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# Imaging at High Beam Energies in the Scanning Electron Microscope

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One recent trend in scanning electron microscope (SEM) imaging has been to work at a low incident beam energy $E_o$ (< 5 keV) in order to minimize beam penetration, beam spread, and sample charging and thus improve surface image resolution. However, high energy imaging can provide complementary information to the data obtained at low $E_o$ and should therefore be used in combination with low energy imaging in some SEM application areas.

One example where high energy imaging can be useful is to study subsurface features using backscattered electrons (BSE) [1, 2]. The depth below the surface that a feature can be imaged is dependent on $E_o$ and the overlayer material: structures can be seen farther below the surface if $E_o$ is increased or the overlayer material is lower in mass density. The maximum $E_o$ for most commercial SEM systems is 30 keV. However, transmission electron microscopes (TEM) equipped with secondary electron (SE) and BSE detectors can allow SEM imaging at energies of 100-400 keV. Fig. 1a shows a BSE image taken at 400 keV of a passivated two-level dual Damascene interconnect. Fig. 1b is a TEM cross-section image of the same interconnect which shows the sample dimensions and subsurface depths. A 0.30 m wide upper level M2 line is connected to a 10x10 m wide lower level M1 plate through a 0.30 m wide V1 via. The BSE image shows the subsurface M1 and M2 lines along with the V1 via in one composite, planar image. Since BSE are strongly dependent on the mass density of the sample material, the TaN/Ta liner [3] can be seen as brighter intensity regions on the edges of both of the Cu M1 and M2 features. The large stress voids seen in the M1 plate near the V1 via is also shown in the BSE image suggesting that defects in Cu lines can be found without having to alter the sample by delayering or cross-sectioning.

A second application for high energy SEM imaging is in the study of C nanotubes grown on lacey $SiO_x$ membranes on Cu grids. The nanotube growth process caused round particles to grow on the $SiO_x$ membrane, see the dark field (DF) scanning transition electron microscope (STEM) image taken at 300 keV in Fig. 2a. The STEM image shows that the particles are higher in mass density than the membrane but the location of the particles is not known. In the 300 keV SE image in Fig. 2b, the particles are not visible but they are seen in 300 keV BSE image in Fig. 2c. These results suggest that the particles were deposited on the backside of the membrane. The 300 keV SE image had excellent resolution (~2 nm) with no signal from the back of the membrane. Using an in-lens SEM, 2 keV and 30 keV SE images of the same side of the membrane were taken, see Figs. 2d-e. At 2 keV, the surface detail of the membrane is not as clearly defined but it is seen at 30 keV. For the unique case where the sample is thin so beam spread will not severely hinder the image quality, the SE image resolution can be improved at high energies possibly due to a reduced electron wavelength.

References

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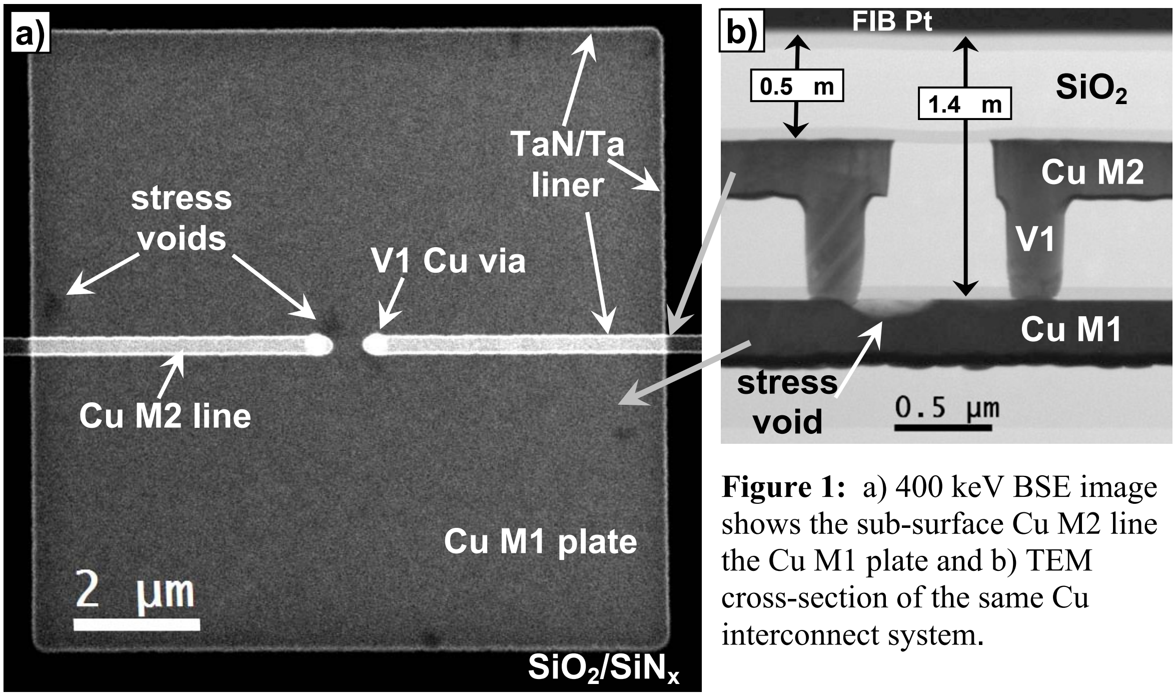


