Holographic tomography of semiconductor devices

Off-axis electron holography of semiconductor devices

Traditionally, electron holography is used to provide 2-dimensional maps of electrostatic potentials in doped semiconductor specimens.

Here, a phase image recorded from a conventional trench FIB-milled Si p-n junction with a dopant concentration in excess of $10^{18}$ cm$^{-2}$ shows a step in potential at the position of the junction.

Experimental procedure

Tilt series acquired of off-axis holograms -70° to +70° in 2° increments

Experimental holograms

Reconstruct with reference hologram

200 nm

Tilt angle (deg.)

-75 -50 -25 0 25 50 75

Spatial frequency [cycle/nm]

-75 -50 -25 0 25 50 75

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The need for electron tomography

The electrical properties of the p-n junction are thought to vary through the thickness of the specimen. This effect can be assessed by combining electron holography with electron tomography to record a three-dimensional image of the potential in the specimen.

Holder design and specimen geometry

A transmission electron microscope (TEM) sample holder has been developed in collaboration with Fischione Instruments that allows semiconductor devices to be examined under an applied bias using electron holography and electron tomography. It also allows samples to be transferred between the TEM and a scanning electron microscope (SEM), a focused ion beam (FIB) workstation and an Ar ion miller.

The end of the sample holder contains a removable cartridge, which is used to make electrical contacts to the front and back surfaces of a cleaved square of semiconductor, via a conducting block and a spring.

A thin membrane is prepared using the FIB at the edge of a cleaved square of silicon. This sample geometry allows full 360° rotation without shadowing the membrane by the bulk specimen.

3-D electrostatic potential

Experimental results

Line profiles can be extracted from the 3D data sets to examine properties close to the centre and surfaces of the membrane.

Simulation

Simulations conducted for:

- 300 nm thick Si specimen
- Crystalline surfaces
- $1 \times 10^{18}$ cm$^{-2}$ dopant concentration
- 0.7 eV surface energy


Summary

Successful reconstruction of the 3-D potential in a semiconductor device using combined electron holography and tomography.

Quantitative determination of mean inner potential and dopant-related potential at any position in a thin specimen.

Very promising technique for examination of real device structures.