Electron holography of a focused ion milled p-n junction examined after low energy, low angle Ar ion milling

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An abrupt Si *p-n* junction comprising a 2.5-µm-thick 4×10^{18} cm^{-3} B-doped (*p*-type) layer on a 4×10^{18} cm^{-3} Sb-doped (*n*-type) substrate was prepared for analysis in the transmission electron microscope (TEM) by focused ion beam (FIB) milling using 30 kV Ga ions in an FEI 200 FIB workstation. A standard trench milling approach was used, finishing with a 70 pA beam current to reduce the effects of Ga implantation. The crystalline sample thickness was measured, using convergent beam electron diffraction, to be 550 ± 10 nm.

Off-axis electron holograms of the specimen were recorded at 200 kV using a Philips CM300 field emission gun TEM, and reconstructed to determine the phase shift ϕ across the junction. The phase shift was then related to the electrostatic potential, V using the equation

$$\phi(x,y) = C_E \int V(x,y,z)dz$$

where C_E is a sample-independent constant, x and y lie in the plane of the specimen and z is the incident electron beam direction. Figure 1 shows the measured phase profiles. The step in phase across the junction was measured to be 3.5-4.0 radians, while the total sample thickness t was determined to be 5.7±0.3 λ from holographic amplitude images, where λ is the mean free path for inelastic scattering [1], as shown in Figure 2.

Previous work has shown that even careful FIB sample preparation can result in the presence of a ~25 nm amorphous layer on the specimen surfaces in addition to crystalline electrically inactive layers of similar thickness [2]. Accordingly, the specimen was Ar ion milled at 1 kV for 6 minutes on each side in an attempt to reduce the thickness of the damaged surface layer [3]. High-resolution TEM images of the sample edges, acquired before and after milling, indicate that the amorphous layer had decreased in thickness from 23 to 4 nm, as presented elsewhere in these proceedings.

The effect of low energy Ar ion milling on the phase shift across the junction is both surprising and interesting. The phase shift decreased substantially after low energy milling, despite the fact that the change in t/λ (Figure 2) was negligible to within experimental error. A further slope (or step) in the phase developed on one side of the junction after low energy milling (Figure 1). The complicated shape of the resulting phase profile may be associated with the combined effects of Ga and Ar implantation on the electrical properties of the thin specimen, which are not understood at present. A systematic investigation of the effect of subjecting similar specimens to a wide range of Ar ion doses is presently being undertaken.

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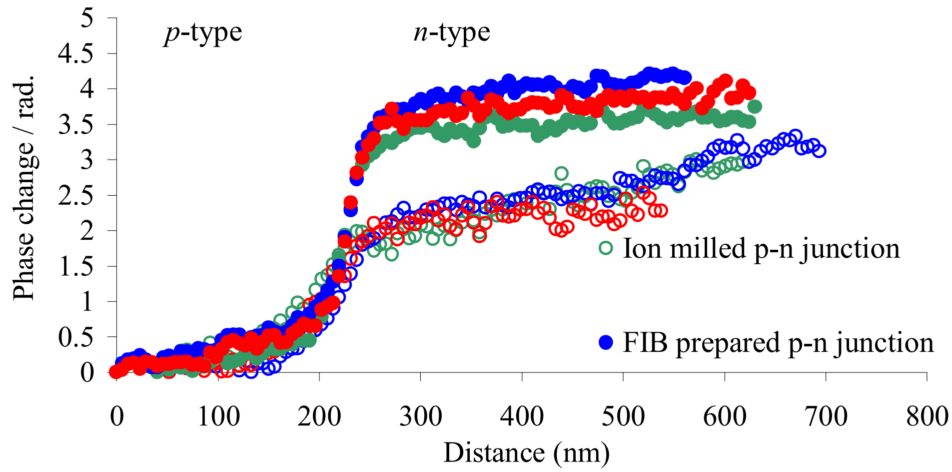

Figure 1. Measured phase shift across the FIB prepared *p-n* junction before and after argon ion milling.

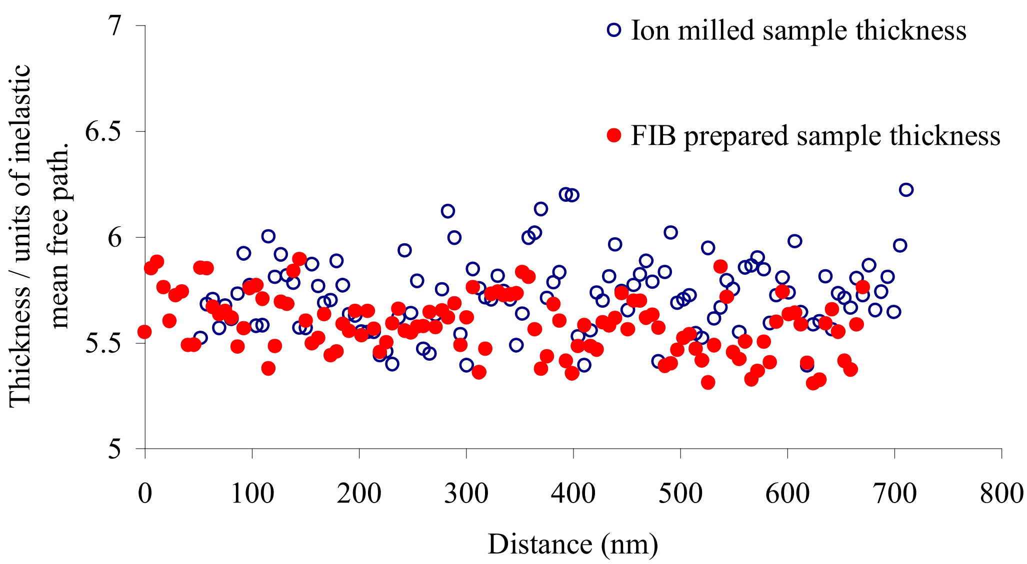

Figure 2. Sample thickness line profiles across the *p-n* junction determined from the reconstructed amplitude image.