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The study on microstructural and optical properties of nanocrystalline germanium films

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Abstract. The germanium film and Ge/Si multilayer structure were fabricated by magnetron sputtering technique on silicon substrate at temperatures of 500°C. Raman scattering spectroscopy measurements reveal that the nanocrystalline Ge occurs in both kinds of samples. Furthermore, from the atomic force microscopy (AFM) results, it is found that the grain size as well as spatially ordering distribution of the nc-Ge can be modulated by the Ge/Si multilayer structure. The room temperature photoluminescence was also observed in the samples. However, compared with that from the nc-Ge film, the intensity of PL from the nc-Ge/a-Si multilayer film becomes weaker, which is attributed to its lower volume fraction of crystallized component.

Introduction

Over the last few years, the properties of the silicon and germanium have made them the materials of choice for microelectronic device fabrication. The silicon film, as an important optoelectronic material, has attracted much interesting due to its wide availability, low cost, and the stability and uniformity of its native oxide layer. In fact, germanium-based materials have also been utilized [1-3]. Compared to silicon material, germanium has many advantages, such as a large dielectric constant, small carrier masses and easily obtainable ohmic contact. In recent years, germanium has regained much attention as a semiconductor material for optoelectronic and electronic applications [4, 5], such as antenna-coupled warm carrier device, thin film transistor (TFT), high speed device and infrared sensor. So far, many efforts have been made to investigate the microstructural properties of nano-crystalline Ge thin films [6-8]. However, due to the coexistence of nanocrystalline and amorphous phases in the films, the properties are quite complicated in nano-crystalline Ge films. In order to further improve the device performance, it is crucial to understand the microstructural and optical properties.

In this paper, the germanium thin film and Ge/Si multilayer structure were fabricated by magnetron sputtering technique. The microstructures and optical properties of the samples were investigated. It is found that the nano-crystalline Ge grains and the room temperature photoluminescence can be obtained for the monolayer and multilayer structures. Meanwhile, the results show that the optical properties and structures are different between the monolayer and the multilayer films. The influence of the structures on the optical properties were proposed and discussed.

Experiments

The germanium monolayer and Ge/ Si multilayer structure with 10 periods were fabricated on monocrystalline silicon substrate by magnetron sputtering technique. The microcrystal germanium and silicon target with high purity of 99.99% were used. The rf power for germanium and silicon film is 50W and 200W, respectively. The chamber pressure and substrate temperature were kept at 2.0 Pa and 500 °C, respectively. The film thickness is about 30 nm for the germanium monolayer. For the Ge/ Si multilayer film, the thickness of Si and Ge sublayer is 7 nm and 1.5 nm, respectively, which anocrystalline

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were monitored by controlling the duration time of sputtering. Meanwhile, the germanium lay was used as cap lay for the Ge/ Si multilayer film.

The structural properties of the samples were characterized by Raman scattering spectroscopy and the atomic force microscopy (AFM). The Raman measurements were performed by Invia 1000. The excitation light source is Ar$^+$ laser with a wavelength of 514.5 nm. The room temperature PL properties were measured by using the Ar$^+$ laser (λ=514.5 nm).

Results and Discussion

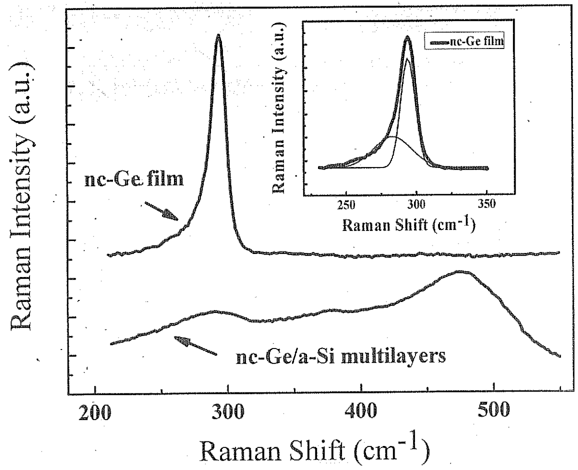

Fig. 1. Raman spectra of the samples. The inset presents the deconvolution of Raman spectrum of the nc-Ge film.

Raman spectroscopy was used to investigate the microstructure of the samples. The Raman spectra of the germanium film and the Ge/Si multilayer sample are shown in the Fig. 1. The signals at 295 cm^{-1}, 385 cm^{-1} and 480 cm^{-1} represent the transverse-optical (TO) vibration mode of the nanocrystalline germanium (nc-Ge), the TO vibration mode of the Ge-Si bond and the TO vibration mode of amorphous silicon, respectively [8]. It is shown in Fig. 1 that the nc-Ge grains are obtained, while the silicon sublayer exhibits the amorphous phase. In order to further study the microstructures in crystallized films, Gaussian deconvolution of the Raman spectra was performed for the Ge film. Two typical components corresponding to a broad distribution at ~280 cm^{-1} associated with the amorphous germanium, and a narrow band with a sharp peak at ~295 cm^{-1} can be obtained as shown in the inset of Fig. 1. According to the empirical formula [9], the average size of the nc-Ge in the germanium film and nc-Ge/a-Si multilayer sample can be estimated based on Raman spectra, which is about 5 nm and 3 nm, respectively. The volume fraction of crystallized component has been estimated based on Raman spectra for the samples, which is 57% and 25% for the germanium film and nc-Ge/a-Si multilayer sample, respectively.

