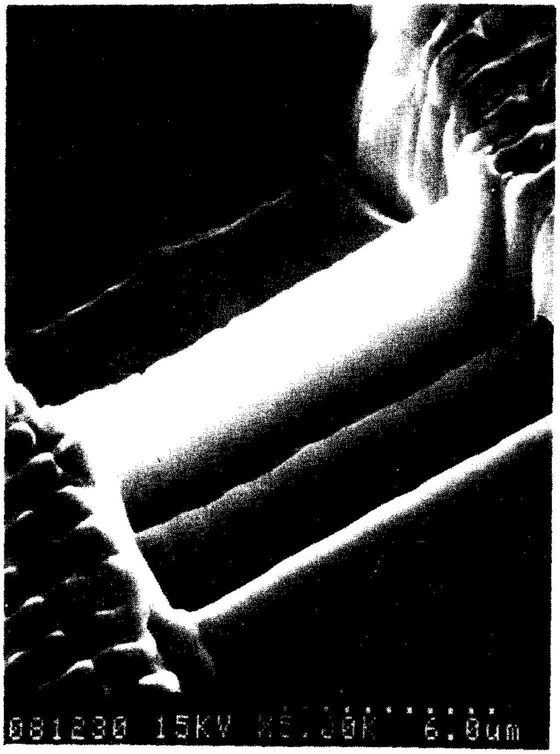

Fig. 2 Scanning electron micrograph showing the tilted view of sample prepared by focused ion beam milling.

A part of memory cell array is shown in Fig. 3(a), exhibiting a gate polysilicon and a polysilicon contact with hole size of ~0.4㎛. It should be noted that three polysilicon contacts to Si substrates are clearly seen even at low magnification, X5000. This indicates that this technique can provide sufficient, large thin-area to examine the gate and part of the adjacent polyilicon contact to Si substrates. A higher magnification, Fig. 3(b), clearly shows that the interface between Si substrates and polysilicon at the contact is seen to penetrate into substrates because of over-etching of contact holes. Accordingly, FIB-assisted TEM sample preparation technique would be particularly attractive for fault finding and the characterization of fabrication process associated with submicron contact technology. Note that the upper part of polysilicon contact, in Fig. 3 (a),is etched out due to the Ga^+ ion damage (arrow marked). In-situ W thin film deposition on the top surface of preselected area was found to protect the top surface from Ga^+ ion damage, thus securing the TEM samples to be less wedge shaped and providing wide vertical area to examine various components from substrate to metal layers(Fig. 4)

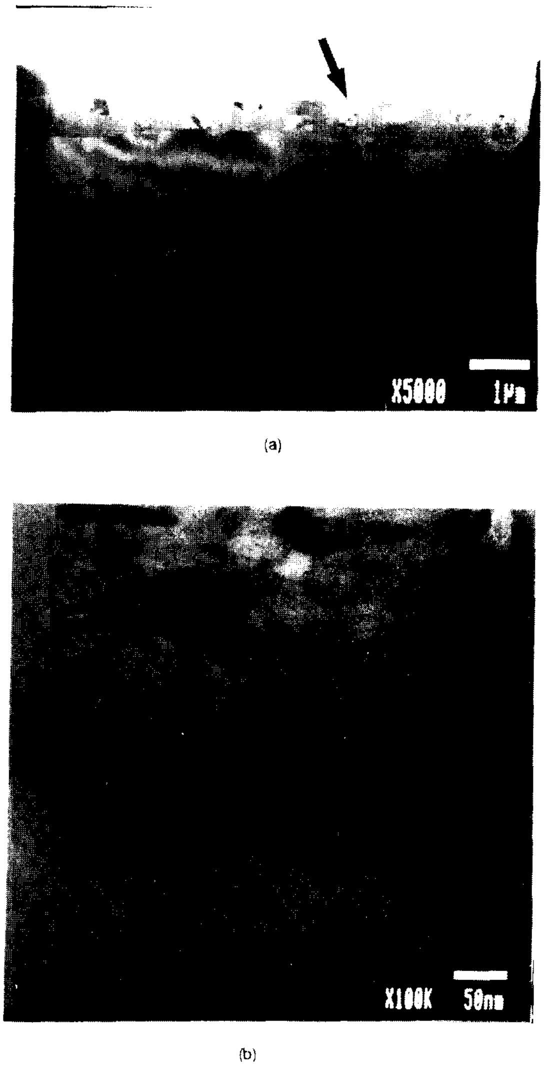

Fig. 3. Bright field cross-sectional TEM micrographs around a polysilicon contact to Si substrate in memory cell array of CMOS DRAM;
(a) low magnification, X5000 and (b) high magnification, X100000.

