LM STEM study of dislocations in thick Si

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It is well known that resolution is one of the key specifications of TEM and STEM applications. For imaging, however, the need for a large field-of-view is frequently overlooked. There are cases in which features have to be investigated using a field-of-view (FOV) as large as possible. Recently we studied dislocations in thick Si wafer using LM-STEM technique which provides both visibility of the defects and a very large FOV.

During manufacturing of integrated silicon devices doping of well defined surface regions is often done by ion implantation. This process generally induces extended dislocation structures within the implantation affected surface zone which need to be cured by subsequent high temperature annealing. Even few remaining dislocations may drastically increase the leakage current of the electrical device. TEM investigations of these dislocations allow more precise localization and characterization of these dislocations, but evidently have to be performed on samples cross-sections which are several micrometers thick. High transmission at a large FOV opens the field for 3D defect investigations in silicon semiconductors [1]

Due to higher transmission TEM investigations on thick samples are preferentially performed at 300 kV or 400 kV accelerating voltage. For thick samples conventional TEM images are strongly affected by chromatic aberrations of the imaging lenses due to inelastic scattering of the electrons within the specimen. Resolution of STEM images is not limited in the same way and is thus favorable for TEM imaging on thick samples [2].

TEM samples from an integrated silicon device were cut using a FIB (see SEM image in Fig.1). The four thin windows are different in thicknesses which were estimated to range from 0.96 μm to 3.6 μm. The sample was observed on a Tecnai F30 ST operated at 300 kV. A HAADF detector was used to record the STEM images.

At high magnification, dislocations within in device surface zone can be detected, but the FOV is limited. A few dislocations can be clearly observed within the 0.96 μm thin window area in TEM mode (Fig. 2; MAG on CCD = 11,5 kx) as well as in HM-STEM mode (Fig.3; MAG = 12 kx), but in both cases the FOV amounts only to a few micrometers.

Going to LM-STEM mode, because of very large camera length, STEM is no longer in a DF imaging mode but more in a BF imaging mode since the bright-field disk falls on the HAADF detector. Fig.4 shows a part of a LM STEM image which was digitally enlarged to enhance the visibility of the same dislocations as in Fig.2; more dislocations within the 0.96 μm thin window are also seen. In fact, the original FOV of the image is more than 40 μm.

Figure 5 is another STEM image taken in LM-STEM mode. The microscope's nominal magnification is 3,400x. All four thin windows are within the FOV. It is also possible to observe dislocations in all those windows. The only challenge is to find the right brightness/contrast settings to see all dislocations, which are in very different specimen thickness, in a common display. That is the reason why the image of the thinnest window (to the right in Fig. 5) is actually displayed differently from the others (as insert). Fig.5 provides a

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FOV of about 50 μm, which can be compared to the SEM image in Fig.1. However, dislocations are only observable in the LM STEM image and not in the SEM image.

References

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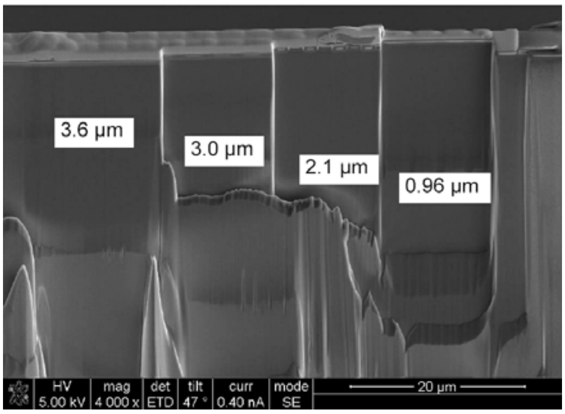

Figure 1. SEM image of the FIB cut sample with four windows of different thickness.

Figure 2. High-magnification TEM BF image showing a few dislocations. FOV is about 2 μm.

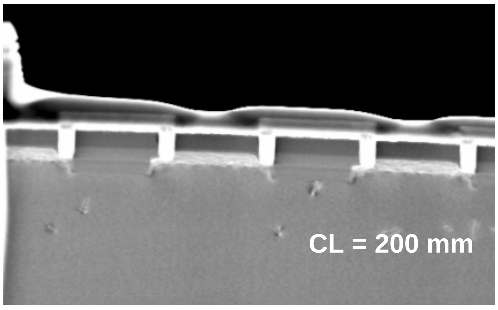

Figure 3. STEM-HAADF image showing similar dislocations as in Fig. 2. The camera length (CL) is 200 mm. FOV is about 8 μm.

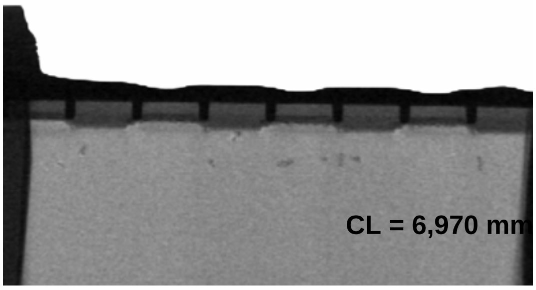

Figure 4. Digitally enlarged detail of a LM STEM image showing the same dislocations as in Fig. 2 and Fig. 3.
CL=6,970 mm; MAG = 3,400x; FOV ~10 μm.

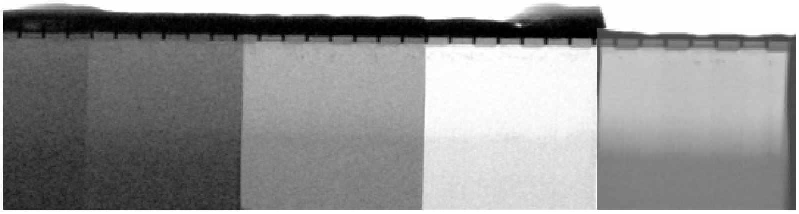

Figure 5. LM STEM image of which the detail in Fig. 4 was cut out. The nominal magnification is 3,400x. The FOV is ~50 μm and thus comparable to the one of Fig. 1, however with discernible dislocation contrast (reproduction/print prevents better visibility).

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