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Precise Ion Milling and 3D TEM technique to Deal with Feature Blocking in TEM Viewing Semiconductor Devices

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Cross sectioning to view a stacking contact that connects a bitline and a passing transistor is a common way of finding possible defects that result in a double bit failure in SRAM device. With the rapid geometry shrinkage of semiconductor devices, the viewing methods have changed from FIB, SEM to TEM due to resolution requirements. Recently, while dealing with 60 nm diameter contacts of SRAM device, we encountered a new problem: a long poly wordline aside of the contact also appears in TEM image and blocks the target area. It results in difficulty in viewing details for root cause finding. According to the cell structure, there are two poly lines located at the sides of the target contact. It can be deduced that the problem occurs because the TEM sample thickness did not change with the shrinkage of the device geometry, resulting in a portion of a poly in the TEM specimen (figure 1). Multiple features within a TEM specimen thickness will soon become a common issue in TEM analysis of semiconductor devices and to solve this issue will prove to be useful for such cases in the near future.

Further thinning the sample and getting rid of the unwanted poly line seems like the direct way. However, further thinning lift out specimens is a difficult issue since the sample sits on a carbon film that cannot withstand ion milling [1]. All discussions that have been published to solve this problem are focused on how to transfer the thin membrane to a stronger support and then mill it with an ion miller. Using an Omini probe [2] to transfer the thin membrane is a convenient way, but requires expensive FIB attachments. The glue method [1] does not need an Omni probe but it is hard to handle, which results in a low success rate. What we have used is the grafting method [3] which does not require expensive equipment and has a very high success rate. The process includes transferring the LO specimen to a thin portion of a polished specimen on mesh grid by pushing it down with a regular probe station, then using FIB to create a window on silicon in the back of the FIB sample in order to allow the beam to reach. Carbon film that attaches to the LO sample helps the transferring because it is easy to stick to silicon surfaces.

The next step is to make the sample thinner with a wide ion beam. A regular ion miller has proven unsuccessful because it uses an optical microscope as a monitoring system, which cannot see small poly lines clearly. This can easily result in over-etching of the specimen. In order to solve this problem, a RES-120 of BAL-TEC, equipped with SEM as monitor was used. The long poly lines can be seen in white with the SEM monitor system (Figure 2A). It was possible to follow the progress of ion milling on the SEM monitor. 2.5 KV, 1.5 mA, 15 degree angle was applied. After the specimen was etched for 16 minutes, partial removal of the poly line was noticeable (Figure 2B). After 3 more minutes etching, the poly line was completely removed (Figure 2C). Figure 3 compares STEM image before and after the poly line removal. We now can see the detailed structure of the defective contact. It very clearly shows nitride surrounding a big void that blocks the contact.

Viewing the sample from a different angle is another way to avoid feature blocking problems. High angle tilting results in viewing a thicker sample with TEM, which reduces imaging resolution. Therefore, preparing a cross-section at a given location and then viewing it from the original 90 degree angle is practical in use. Such A "3D TEM" specimen was prepared from an existing TEM specimen. The steps in 3D specimen preparation include: 1) creating a thin film at the target location that is electron transparent and then 2) tilting a portion of the specimen 90 degree relative to the original specimen orientation so that the thin target area will be facing the electron beam in TEM. The first step is not difficult with FIB's precise cutting capability but the second step, tilting the specimen, was previously accomplished by transferring the sample to a second grid [4,5], which can be complicated and results in a low yield of 3-D specimen. Direct tilting of a portion of the specimen takes advantage of the phenomenon that a small portion of the silicon bends upward while it is being cut free of its substrate. The force that causes the upward bending towards the beam is believed to be electrostatic in nature. This method greatly simplifies the preparation procedure and increases the yield of 3D specimens. The detailed procedure has been published [6]. The actual cross-section of Figure 3 is shown in Figure 4. In combining Figure 3 and Figure 4, we can clearly see the defective structure and conclude that spacer nitride defect is the root cause.

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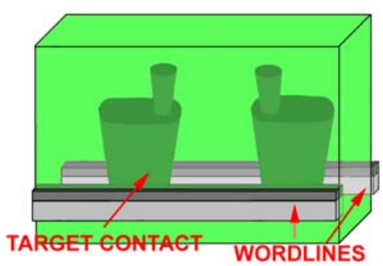

Figure 1: A diagram illustrates the TEM sample and relative target location

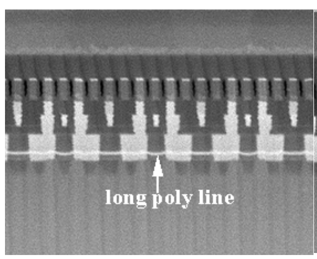

Figure 2A: SEM image show poly line: before etching, the white long poly line can be seen.*

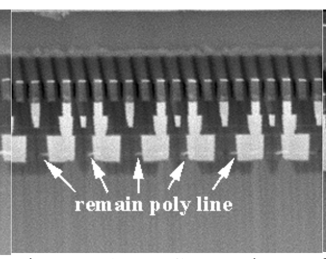

Figure 2B: SEM image: After 16 minute etching, the white long poly line has become short lines.*

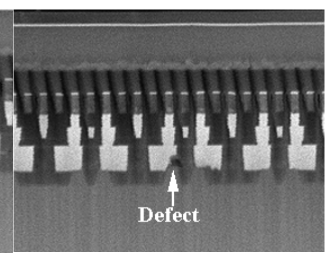

Figure 2C: SEM image at the target location: after etch 19 minutes: the long poly line has been removed.

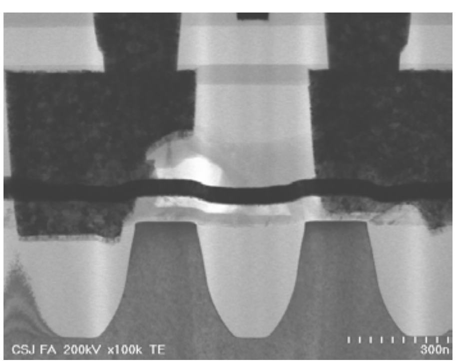

Figure 3A: A transparent image before ion milling: the long poly lines blocks the void under the defect contact

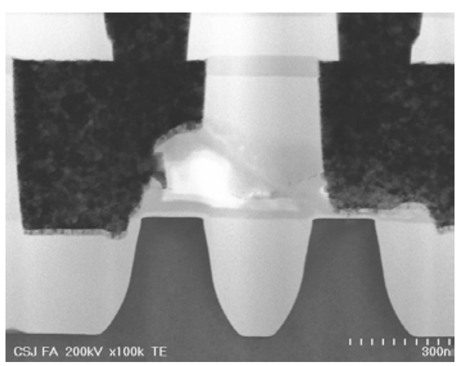

Figure 3B: A transparent image after ion milling: the long poly has been removed

Figure 4: A cross sectional image of Figure 3B at defect location

*Photos in Figures 2A and 2B are near the defective contact, not at it, but they accurately show what the whole sample looked like prior to ion milling.

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