QUANTITATIVE ELECTRON HOLOGRAPHY OF BIASED SEMICONDUCTOR DEVICES

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The ability to measure electrically active dopant distributions in semiconductor devices quantitatively, reliably and at high spatial resolution is of paramount importance to the microelectronics industry[1]. Electron holography allows such measurements to be made in the field emission gun transmission electron microscope (FEGTEM)[2]. The technique relies on the use of an electrostatic biprism (eg. a quartz wire coated with gold) to overlap an electron wave that has passed through an electron-transparent sample with a wave that has passed only through vacuum. The interference pattern (or hologram) that forms in the overlap region contains information about the phase change of the electron wave that has passed through the sample. This phase image can in turn be used to determine the electrostatic potential in the sample[3]. Here, we conduct a systematic series of experiments that involve the application of electron holography to a Si p-n junction in a Philips CM300 FEGTEM as a function of applied reverse bias. A single-tilt biasing holder (Fig. 1a) is used to examine cleaved wedge specimens, which have spring contacts made to their front and back faces. Areas of uniform thickness are micro-machined on the cleaved samples using focused ion beam (FIB) milling (Fig. 1b).

Figure 2a shows a 200 kV holographic phase image obtained from an unbiased p-n junction prepared by FIB. The dark and bright contrast in the image corresponds to the p and n-type regions in the sample, respectively. An additional grey band along the edge of the sample is thought to result from the presence of an electrically dead layer that runs around its entire surface. A line trace showing the phase profile across the junction is plotted in Fig. 2b. Figure 2c shows the corresponding charge density profile determined from Fig. 2b using Poisson s equation. Electrostatic fringing fields (Fig. 2d) were only observed outside reverse-biased cleaved wedge specimens that had not been machined by FIB. Fringing fields were never observed outside unbiased cleaved wedges or any FIB-prepared samples[4]. The projected thickness of each sample was measured both from the holographic amplitude image and by convergent beam electron diffraction. The fact that only the latter technique provides the *crystalline* thickness of the sample was used to infer the presence of a 30 nm thick amorphous layer on each surface of the sample. Figure 3a shows a plot of the phase shift across a p-n junction as a function of applied reverse bias in a sample whose crystalline thickness is 390 nm. The gradient of this graph can be used to determine that the *electrically active* thickness of the sample is 340 nm, while its intercept with the vertical or the horizontal axis can be used to determine that the built-in voltage is 0.9 V. The dopant concentration is measured to be $1x10^{-18}$ cm^{-3}, which is slightly lower than secondary ion mass spectrometry measurements suggest. The depletion width increases with bias voltage in the expected manner. Data obtained from a range of sample thicknesses and bias voltages allow us to infer the cross-sectional structure of the sample, which is shown in Fig. 3b. The sample surfaces are amorphous, within these are crystalline but electrically dead layers and within these is the electrically active junction of depletion width W.

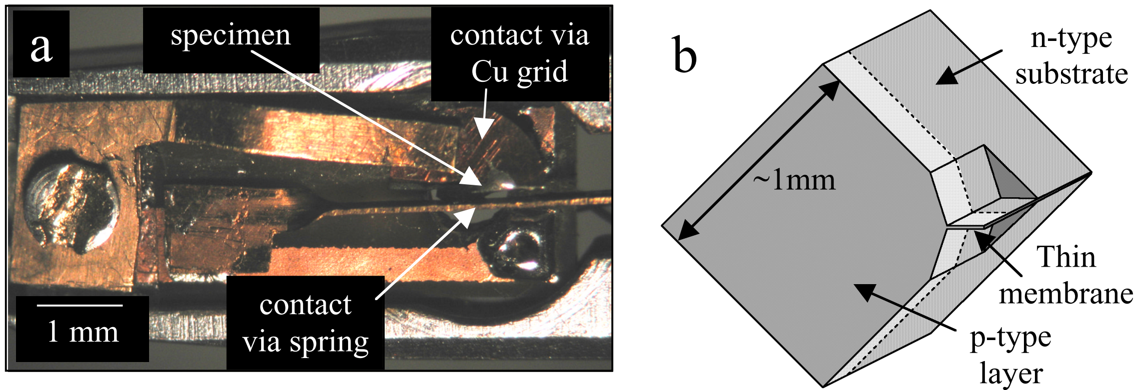

Figure 1 (a) Electrical biasing holder; (b) Specimen geometry after cleaving and FIB.

