The use of low energy Ar ion milling to reduce surface damage on silicon resulting from focused ion beam milling

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Focused ion beam (FIB) milling is increasingly used to prepare site-specific regions of semiconductor devices for transmission electron microscopy (TEM). However, the Ga ion beam causes severe damage to the crystal lattice close to the specimen surfaces [1]. Here, we show that low energy Ar ion milling [2] can be used to remove much of the damage on the surfaces of FIB milled silicon samples.

A [110] Si cross-sectional sample containing a single p-n junction was prepared for TEM examination using an FEI FIB 200 workstation. The top surface of the wafer was protected by depositing a Pt strap before milling. The thinned specimen, whose geometry is shown schematically in Figure 1, was then glued onto a semicircular Cu ring. A bright field image of the edge of the thin membrane, which was acquired at 300 kV using a JEOL 3010 TEM, is shown in Figure 2. A 23 nm amorphous layer is visible at the specimen edge, and the Si lattice fringes can barely be resolved.

A low energy Ar ion gun [3] was used to thin both sides of the specimen at 1 kV for 6 minutes at an angle of incidence (θ) of 75^o measured from the surface normal. Final thinning was carried out at 300 eV for 15 minutes. Both cases the sample was oscillated by ± 10^o during thinning. The Ar ion beam hit the sample from the side of the Pt coating layer. An equation was derived from our experimental data, which predicts the thickness of the damaged layer in the function of energy and angle of incidence: $d[nm]=20*E[keV]^{0.6}*\cos\theta$. The equation is valid for silicon for Ar ions and predicts the thickness of 2.5 nm for the amorphous surface layer in the case of the present experimental data.

High-resolution images revealed that the amorphous layer at the specimen edge had been reduced to a thickness of 3-4 nm (Fig. 3). This shows that the amorphous coverage of the sample should be around the predicted data. Although Si and Pt lattice fringes could be resolved clearly after low energy milling, it should be noted that care is required using this procedure to avoid bending of the final specimen due to internal stresses in the membrane [4].

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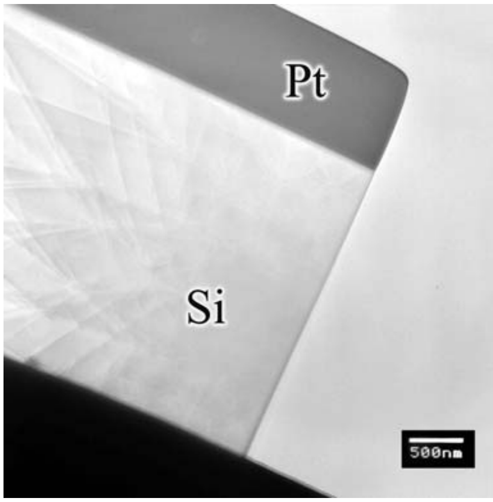

Figure 1. Overview of the sample after FIB preparation.

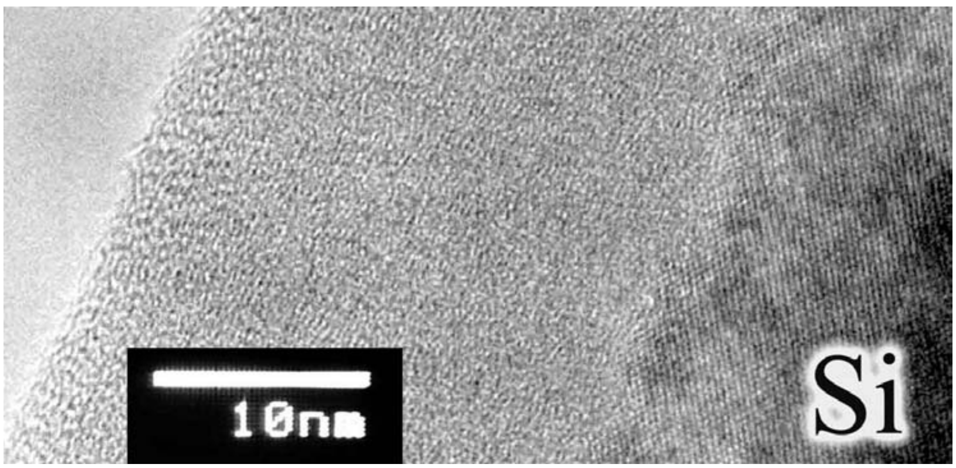

Figure 2. High resolution image taken on the Si sample after FIB preparation. Thick amorphous coverage is evident from the image taken at the edge of the sample.

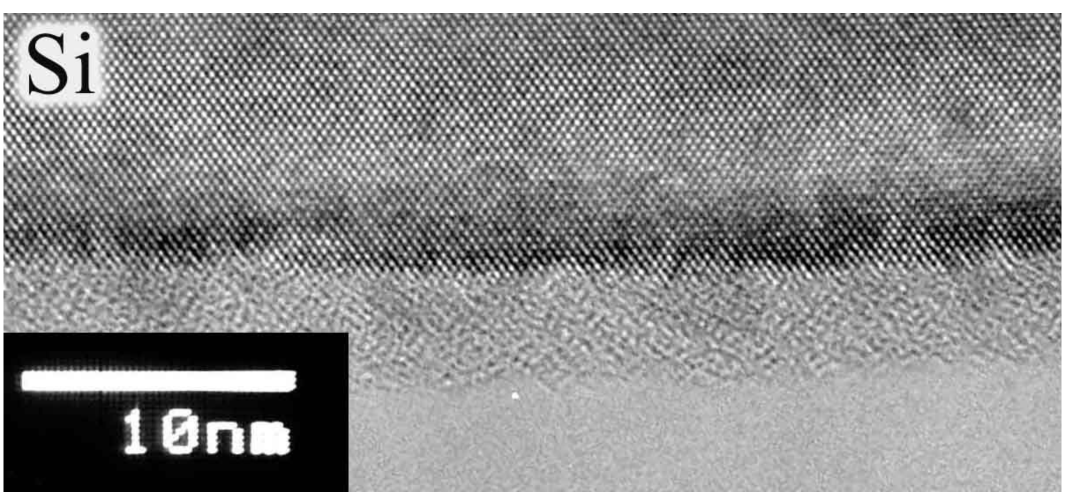

Figure 3. High resolution image taken on the above sample after low energy Ar ion bombardment. The damage is reduced substantially.