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Spherical SiGe Quantum Dots Prepared by Thermal Evaporation Method

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Abstract

The thermal evaporation technique was used for the first time to synthesize spherical SiGe alloy quantum dots. In the past, Si quantum dots grown by the same method have been investigated by Morisaki et al.[1] This is different from the popular method such as molecular beam epitaxy (MBE) which synthesize SiGe quantum dots in nonspherical shape. The TEM images of nanoparticles grown by this method were investigated. Figure 1 display the TEM image of SiGe quantum dots grown at a pressure of 0.5 torr. It shows that the shapes of these SiGe particles are ball-like and the average size of the particles is about 20 nm. The smallest size of SiGe quantum dots thus prepared is 15 nm.

In order to make sure that the structure of these dots was Si-Ge alloy but not pure Si dot or Ge dot, the Raman spectrum of SiGe quantum dots grown at a pressure of 1 torr were measured and shown in Fig. 2. Three peaks are found in the spectrum, which correspond to different vibration modes in the dots. The peak location are 477 cm^{-1}, 291 cm^{-1} and 396 cm^{-1}, which correspond to TO phonon of silicon, germanium and Si-Ge alloy, respectively. The TO phonon peak of Si shifts from 521 cm^{-1} to 477 cm^{-1} because of the content of Ge in the dots is high. Alonso et al. have studied the relationship between the peak location and Ge content in the SiGe bulk.[2] Base on this result, it could be estimated that the fraction of Ge in the dots is near 0.6. A very close result have been observed by calculating the lattice constant of these dots from the electron diffraction pattern. It shows that the dots formed in the Ar gas is of the structure of crystalline Si-Ge alloy.

Shown in Figs. 3 are Si dots grown at different evaporation rates, where (a) and (b) are the TEM image and its diffraction pattern of the dots grown at low evaporation rate and (c) and (d) at higher rate. The results show that if the collision events were too few in the Ar gas, the size of these dots would be rather small. Hence, when they are deposited on the substrate, the structure of these dots would be distorted by the subsequent deposition of other dots which leads to an amorphous Si structure. If the collision events are increased, the dot size becomes larger and the surface distortion effect would be reduced and the structure of Si dots would become polycrystal. Figures 4. shows the Raman spectra of the samples show discuss previously. The peak located at 480 to 520 cm^{-1} corresponds to the TO phonon of silicon. As shown in figure 4(a), when the dots were grown at low evaporation rate, the peak was located at 480 cm^{-1}, which corresponds to amorphous structure. When the dots were grown at high evaporation rate, the peak was located at 510 cm^{-1}, which corresponds to polycrystalline structure.

Finally, it is concluded that thermal evaporation technique have successfully been used to synthesize SiGe quantum dots with spherical shape. This method is much simpler than the present MBE technology and have a high potential in optical application. The TEM images and Raman spectra of samples prepared at different evaporation rates tell us more about the growth mechanism

of the dots grown by this method.

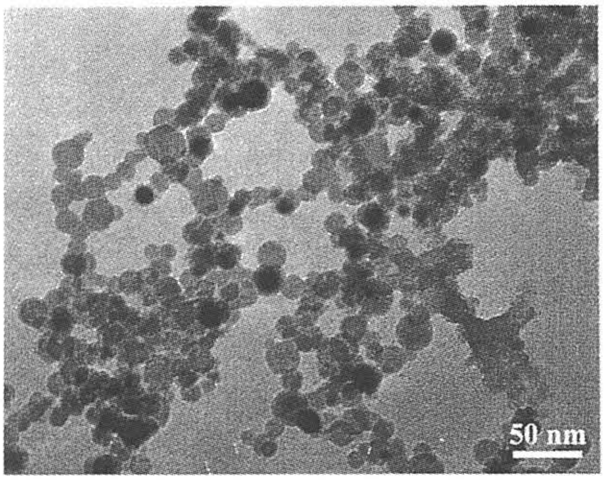

FIG. 1. TEM image of SiGe nanoparticles grown by thermal evaporation method at 0.5 torr.

