

Photoluminescence and Raman Analysis of Ge-Rich SiGe Nanowires

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Introduction

Semiconductor nanowires have attracted enormous attention as building blocks for nanoscale electronics [1], photonics [2], thermoelectrics [3], and etc., thanks to their unique electronic, optical, and phonon properties [4]. Self-assembled SiGe Nanowires (NWs) have been of extensive interest mainly because of their potential applications in novel devices compatible with the sophisticated Si integration technology. For novel device applications, it is demanded to understand the fundamental properties of SiGe alloy nanowires. For instance, carrier confinement in nanoscale SiGe alloys is expected to enhance the material properties of SiGe alloys [1].

In this letter, photoluminescence spectra and Raman spectra were obtained from ten layers of SiGe nanowires, which were self-assembled during Ge deposition on miscut Si (001) substrates with $\sim 8^\circ$ off toward $\langle 110 \rangle$ by molecular beam epitaxy (MBE). The power dependence and the temperature dependence of PL spectra from SiGe NWs were systematically investigated. Raman spectra of SiGe NWs was also analyzed to extract Ge composition.

Experimental

Materials

The samples were grown by MBE in a Riber Eva-32 on miscut Si (001) substrates with $\sim 8^\circ$ off toward $\langle 110 \rangle$, which is also called as (1 1 10) substrates. The substrate was cleaned using RCA method followed with HF treatment to form hydrogen terminated surface. After a thermal desorption, a 100 nm thick Si buffer layer was grown at a rate of 0.5 Å/s to obtain smooth and clean surface. Ten layers of GeSi nanowires were obtained. In each layer, 0.8 nm Ge were deposited at 530 °C at a growth rate of 0.08 Å/s, which was separated by 10 nm Si spacer grown with ramping substrate temperature from 500 °C to 530 °C to suppress Si-Ge intermixing. Considering the Si-Ge intermixing during Ge deposition, we believed that the obtained nanostructures were SiGe alloy.

Apparatus and Procedures

The Raman measurement was carried out at room temperature in the back scattering configuration using a Jobin-Yvon HR800 micro-Raman spectrometer. The excitation wavelength was the 514.5 nm line of an Ar-ion laser. The laser beam was focused to a $\sim 1 \mu\text{m}$ diameter spot on the sample surface.

The PL measurement was performed with a frequency-doubled Nd:YAG laser, giving the wavelength 532 nm. During measurement, the laser was focused down to around 1 μm diameter spot on sample surface. The spectrometer is equipped with a liquid-nitrogen cooled InGaAs array detector.

Results and Discussion

Figure 1(a) shows PL spectra of ten layers of SiGe NWs obtained at 10K under different excitation powers. In general, the relationship between the integrated intensity (I) of PL peak and the excitation power (P) can be formulated by $I \propto P^m$ [5]. The power exponent m is found to be 0.60, as shown in Fig. 1(b). The sublinear power dependence of PL intensity from GeSi NWs is typical for a type II band alignment, which is attributed to a limited density of localized states for excitons, or nonradiative Auger recombination channels, or the influences of Coulomb screening due to large exciton densities [5]. With the increase of excitation power, a significant blue shift of PL peak was clearly observed, as shown in Fig. 1 (c).

Figure 2(a) shows PL spectra at different temperatures. With the increase of the substrate temperature, a significant red shift of PL peak related to SiGe NWs is clearly observed, which is mainly attributed to the temperature dependence of SiGe band gap. Fig. 2(b) shows temperature dependence of the integrated intensity of PL peaks of SiGe NWs. According to the formula [6],

$$I(T) = I(0) / [1 + \text{Cexp}(-E_a/kT)],$$

the activation energies for PL peaks from SiGe NWs is about 12.2 meV, as shown in Fig 2(b).