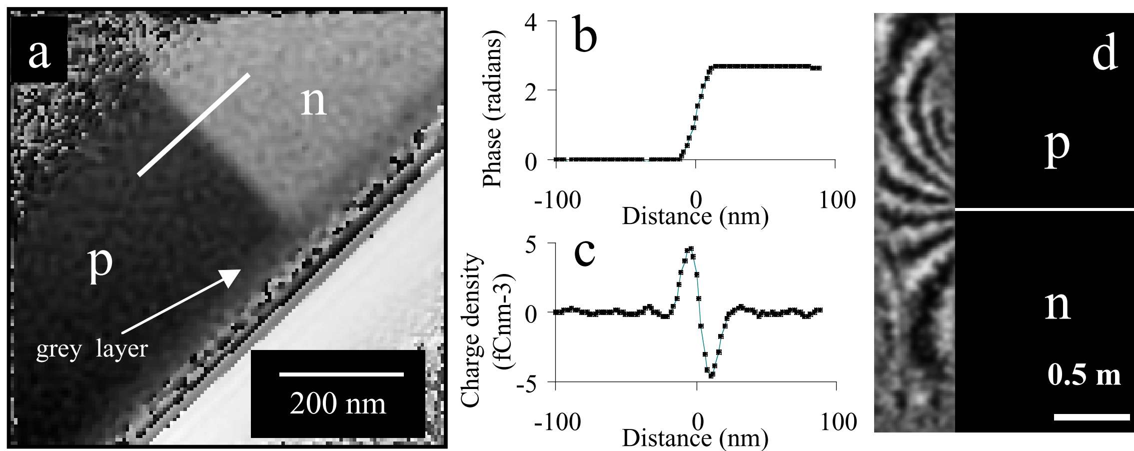

Figure 2 (a) Reconstructed phase image of a Si p-n junction. (b) The phase and charge density across the junction. (c) Stray fields from non-FIB sample at 2 V reverse bias.

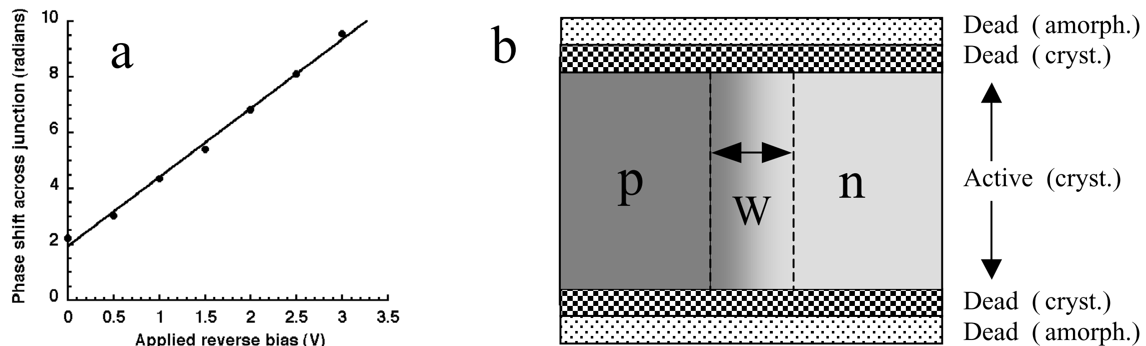

Figure 3 (a) Phase change across junction as a function of reverse bias for sample with measured crystalline thickness of 390 nm. (b) Model used to explain the results.

References

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