Supporting Information

Solvent Vapor Growth of Axial Heterostructure Nanowires with Multiple Alternating Segments of Silicon and Germanium

Grace Flynn, Quentin M. Ramasse, Kevin M. Ryan*
† Materials and Surface Science Institute and Department of Chemical and Environmental Sciences, University of Limerick, Ireland
‡ SuperSTEM Laboratory, SciTech Daresbury Campus, Daresbury WA4 4AD, United Kingdom

Figure 2 (a) : Si-Ge
Approx. Segment Length (nm) 900 600 ---- ----
Growth Time (min) 40 7.5 ---- ----
Growth Rate (nm/min) 22.5 80 ---- ----

Figure 2 (b) : Ge-Si
Approx. Segment Length (nm) 390 240 ---- ----
Growth Time (min) 5 10 ---- ----
Growth Rate (nm/min) 78 24 ---- ----

Figure 2 (d) : Ge-Si-Ge
Approx. Segment Length (nm) 1400 1800 750 ----
Growth Time (min) 20 70 10 ----
Growth Rate (nm/min) 70 25.7 75 ----

Figure 2 (e) : Si-Ge-Si-Ge
Approx. Segment Length (nm) 1460 880 960 810
Growth Time (min) 60 10 40 10
Growth Rate (nm/min) 24.3 88 24 81

Average Growth Rate for Si $24.1 \pm 1.14 \text{ nm/min}$
Average Growth Rate for Ge $78.7 \pm 6.06 \text{ nm/min}$

Figure S1: Comparison of the segment lengths and growth times for the Si-Ge, Ge-Si, Ge-Si-Ge and Si-Ge-Si-Ge heterostructure NWs seen in Figure 2 (a), (b), (d) and (e) respectively. It can be noted that the growth rate for the Ge segments is over three times the growth rate for the Si segments.
Figure S2: Interfacial abruptness determination of a Ge-Si hNW (a) Low magnification BFSTEM image of a Ge-Si hNW. (b) Rotated HAADF image of the region indicated by the red box in (a). (c) HAADF image of the spectrum region used for EELS analysis as highlighted by the red rectangle in (b). (d) EELS map corresponding to the HAADF in (c) showing the elemental distribution, with the Ge and Si signals indicated by red and green respectively. (e) Graph generated of the normalised intensity across the Ge-Si interface with the direction given by the arrow in (c). The HAADF image was acquired simultaneously with the EELS data.
Figure S3: Phase diagrams for Si-Sn and Ge-Sn. (a) Phase diagram for the Si-Sn alloy and (b) phase diagram for the Ge-Sn alloy.
Figure S4: Interfacial abruptness determination of a Ge-Si hNW with a more complicated interface (a) Low magnification BFSTEM image of the Ge-Si hNW. (b) HAADF image of the region indicated by the red box in (a). (c) HAADF image of the spectrum region used for EELS analysis as highlighted by the rectangle in (b). (d) EELS map corresponding to the HAADF in (c) showing the elemental distribution, with the Ge and Si signals indicated by red and green respectively. (e) Graph generated of the normalised intensity across the Ge-Si interface with the direction given by the arrow in (c). The HAADF image was acquired simultaneously with the EELS data.
Figure S5: A Ge-Si hNW from a Ge-Si hNW reaction without a toluene rinse before the subsequent Si reaction, similar to the hNW observed in Figure 4. (a) and (b) TEM and STEM images respectively (with higher magnification images inset) of the Ge-Si hNW, where the contrast difference clearly shows the re-incorporation of a Ge rich region. (c) to (f) EDX line scans corresponding to the blue, green, yellow and orange arrows in (b) and inset of (b), showing the complex transition where there is a Ge rich region, before the pure Si segment commences. The increased Sn intensity in (c) corresponds to a region where a Sn seed is lying on the NW surface.
Figure S6: STEM images of different Ge-Si hNWs produced for a Ge-Si hNW reaction without a toluene rinse before the subsequent Si reaction. (a) a graded Ge-SiGe (alloy) hNW where the contrast difference shows continuous changes in the material along the length of the “Si” segment, (b) – (f) Ge-Si hNWs showing varying compositions for the “Si” segment, ranging from a large transitional region to quite a sharp transition, with corresponding EDX line scans.
Figure S7: TEM, DF-STEM and EDX line profile of the Sn-Si interface for a Si-Ge-Si hNW. (a) and (b) Low magnification TEM and DF-STEM images of a Si-Ge-Si hNW. (c) Higher magnification DF-STEM image of the Sn-Si interface, with the corresponding EDX line scan in (d).
Figure S8: TEM images and EDX line profile for a Ge-Si-Ge hNW. (a) and (b) Low magnification TEM and DF-STEM images of a Ge-Si-Ge hNW. (c) Higher magnification DF-STEM image of the Ge-Si interface indicated by the red box in (b), with the corresponding EDX line scan given in (d). (e) and (f) Higher magnification DF-STEM image of the Si-Ge interface indicated by the blue box in (b) with corresponding EDX line scan.