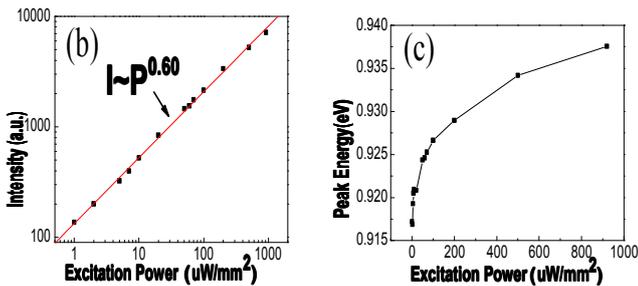
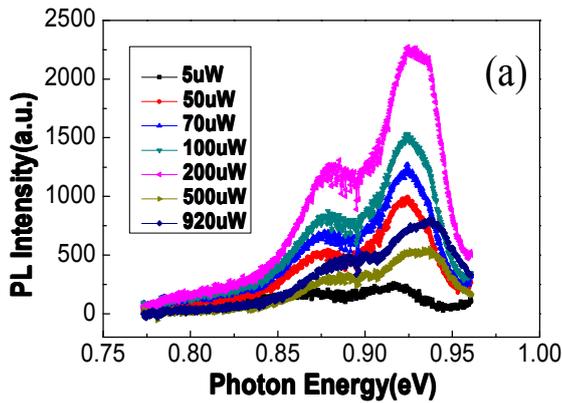


Figure 1.(a) PL spectra from ten layers of SiGe NWs temperature at 10K under different excitation powers. (b)Power dependence of integrated intensity of PL peaks. (c) Power dependence of the energies of PL peaks.

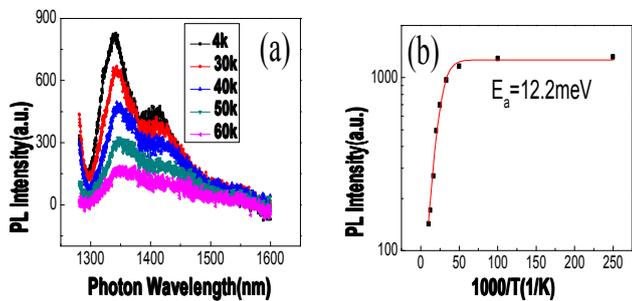


Figure 2 (a)PL spectra from ten layers of SiGe NWs under excitation power of 50uW/mm² at different temperatures. (b)Temperature dependence of PL intensity.

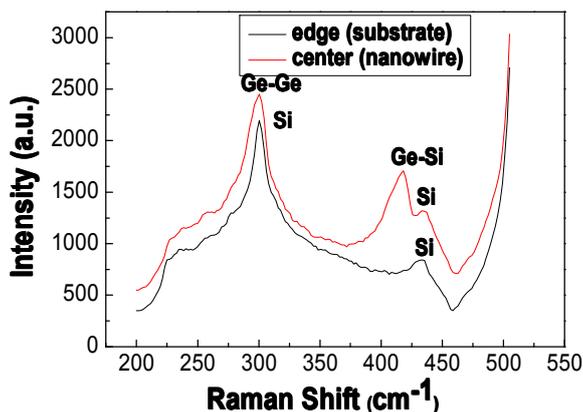


Figure 3. Raman spectra of Si substrate and SiGe NWs. The Ge–Si

and Ge–Ge modes originating from the nanowires are located at 417.8 cm⁻¹ and 295.3 cm⁻¹, respectively.

Figure 3 shows Raman spectra of Si substrate and SiGe NWs. The Ge–Si and Ge–Ge modes are located at 417.8 cm⁻¹ and 295.3 cm⁻¹, respectively. Renucci et.al.[7]have proposed a equation for the Ge–Si and Ge–Ge modes to derive Ge composition x in SiGe alloy,

$$I(\text{Ge-Ge})/I(\text{Ge-Si}) \sim (1-x)/(2x).$$

By fitting, I(Ge-Ge)=597.25, I(Ge-Si)=767.5, the composition of Ge in the SiGe NWs, is about 61%.

Conclusion

PL spectra of ten layers of SiGe NWs at 10K under different excitation powers are obtained. Power dependence of integrated intensity of PL is fitted and get power exponent is 0.60. No obvious saturation of PL intensity was observed in the present power excitation range. PL spectra in ten layers of SiGe NWs under excitation intensity of 50uW/mm² at different temperatures are measured. Temperature dependence of SiGe NWs PL intensity is fitted, and get the activation energy is 12.2meV, closing to the exciton binding energy in the SiGe QWs. By comparing the Raman spectra of Si substrate and SiGe NWs , the composition of the SiGe NWs is estimated to be about 61%.

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