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An ultra-high-tilt two-contact electrical biasing specimen holder for electron holography and electron tomography of semiconductor devices

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The concept of a "laboratory in an electron microscope", which allows high spatial resolution analytical techniques to be combined with experiments that are traditionally carried out *ex situ*, is highly attractive for tackling a wide range of problems in nanoscience and nanotechnology. Here we describe a transmission electron microscope (TEM) sample holder designed by E.A. Fischione Instruments, Inc. that allows a semiconductor device to be examined under an applied bias using electron tomography and electron holography, as well as allowing the sample to be transferred to a scanning electron microscope (SEM), a focused ion beam (FIB) workstation or an Ar ion miller in a universal removable cartridge assembly. Figure 1a shows the end of the sample holder, which has been designed for use in a Philips CM300ST field emission gun TEM. The tip of the holder (Fig. 1b) contains a removable cartridge (Fig. 1c), which is used to make electrical contacts to the front and back surfaces of the sample (a cleaved square of semiconductor wafer), via a small conducting block and a second spring contact. A loading station (Fig. 1d) allows the spring contact to be pulled away from the conducting block when inserting the sample. The cartridge can then be transferred to a FIB workstation to mill an electron-transparent membrane of uniform thickness at one corner of the cleaved wafer, with the cartridge held in a custom-built SEM/FIB stub (Fig. 2a). The sample geometry is described in detail elsewhere [1]. In the TEM, tilts of ±80˚ can be achieved before the region of interest on the sample is obscured by the edges of the holder. This combined approach allows samples at different stages of examination or preparation to be stored in separate cartridges (Fig. 2b), biasing experiments to be carried out on the same sample in either the TEM, the SEM or the FIB workstation, and each sample to be plasma-cleaned while in its cartridge.

Figures 3a and b show representative experimental defocus series of images of an FIB-prepared Si p-n junction, in which the concentration of the B and Sb dopants on each side of the junction is $\sim 10^{18} cm^{-3}$. These images were acquired at 200 kV using the sample holder shown in Fig. 1 to apply a range of reverse and forward bias voltages across the junction. The total specimen thickness is 335±20 nm. The variation in phase shift across the junction with applied voltage (Fig. 3c), measured directly using off-axis electron holography, indicates that almost all of the applied voltage has been dropped across the junction successfully. The change in the slope of the graph in Fig. 3c is interesting, but is not understood fully at present. Further studies will combine electron holography with electron tomography to characterize electrostatic potentials in working semiconductor devices, as well as their microstructure and chemistry, in *three* dimensions rather than in projection [2].

References

[1] A.C. Twitchett et al., *Phys. Rev. Lett.* 88 (2002) 238302.
[2] We thank the Royal Society, the EPSRC and Newnham College, Cambridge for financial support, and Stuart Holmes for help with the electrical connections to the SEM stub.

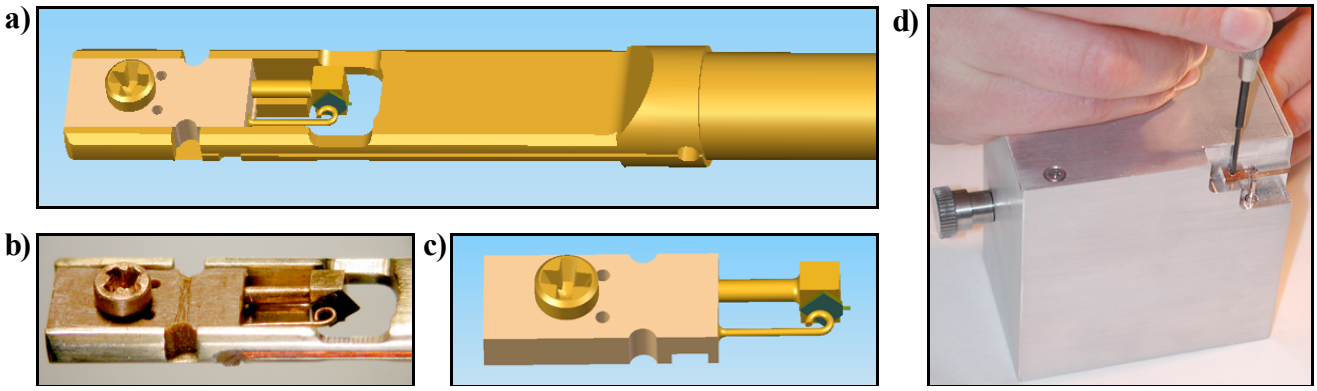

FIG. 1. a) Design drawing of the end of the ultra-high-tilt two-contact cartridge-based electrical biasing holder with a sample in place in the cartridge. b) Photograph of the tip of the holder with a cleaved FIB milled Si sample in the cartridge. c) Design drawing of the cartridge and sample alone. d) The loading station used to pull the spring contact back to load the sample into the cartridge.

