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Ni induced lateral crystallization of high density Ge-dots/Si heterostructures

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Abstract

In this work, we propose a novel method for obtaining high-density Ge-dots/Si multilayered heterostructures. The high-density self-assembled Ge dots are firstly grown on a-Si layer using low-pressure chemical vapor deposition (LPCVD), and then low-temperature recrystallized by Ni based metal induced lateral crystallization (MILC). According to optical micrograph, microprobe Raman spectroscopy and transmission electron microscopy (TEM) observations, it has been found that the Ni induced lateral crystallized Si film has large leaf-like grains elongated along the MILC direction with (110) preference. The strain shift of Ge dots reveals the formation of high quality interface between the crystallized Si and Ge dot.

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Keywords: Metal induced lateral crystallization; Heterostructure; Ge; Si

1. Introduction

During the last decade, self-assembled Ge quantum dots have attracted a great deal of interests for the realization of silicon-based quantum electronic and optoelectronic devices, such as mid-infrared quantum dot photodetectors [1–4]. In principle, it is expected that quantum dots have high density and size well controlling. Moreover, multilayered quantum dots are very important for some applications [4]. Due to the strain related self-assembled Ge dot formation mechanism deposited by molecular beam epitaxy (MBE) or chemical vapor deposition (CVD), the Ge dots on crystalline Si surface have low density usually with the disk-like shape of 40–80 nm in base diameter and 3–10 nm in height. Recently, it was demonstrated that the deposition of Ge dots on amorphous or microcrystalline Si surface (a-Si or μc-Si) could obtain high density and small size [5–7]. Unfortunately, a-Si or μc-Si is unacceptable for high performance devices. On the other hand, the metal-induced lateral crystallization (MILC) of a-Si has been intensively investigated, which is one of practical and promising low-temperature crystallization technique for high quality poly-Si [8–10]. This method has succeeded in crystallizing a-Si unitary system. Most recently, the influence characteristics of Ge doping in a-Si on MILC processing were reported [11,12]. The important advantages are that MILC velocity effectively increases, and that the inter-diffusion of Ge and Si hardly occur during MILC processing.

In this paper, we report on the fabrication of the high density Ge-dots/Si multilayered heterostructures combining LPCVD and Ni-based MILC processing. The crystallization characteristics of samples are investigated in details. The experimental results demonstrate that it is a promising fabrication method to obtain high quality Ge-dots/Si multilayered heterostructure films.

2. Experimental

The samples used in this work were prepared on the thermally oxidized SiO_2/(100) Si substrate. By using a low-pressure chemical vapor deposition (LPCVD) system, a 50 nm thick a-Si layer was first grown at 500 °C, and followed by several periods of self-assembled Ge dot layers separated by 30 nm thick a-Si spacer layers. Finally, a 50 nm thick a-Si top layer was capped on this multilayered structure. After the deposition, the finished samples were covered by 200 nm thick low temperature oxide (LTO), and then 10 nm thick Ni was sputtered onto patterned

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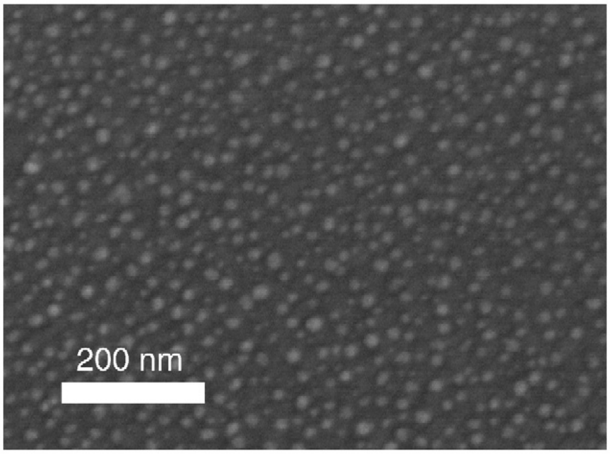

Fig. 1. SEM image of the Ge dots deposited on a-Si surface.

windows in a DC magnetron sputtering system at the rate of around 0.02 nm per s. The MILC annealing processes for the Ge-dots/a-Si films were performed at 550 °C for 1–20 h in a vacuum furnace. After the MILC processing, each sample was examined by optical microscopy (Orthoplan) and microprobe Raman spectroscopy (Jobin-Yvon T64000), to evaluate the growth length and crystal quality. The microstructures were characterized by scanning electron microscope (SEM: Leo 1530VP) and transmission electron microscopy (TEM: Tecnai F20), respectively. All measurements were performed at room temperature.

3. Results and discussion

Fig. 1 shows the top-view SEM image of self-assembled Ge dots grown on a-Si surface. It can be clearly seen that the Ge dots are quasi-sphere with the average size of ~10 nm and the density of 5×10^{11} cm^{-2}. At the same condition of deposition, in addition, it is observed that the Ge dots grown directly on crystalline or dioxided Si surface are disk-like shape with the large size of 80 nm.

