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Hanif, Imran, Hinks, J. A. and Donnelly, S. E.

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Transmission Electron Microscopy of Amorphisation and Recrystallisation of Silicon Nanowires under *in situ* Ion Irradiation

I Hanif*, JA Hinks and SE Donnelly
Computing and Engineering, University of Huddersfield, Huddersfield, HD1 3DH

Introduction

In the last decade, nanowires (NWs) have been the subject of intense scientific research and of particular interest are semiconductor NWs. Silicon (Si) is an attractive material for the microelectronic industry due to its mechanical strength, abundance, cost, electrical properties, ease of wafer production and high-temperature performance. The quest to continually miniaturise Si-based microelectronics poses challenges as the limits of current technologies are reached. For example, at increasingly small dimensions issues such as leakage current and short channel effects become critical. Therefore novel solutions are required with similar thermal, electrical, mechanical and optical properties whilst overcoming the shortcomings of bulk Si. Silicon NWs are one of the main candidates as they posses many of the same properties as bulk Si whilst offering solutions to many of the challenges faced by virtue of their geometry.

Ion irradiation is the main processing technique for Si based devices. The current work is focused on understanding the underlying physics and mechanisms of amorphisation and recrystallisation of single crystal Si NWs under ion irradiation. The ion irradiation causes displacement of atoms and accumulation of damage resulting in the amorphisation of the NWs. However, the probability of the ions being implanted into the NW and the amount of damage they cause both vary as complicated functions of ion species, energy and NW diameter. Implanted ions may perturb the amorphisation and recrystallisation processes under study. Therefore the irradiation conditions must be designed to achieve maximum damage with the minimum amount of implanted ions. Monte Carlo calculations have been performed using the Stopping Range of Ions in Matter computer code [1] and these have been used to determine the optimum irradiation conditions, Fig 1.

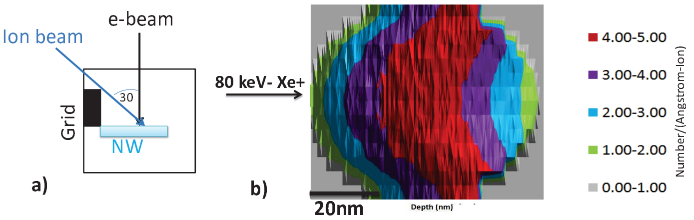

Figure 1: (a) Shadowing effect of grid on nanowire, (b) cross-section of the nanowire with the damage plotted across the two spatial dimensions for 50nm Si NW with 80keV- Xe+ calculated from SRIM.

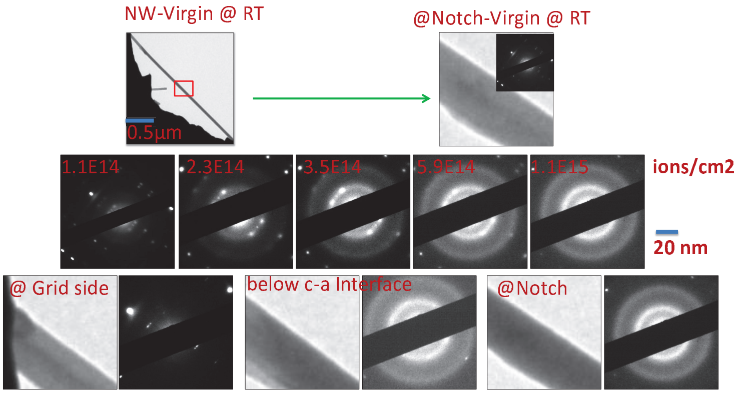

Figure 2: BF TEM images of a Si nanowire fixed with TEM Cu grid (1st row), DPs at different fluence (2nd row) for amorphisation. BF TEM images with DPs showing the shadowed region (bottom left), c-a interface region (centre) and the irradiated region (bottom right).

Experimental

Preliminary experiments have been carried out using the Microscope and Ion Accelerator for Materials Investigations (MIAMI) facility at the University of Huddersfield. Irradiation of Si NWs with 40 keV Ar^+ ions has been performed *in situ* within the JEOL JEM-2000FX transmission electron microscope (TEM) to induce amorphisation within the NWs. Commercially available polydispersed Si Nanowires were used and have been irradiated at room temperature. The nanowires have been irradiated with a flux of 6.30×10^{14} ions $cm^{-2}\ s^{-1}$.

Results and Discussion

Figs 2 and 3 represent a transition from crystalline Si (c-Si) to amorphous (a-Si) phase. Since c-Si has lower free energy than amorphous Si, so there is a tendency to recrystallise from a-Si phase to c-Si phase at elevated temperatures. It has been observed during the experiment that recrystallisation occurs at temperatures above 450C.

Through design of the experimental geometry, it has been possible to use the sample support to shadow part of the NWs from the ion beam and thus create a crystal-amorphous (c-a) interface across the diameter of a NW. Further, by careful tuning of the ion energy to the NW diameter it has been possible to create a buried c-a interface along the length of a NW. The irradiation caused the amorphisation of the 80 nm thick nanowire to be examined, with few dots in the diffraction pattern (DP) showing crystallites at back side of nanowire due to low fluence of ion beam, Fig 2.

Upon thermal annealing, Si NWs undergo a recrystallisation processes which have been found to cause either a return to a single-crystalline state similar to the pre-irradiated state or a polycrystalline state. Preliminary results suggest it is possible to control the recrystallisation via the engineering of the c-a interface. TEM images and diffraction patterns (DPs) are presented showing the amorphisation and recrystallisation processes in the crystalline, c-a interface and amorphous regions. Further work will focus on the fundamental mechanisms behind the amorphisation and recrystallisation processes in Si NWs. It has been analysed from the DPs that the irradiated region of nanowire in Fig 3, mixed regrowth mechanism occurred showing the recovery via layer by layer process called epitaxial growth and random nucleation growth (RNG) for amorphous Si resulting in single crystal recovery.

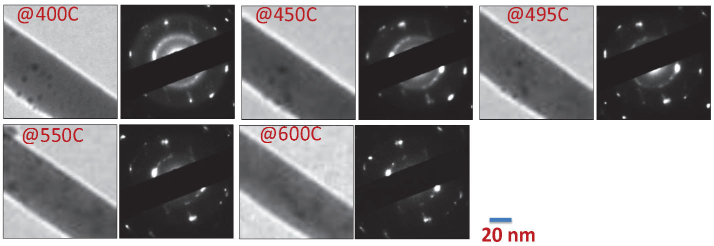

Figure 3: BF TEM images of Si nanowire at Irradiated region (notch) with DPs at different temperatures during annealing treatment.

Conclusions

Both the Solid Phase Epitaxial Growth (SPEG) and Random Nucleation Growth (RNG) were seen in the amorphised Si nanowire during annealing experiment. Further experiments are needed to fully amorphise the NW at the calculated fluence of the ion beam w.r.t the diameter of Si NW and to quantitatively verify the recrystallisation phenomena occurring at temperature of 450C for Si NWs.

References

[1] JF Ziegler, M Ziegler and J Biersack Nucl. Instrum. Meth B 268 (2010) p1818.
[2] A Irrera, E F Pecora and F Priolo, Nanotechnology, 20 (2009) 135601 (7pp).
[3] A. Battaglia and S. U. Campisano, J. Appl. Phys. 74, 6058 (1993).
[4] Emanuele F. Pecora · Alessia Irrera · Simona Boninelli, Appl Phys A (2011) 102: 13-19.

*E-mail: imran.hanif@hud.ac.uk