Why Does Semiconductor Research Require Electron Holography?

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The ability to characterize ever smaller device features is of importance for the future development of semiconductor technology. For this reason, the semiconductor industry has demanded a reliable technique that can be used to obtain quantitative information about dopant distributions in semiconductors with a spatial resolution of better than 10 nm, both for the evaluation of process parameters and to provide input to simulations of dopant diffusion. Off-axis electron holography in the transmission electron microscope (TEM) has the potential to provide such information. However, further work is required to obtain a full understanding of the effect of TEM specimen preparation and electron beam irradiation on results obtained from semiconductor devices using electron holography. FIG. 1 shows holographic phase profiles acquired from a GaAs *p-n* junction that was prepared for TEM examination using focused ion beam (FIB) milling. *In situ* annealing of this specimen in the TEM is found to increase the phase shift across the junction, while at the same time decreasing noise in the recorded phase profile, suggesting that annealing can be used to remove defects resulting from Ga+ implantation and to reactivate dopant atoms in thin TEM specimens [1]. Measured phase profiles can also be sensitive to the electron beam current, i.e., to the rate at which charge is dissipated from the area of interest. An understanding of these issues can be obtained experimentally by combining electron holography with electron tomography to obtain three-dimensional measurements of electrostatic fields in materials directly. FIG. 2 shows a measurement of the three-dimensional potential in an FIB-milled Si TEM specimen containing a *p-n* junction [2]. Although *in situ* annealing can be used to reduce the thicknesses of electrically-altered near-surface layers such as those seen in FIG. 2, the effects of surface depletion on the potential in a thin specimen are always expected to be present. A simulation of the effect of surface depletion on the electrostatic potential in a thin Si *p-n* junction specimen is shown in FIG. 3.

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[2] Twitchett, A.C., Dunin-Borkowski, R.E., Yates, T.J.V., Midgley, P.A. and Newcomb, S.B. *J. Phys. Conf. Ser.* **26** (2006) 29-32

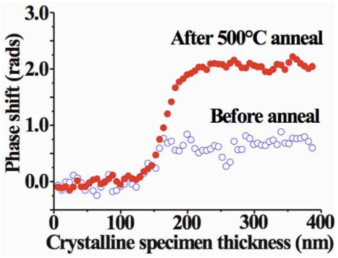

FIG. 1. Phase profiles across a *p-n* junction in a 300 nm focused ion beam milled GaAs specimen measured before (open circles) and after (closed circles) heating at 500°C.

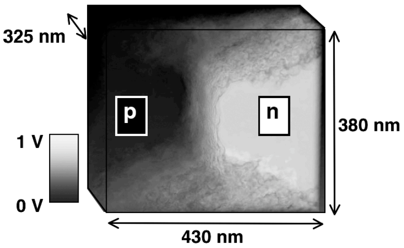

FIG. 2. Three-dimensional potential in a Si *p-n* junction specimen prepared using focused ion beam milling, measured from a tilt series of holographic phase images acquired every 2° over ±70°.

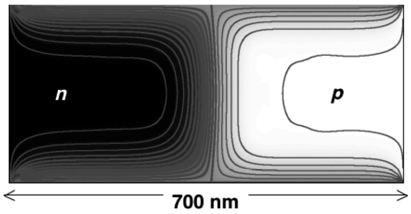

FIG. 3. Simulated potential in a 300 nm Si specimen containing a *p-n* junction formed from 10^{17} cm^{-3} Sb and B. The surface potential is 0.7 eV above the Fermi level. 0.05 V contours are shown.