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

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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. Si nanowires are one of the main candidates as they possess 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 focus is 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. Implant 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.](image)

Experimental
Preliminary experiments have been carried out using the microscope and ion accelerator of the Materials Investigation (MAMI) facility at the University of Huddersfield. Irradiation of Si NWs with 40 keV Ar+ ions has been performed in situ with the JEOL JEM-2000FX transmission electron microscope (TEM) to induce amorphisation within the NWs. Commercially available poly(p-terphenyl) Si Nanowires were used and have been irradiated at room temperature. The nanowires have been irradiated with a flux of $6.3 \times 10^4$ 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, 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 450°C.

![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-Si interface region (centre) and the irradiated region (bottom right).](image)

![Figure 3: BF TEM images of Si nanowire at irradiated region (notch) with DPs at different temperatures during annealing treatment.](image)

Conclusions
Both the Single 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 characterise the NWs at the calculated fluence of the ion beam with the diameter of SI NW and to quantitatively verify the recrystallisation phenomena occurring at temperature of 450°C for Si NWs.

References

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