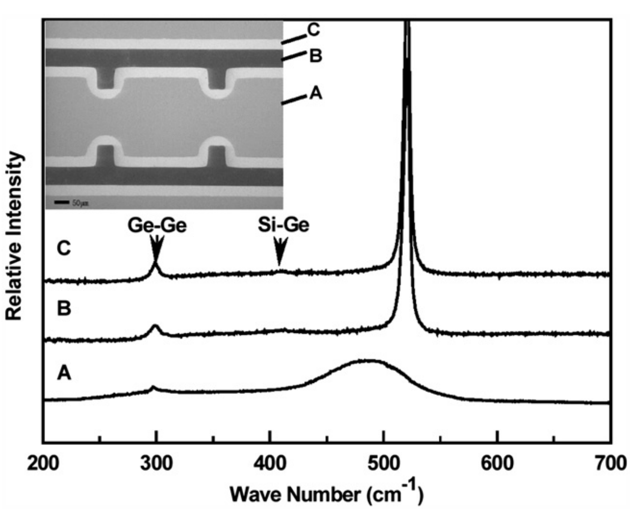

Fig. 2. Microprobe Raman spectra obtained in amorphous region (A), MIC region (B), and MILC region (C) in the Ge-dots/a-Si multilayered film with 3 periods after the MILC processing at 550 °C for 16 h. The inserted image is the optical micrograph of the corresponding sample. The length of the scale is 50 μm.

After the MILC processing, the crystallinity of the Ge-dots/Si multilayered heterostructure was evaluated by using microprobe Raman spectroscopy with the spot diameter of 1 μm and the spectral resolution of 0.5 cm^{-1}. The Raman spectra of the sample with 3 periods obtained in amorphous region (A), MIC region (B), and MILC region (C) are shown in Fig. 2, respectively. The Raman spectrum of the region A shows a broad peak near 480 cm^{-1} with a full width at half maximum (FWHM) of 60 cm^{-1} and an obvious Ge–Ge bond at 297.5 cm^{-1}. The broad peak at a frequency of 480 cm^{-1} is a transverse optical mode associated with a-Si, which reveals that the deposited Si is typically an amorphous phase. The position of the Ge–Ge bond implies that the Ge dots are crystallized and unstrained though the annealing at 550 °C. Furthermore, two visible peaks due to the vibration modes of the Si–Si bond at 520 cm^{-1} with the FWHM of 6 cm^{-1} and the Ge–Ge bond at 299 cm^{-1} are observed both in MIC and MILC regions. These data clearly indicate that the a-Si has well been crystallized to large

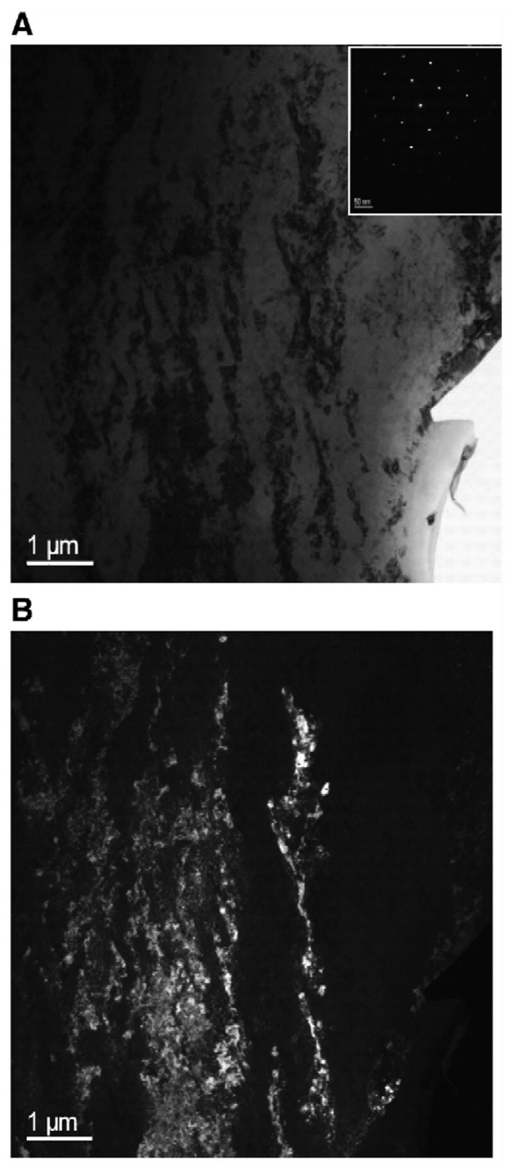

Fig. 3. TEM images of the sample given in Fig. 2: (A) bright field image of MILC region, (B) dark field image by using (220) diffraction spot.