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Structural, optical and electronic properties of Si/Ge nanowire heterojunctions

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Despite the known significant lattice mismatch (~ 4%), SiGe heterostructures and devices found numerous applications in electronics and photonics [1]. In many cases, including SiGe bipolar heterojunction transistors, the problem with the lattice mismatch and strain is solved by using $Si_{1-x}Ge_x$ alloys with $x < 0.2$. High-quality, low-defect density $Si/Si_{1-x}Ge_x$ superlattices typically have a similar Ge content (~ 0.2) while three-dimensional, cluster morphology $Si/Si_{1-x}Ge_x$ multilayer nanostructures might have Ge content x approaching 0.4-0.5 [1]. While a higher Ge composition is desirable, the device geometry and performance are limited by the critical thickness, strain and unavoidable formation of structural defects (e.g. dislocations, etc.).

Semiconductor nanowires grown by the vapor-liquid-solid (VLS) method are known since 1970s but high quality nanowire heterojunctions were demonstrated only recently [2]. Also, it was suggested that in lattice mismatched axial nanowire heterojunctions (e.g., Si/Ge, etc.), strain can be relaxed by the nanowire lateral expansion (in the direction perpendicular to the growth direction [3]). This approach can lead to successful development of Si/Ge heterojunctions with no limitations associated with strain and critical thicknesses.

In this work, Si/Ge and Si/Ge/Si axial nanowire heterojunctions are grown by the VLS method using Au nanoparticles as a precursor. Their structural and optical properties are studied by using high resolution transmission electron microscopy (TEM), Raman scattering (RS) and photoluminescence (PL). Figure 1 shows TEM micrograph of Si/Ge nanowire heterojunction. The theoretically predicted lateral nanowire expansion in the vicinity of Si/Ge heterojunction is clearly observed. Detailed structural analysis of the Si/Ge heterointerface composition within the nanowire is performed and will be discussed.

In addition to the observed nanowire lateral expansion, the lattice mismatched induced strain could be relaxed by other mechanisms including nanowire bending and kinking, formation of structural defects and amorphization. The lattice-mismatch is found to be accompanied a mismatch in thermal expansion, which introduces additional strain detected by PL measurements. Electrical measurements reveal that carrier transport across Si/Ge heterointerface is controlled by the heterointerface carrier scattering.

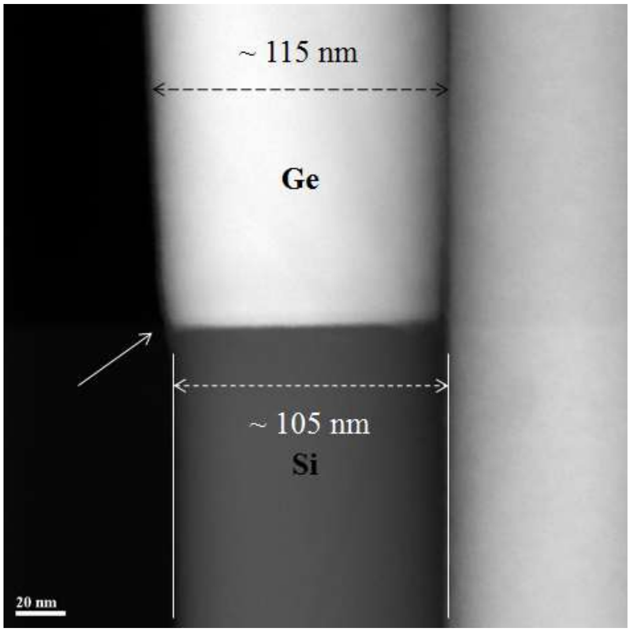

Fig. 1. High angle annular dark field STEM image of Si/Ge nanowire heterojunction showing the nanowire lateral expansion.

References

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