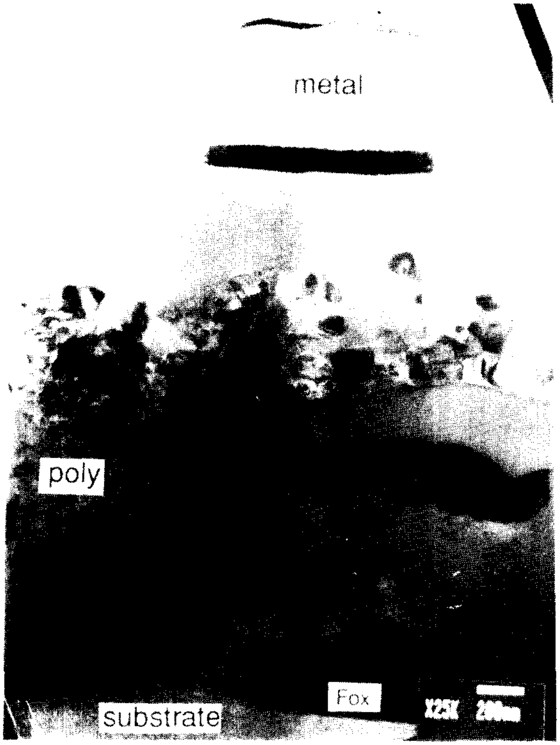

Fig. 4. Cross-sectional TEM micrograph showing various components from substrate to metal layers.

It seems that a conventional ion milling technique does not give good quality of TEM image in case that the sample has severe hardness differential between the various component materials of semiconductor devices. A soft area is etched out in the early time, leaving the hard region still thick. Continued milling results in preferential thinning of interface region and finally leading to a loss of hard parts. One of the most typical cases is the microstructural study on the W chemical vapor deposition technology in semiconductor process. Since a W phase has higher hardness as compared to the surrounding phases such as Si, SiO_2 and Al, a clear imaging of the interfaces between each component becomes very difficult. The FIB-assisted TEM sample preparation technique overcomes these difficulties. The TEM photograph at the contact bottom for tungsten plug contact is exhibited in Fig. 5, which shows good image in each layer even with a great difference in hardness.

In conclusion, this new technique enables TEM specimens to be prepared at prespecified areas of a wafer. In-situ W thin film deposition on the top surface of selected area was found to secure TEM specimens to be less wedge shaped. This techique is quite useful for the TEM sample preparation for fault finding and the characterization of fabrication process associated with submicron contact technologies.

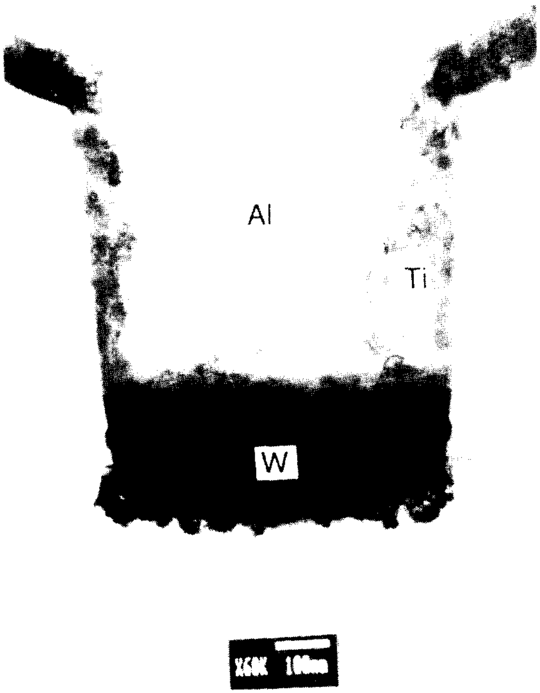

Fig. 5. Cross-sectional TEM micrograph at the contact bottom for selective-W / Ti structure.

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