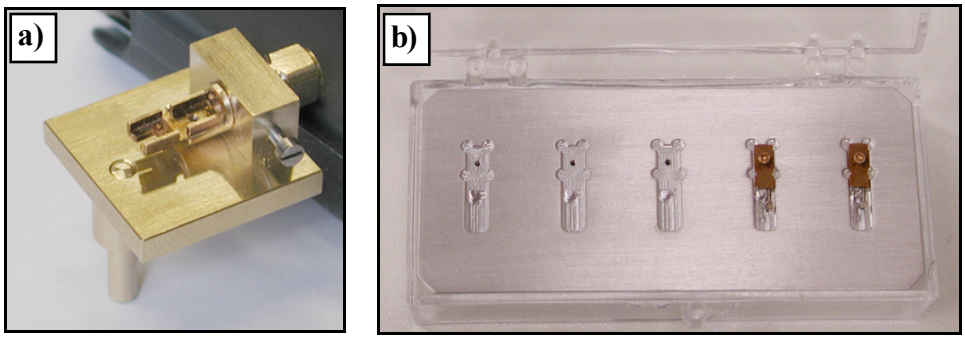

FIG. 2. a) Stub used to mount the cartridge in the FIB workstation or the SEM at any desired angle about the cartridge axis. b) Storage and transfer box for multiple cartridges and samples.

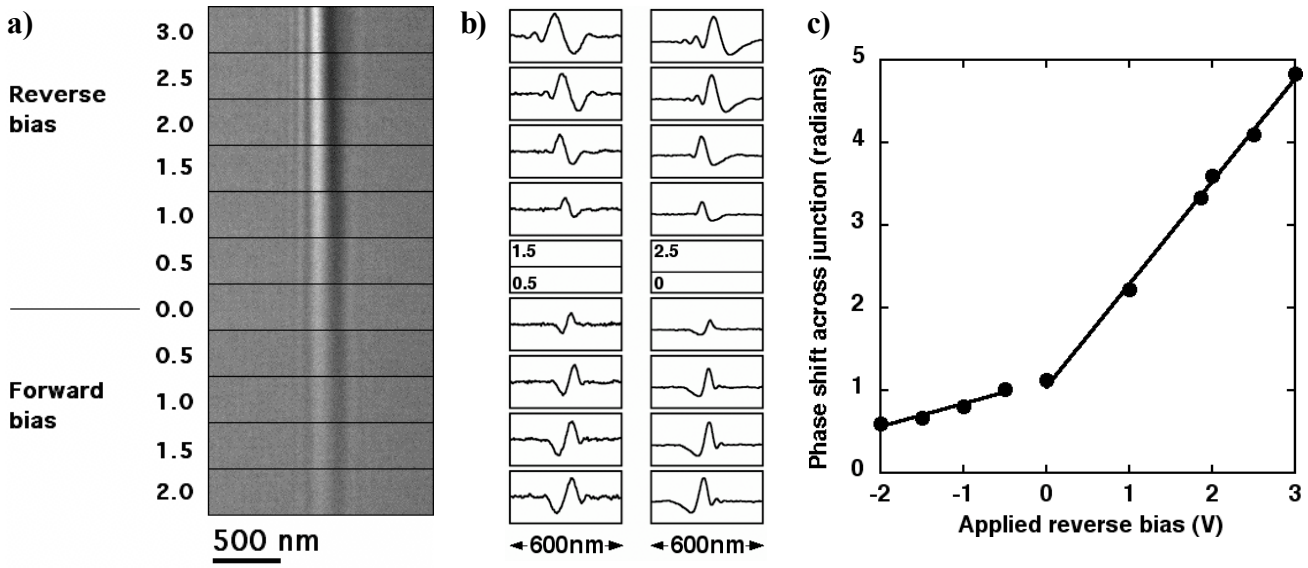

FIG. 3. a) Montage of energy-filtered images of a Si p-n junction acquired as a function of applied voltage at a defocus of -3.5 mm. b) Line profiles across the junction at reverse bias voltages of 0V (left) and 2V (right), for a defocus range of –3.5 mm (top) to +3.5 mm (bottom). c) Phase shift across the junction measured from off-axis electron holograms acquired as a function of applied voltage.