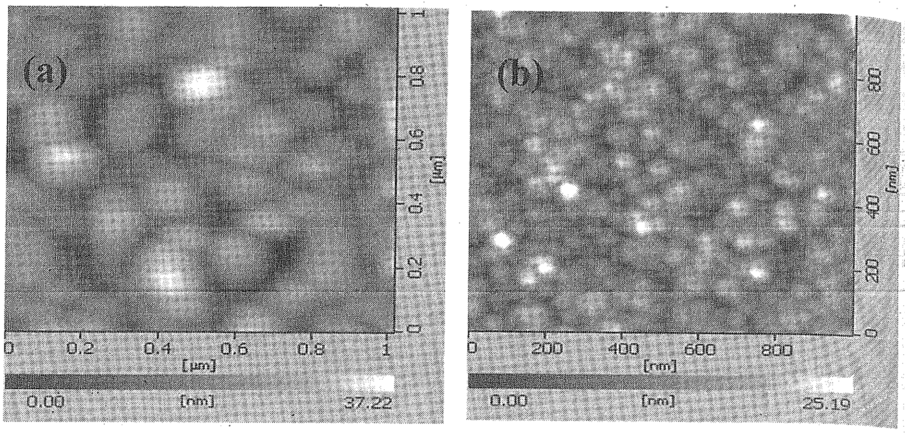

Fig. 2. The AFM image of samples: (a) nc-Ge film. (b) nc-Ge/a-Si multilayer film.

Figs. 2 (a) and (b) show the AFM image of nc-Ge monolayer and nc-Ge/a-Si multilayer films. Compared with the nc-Ge film, the grain size is smaller for the nc-Ge/a-Si multilayer film, which is consistent with the Raman results. The area density of germanium grains can be estimated as high as 1×10^{11} cm^{-2} for the nc-Ge/a-Si film. These results indicate that the grain size and spatially ordering distribution of germanium can be modulated by the Ge/Si multilayer structure. Combining the Raman spectra and AFM surface morphologies, we can investigate the change of microstructures between the nc-Ge monolayer and nc-Ge/a-Si multilayer films. For the nc-Ge/a-Si multilayer film, the average size and the volume fraction of nc-Ge is smaller than the nc-Ge film. However, a high area density of germanium grains on the surface can be obtained in the nc-Ge/a-Si multilayer structure.

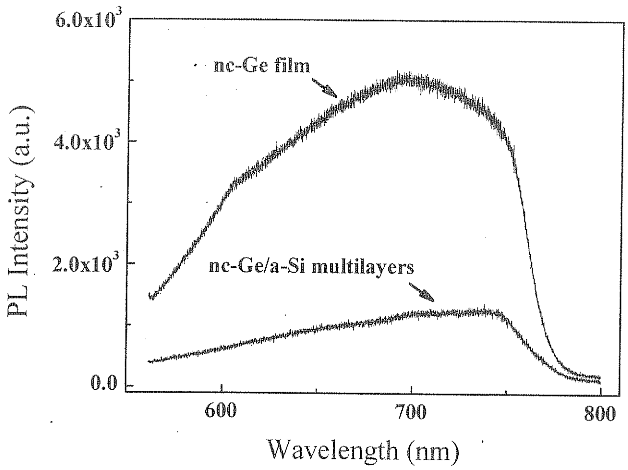

Fig. 3. The room-temperature visible photoluminescence spectra of the samples.

Room temperature photoluminescence (PL) of the samples were measured under 514.5 nm Ar^+ laser excitation. It is found that similar PL spectra can be achieved for the nc-Ge and the nc-Ge/a-Si multilayer films, and the PL peak centered at about 700 nm was observed, as given in Fig. 3. This result indicates that the presence of nc-Ge is responsible for the light emission in the nc-Ge/a-Si multilayer film. Compared with the nc-Ge film, the position of PL peak is not changed in the nc-Ge/a-Si multilayer sample for its smaller nc-Ge size, which implies that the effect of quantum confinement does not contribute to the optical properties of the nanocrystals. According to L. Gao et al. [10], the PL peak located at around 700 nm in the nc-Ge films is caused by the cluster of nc-Ge grains, which indicates that the volume fraction of crystallized component dominants the optical properties of the films. Thus, it can be implied that the decrease of PL intensity for the nc-Ge/a-Si multilayer sample should be caused by the lower volume fraction of crystallized component (25%) compared with that of nc-Ge film (57%).

Conclusion

The microstructures and optical properties of the nc-Ge and nc-Ge/a-Si multilayer films were studied. It was found that the grain size and spatially ordering distribution of the nc-Ge can be modulated by the Ge/Si multilayer structure. The room temperature photoluminescence dominated by the nc-Ge component was obtained at around 700 nm. As a lower volume fraction of crystallized component, the sample started from multilayer has a lower luminescent intensity compared with the sample started from nc-Ge film.

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