Multiple double XTEM sample preparation of site specific sub-10 nm Si nanowires

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The ability to prepare a transmission electron microscope (TEM) cross-section (X-TEM) sample of a sub-30 nm Si nanowire (NW) semiconductor device from a previously prepared X-TEM sample has been demonstrated.[1] In [1], an X-TEM sample of a Si NW device was first sectioned in the direction along the wire using a dual beam focused ion beam (DB-FIB) and the device gate length and morphology were determined from TEM images of this sample. The X-TEM sample was then placed back in the DB-FIB and sectioned at 90 degrees from the original direction. Here, the Si NW diameter and gate stack films could also be characterized. From [1], both the gate length and the NW diameter could be measured in the same electrically tested Si NW device breaking the barrier where one had to choose one or the other physical measurement to understand the electrical measurements. In this paper we demonstrated how this method is further extended to allows multiple X-TEM samples to be prepared from one X-TEM sample of a sub-10 nm Si NW device and the results of this process are presented in this paper.

In Fig. 1a, a low magnification TEM image of a sub-10 nm Si NW device is shown. The X-TEM sample oriented along the NW direction was prepared in a DB-FIB using in-situ liftout sample preparation. In the section, six Si NW's devices were imaged, see Fig. 1b for an intermediate magnification TEM image of one of the Si NW devices. This X-TEM sample was sufficiently thin that high resolution TEM (HR-TEM) imaging of the Si lattice in the NW could be obtained in the gate region. This X-TEM sample was then placed back in the DB-FIB and four of the six NW's in the original X-TEM sample were targeted for re-sectioning. The original X-TEM sample was attached to an in-situ liftout probe and detached from the original TEM grid. A second in-situ liftout grid was rotated at 90^{o} from the original sample direction and the targeted regions of the original X-TEM sample were then reattached to separate fingers on the second grid. Once on the grid, the targeted regions were thinned to TEM transparency using the FIB ion beam.

Fig. 2 shows a series of TEM images of the four targeted regions. Successful second X-TEM samples of sub-10 nm Si NW's were obtained for three of the four regions. Considerable bend in the NW sample is seen in the second samples which could have been caused from stress generated from encapsulating the samples in FIB deposited e-beam Pt. The pitch between consecutive X-TEM samples is 1.1 μm. The damage layer in the Si substrate from the first X-TEM sample ion beam preparation is ~ 13 nm. The Si NW diameters ranged from 8.0 to 9.7 nm. Fig. 3a shows a HR-TEM image of the NW diameter and Fig. 3b shows a HR-TEM image of the NW length. These images show that HR-TEM imaging of an identical region can be obtained in directions that are 90^{o} from each other. This method was proved to be especially useful to study process variation in an array of adjacent devices.

References:

1. L.M. Gignac, S. Mittal, S. Bangsaruntip, G.M. Cohen, and J.W. Sleight, Microscopy Microanalysis, **15**, 330 (2009).

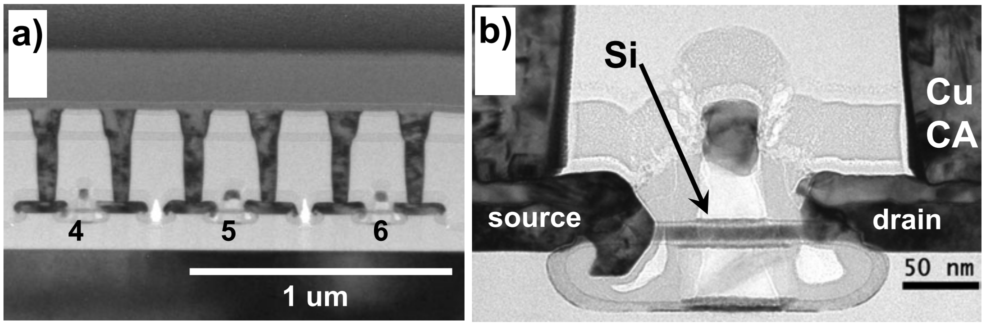

Figure 1: a) Low magnification TEM image of sub-9 nm diameter Si NW's sectioned along the NW direction and b) higher magnification TEM image of NW 4.

Comment: Not clear if the arrow points to poly-Si in the gate or the Si-NW

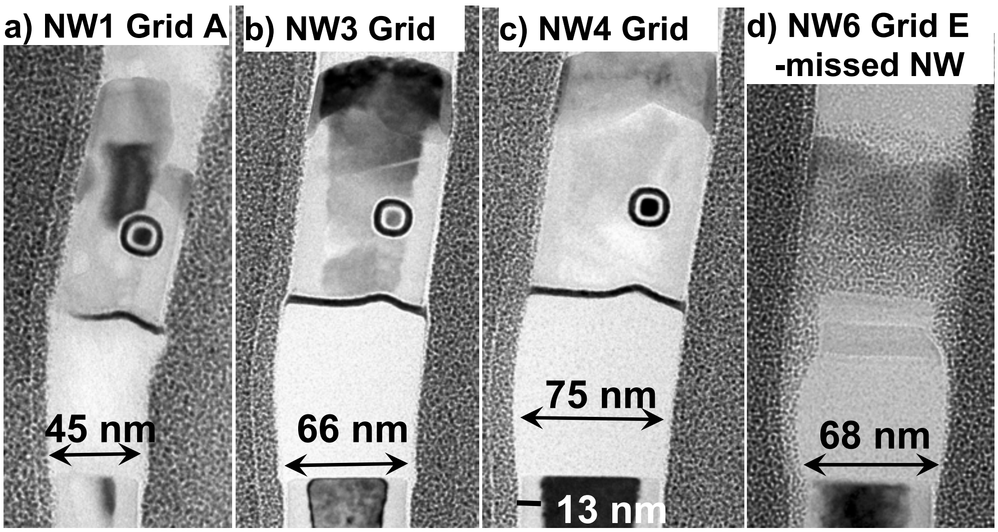

Figure 2: TEM images of a) NW 1, b) NW 3 and c) NW 4 obtained from samples prepared from the X-TEM sample in Fig. 1. d) NW 6 was missed while sectioning.

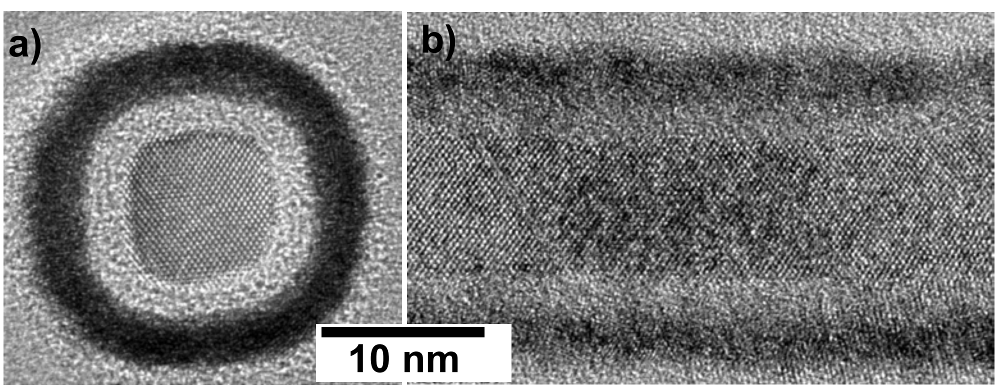

Figure 3: HR-TEM images of NW 4 sectioned a) perpendicular and b) parallel to the NW direction.