**Figure 1:** a) 400 keV BSE image shows the sub-surface Cu M2 line the Cu M1 plate and b) TEM cross-section of the same Cu interconnect system.

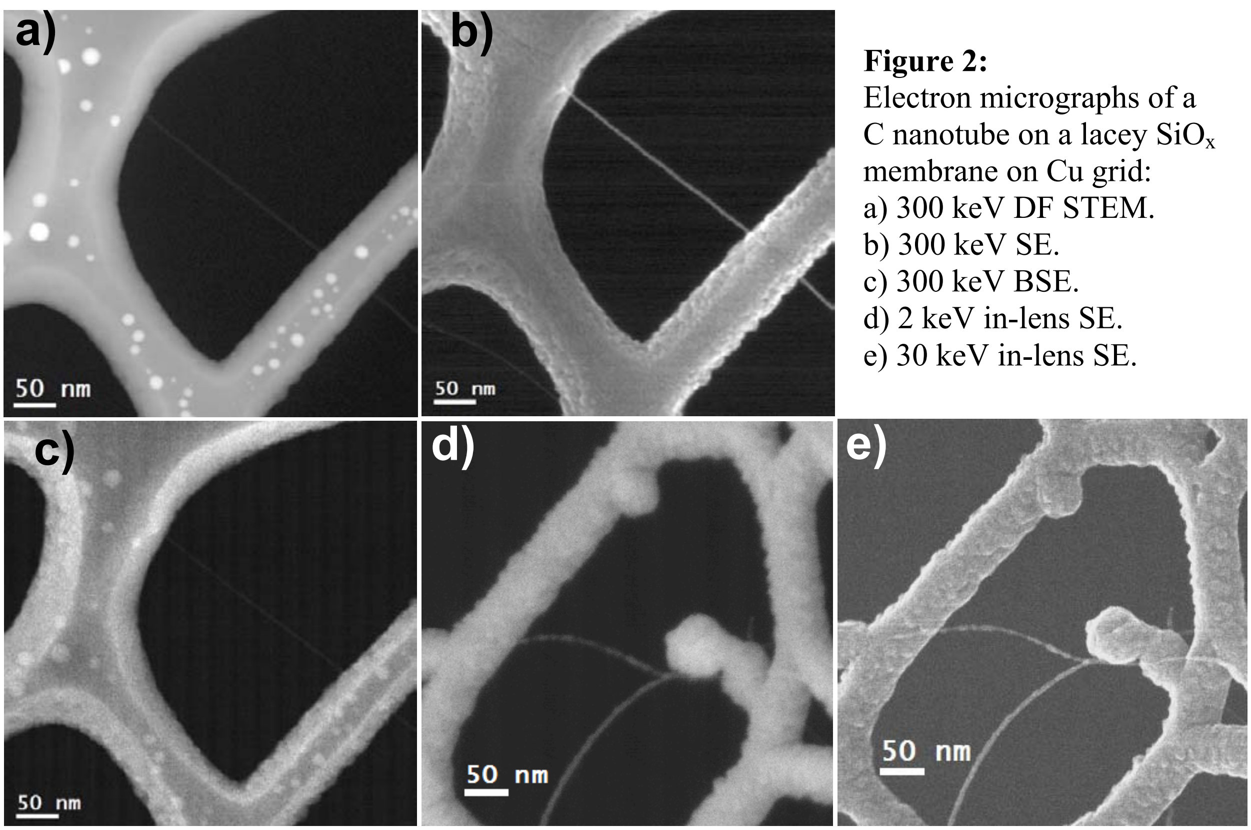


**Figure 2:**
Electron micrographs of a C nanotube on a lacey $SiO_x$ membrane on Cu grid:
a) 300 keV DF STEM.
b) 300 keV SE.
c) 300 keV BSE.
d) 2 keV in-lens SE.
e) 30 keV in-lens SE.

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