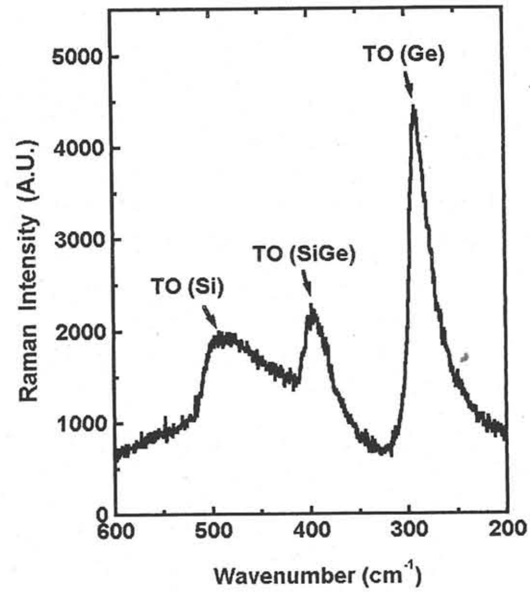

FIG. 2. Raman spectra of SiGe quantum dots grown by thermal evaporation method at a pressure of 1 torr.

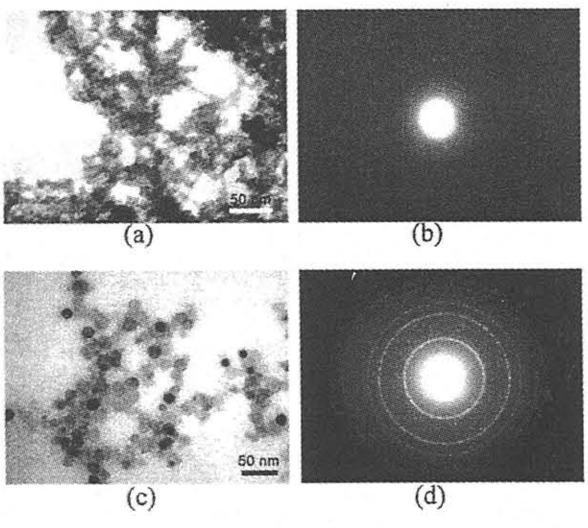

FIG. 3. (a) TEM image of Si quantum dots grown at low evaporation rate at 1 torr. (b) Diffraction pattern of (a). (c) TEM image of Si quantum dots grown at high evaporation rate at 1 torr. (d) Diffraction pattern of (c).

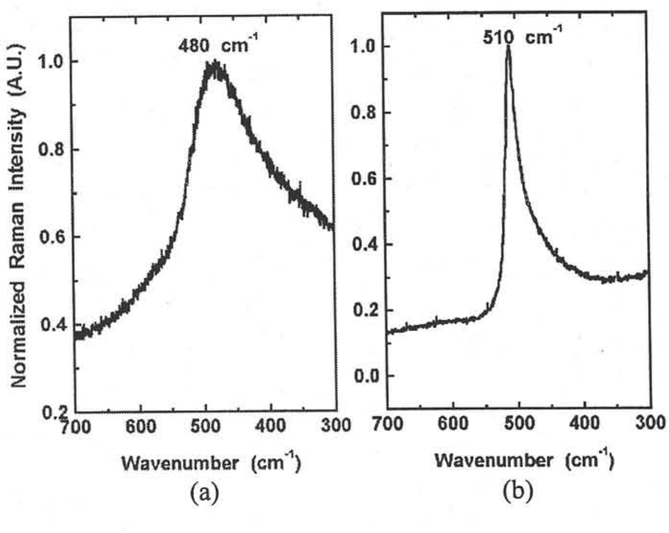

FIG. 4. Raman spectra of Si quantum dots shown in (a) Figs. 3(a) and 3(b) which were grown at low evaporation rate; (b) Figs. 3(c) and 3(d) which were grown at high evaporation rate.

[1] H. Morisaki, F. W. Ping, H. Ono and K. Yazawa, J. Appl. Phys. 70 (3), 1869 (1991).

[2] M. I. Alonso and K. Winer, Physical Review B 39 (14), 10056 (1989).