# An ultra-high-tilt 2-contact electrical biasing specimen holder for electron holography and electron tomography of semiconductor devices


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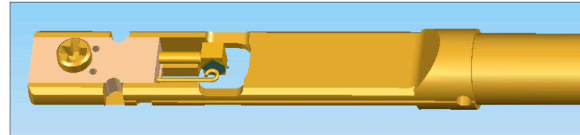
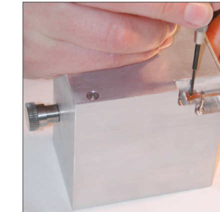
## Holder design and specimen geometry

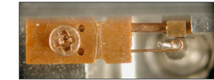
The concept of a "laboratory in an electron microscope" is highly attractive for obtaining new information about nanoscale materials and devices.

Here we describe a transmission electron microscope (TEM) sample holder 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.

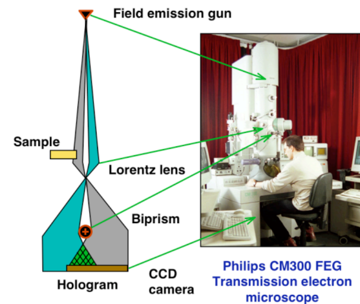




A loading station allows the spring to be pulled away from the conducting block when inserting a sample.

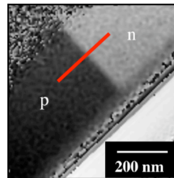
## Off-axis electron holography of semiconductor devices

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




Philips CM300 FEG Transmission electron microscope

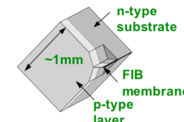
Here, a phase image recorded from a conventional 'trench' FIB-milled Si p-n junction with a dopant concentration in excess of $10^{18}$ $cm^{-3}$ shows a step in potential at the position of the junction.



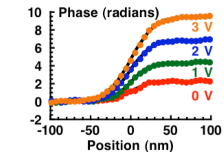


R E Dunin-Borkowski, M R McCartney & David J Smith. Electron holography of nanostructured materials. In the "Encyclopaedia of Nanoscience and Nanotechnology" (American Scientific Publishers, 2004).

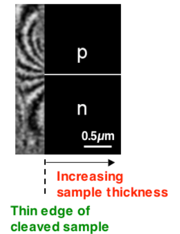

## Results from reverse-biased FIB-milled specimens




The new Fischione holder allows samples such as the Si p-n junction to be examined with a bias applied to them in the TEM. An FIB membrane is milled onto one corner of the cleaved square of wafer shown in the design drawing above.



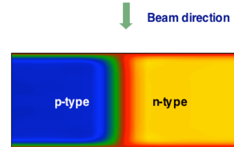

After FIB milling, the step in phase across the junction increases linearly with applied reverse bias, confirming that the device is working in the microscope.




Electrostatic fringing fields are only seen outside the edge of a cleaved specimen before it is FIB-milled, indicating that the sample surface is an equipotential after FIB milling.

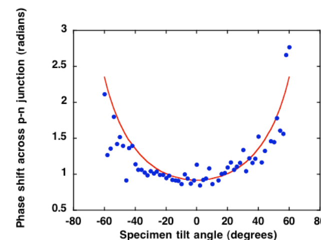

A C Twitchett, R E Dunin-Borkowski and P A Midgley. Quantitative electron holography of biased semiconductor devices. Phys. Rev. Lett. 88 (2002), 238302.


## 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.

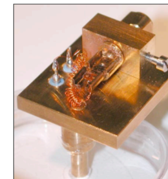
In the Fischione holder, tilts of ±80° can be achieved before the region of interest on the sample is obscured by the edges of the holder. The entire thin edge of the cleaved square is then FIB milled to avoid shadowing.




Electron holograms are acquired at high tilt angles to measure the potential in the specimen in three dimensions.

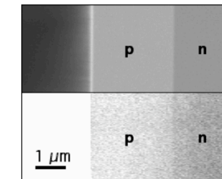

P K Somodi, R E Dunin-Borkowski, A C Twitchett, C H W Barnes and P A Midgley. Simulations of the electrostatic potential distribution in a TEM sample of a semiconductor device. Inst. Phys. Conf. Ser. 180 (2003), 501.


## Compatability of specimen cartridge with other instruments



The specimen cartridge can be transferred between the TEM holder and a FIB/ SEM stub.

Samples at different stages of preparation can be stored in separate cartridges.




The effect of TEM sample preparation on the electrical properties of the specimen is illustrated by the fact that SEM secondary electron contrast is 5 times higher from a cleaved sample than after FIB milling.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