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In Situ Transmission Electron Microscopy Observation of 3C-SiC Heteroepitaxial Growth on Si Nanomembrane

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In situ transmission electron microscopy (TEM) is an ideal technique for unveiling growth process at the nanoscale. It is especially useful to study the growth process of thin film or two-dimensional materials [1]. Among of them, many researchers are interested in a study of heteroepitaxy for 3C-SiC. However, the lattice mismatch between the 3C-SiC and Si substrate (a_{SiC} = 0.436 nm and a_{Si} = 0.543 nm, ~19%) makes controlling the large area production and high quality difficult. The mismatches in the lattice parameters are the issues for the heteroepitaxial growth. Several growth model and analysis methods have been proposed to overcome these issues [2].

Herein, we demonstrate the growth process of 3C-SiC nanostructures on (001) Si nanomembrane (NM) using in situ heating TEM. Si NM is made by a (001) silicon on an insulator wafer thorough the control of thickness in oxidation and etching process. Detailed steps for preparing Si NM to observe the heteroepitaxial growth of 3C-SiC at nanoscale is described in reference [3]. To study the growth process of 3C-SiC on the Si NM, heating experiments were carried out at 700 °C. We observed that the etching of surface layer proceeded and 3C-SiC nanostructures laterally grew from the exposed surface along the specific orientation of Si NM in TEM (Figure 1). These results indicated that surface deformation compensated the lattice difference between Si NM and 3C-SiC, and supply of reactant molecules would be required for further growth of 3C-SiC. Reactant molecules for growth corresponds to the hydrocarbon contamination (C_xH_y) are absorbed during preparation of the Si NM or comes from within the TEM column. It was confirmed that the amorphous C_xH_y was crystallized during heating in TEM. Through the HRTEM image, we also showed the lattice distance of the (220) 3C-SiC 1.58 Å, increase of 3% from the existing value of 1.53 Å. This is considered the bowing effect that compensated the lattice misfit as bending of Si NM at nanoscale (Figure 2). The bowing effect results in elongation about the Si surface lattice, which helps to grow the 3C-SiC without defects. We provide experimental evidence for the heteroepitaxial growth of 3C-SiC through the comparison of similar intensity between the simulation and the experimental image in TEM (Figure 2) [4].

Heteroepitaxial growth of 3C-SiC is observed using the thermal E-chip of in situ heating TEM system on a double-tilted platform called Aduro Protochips that provides atomic resolution with a highly accurate temperature control. TEM experiments were performed by FEI Titan cube G2 60-300 operated at an acceleration voltage of 200 kV [5].

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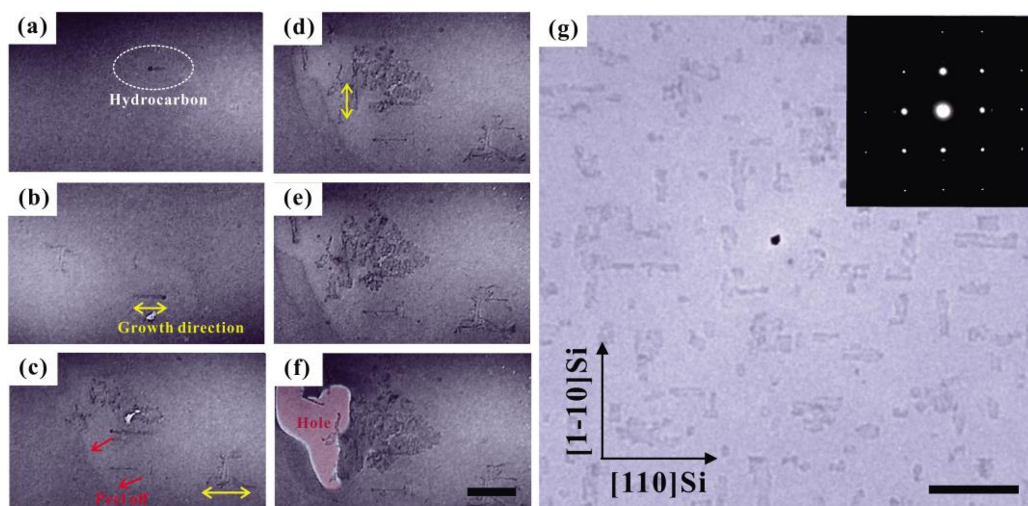

Figure 1. (a-f) TEM images show the process of surface etching and lateral growth of 3C-SiC. Outer layer etched and 3C-SiC grow along the yellow arrow. The scale bar is 200 nm. (g) TEM image of the region without transmitted electron beam shows the nanostructures of 3C-SiC grown along the Si NM. The scale bar is 200 nm. Diffraction pattern indicates the heteroepitaxial growth (001) 3C-SiC nanostructures on (001) Si (inset).

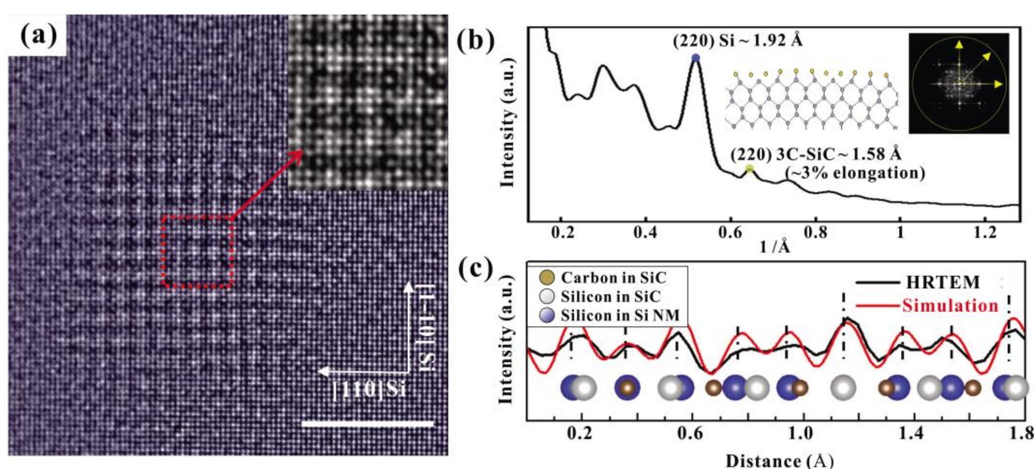

Figure 2. (a) HRTEM image shows the heteroepitaxial growth of 3C-SiC nanostructure on Si NM. The white arrows are the orientation of the Si NM. The scale bar is 5 nm. (b) Radial distribution function from the FFT image (inset) for 3C-SiC on Si NM. (c) Result of intensity comparison between the HRTEM image and result of simulation.

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