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Fast crystallization of Ge nanodot array on Si substrate by local pressure method

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Abstract- **The poly-crystalline germanium (poly-Ge) nanodots (~60 nm) have potential for easier and faster to fabricate on Si substrate. Utilizing the laser annealing to improve the quality of evaporated germanium (Ge) nanodot array on Si substrate, and a method of using local pressure for sandwich structure is developed to affects the treated Ge nanodot. Therefore, the amorphous Ge can be faster crystallized and tranforms into poly-crystalline Ge nanodot. In addition, selective deposition of Ge material is developed to obtain regular dot arrays. To evaluate the crystal quality of the Ge nanodot array was investigated by Raman signal measurement. Finally, the Raman spectrums are well fitted, whose narrow FWHM of the Ge nanodot array is 5.29 cm^{-1} and peak position at 302.745 cm^{-1} is approach the Ge bulk. Those results show that the processed Ge nanodot is poly-crysalline. The Ge nanodot arrays may be promising for use in nonvolatile memories (NVM).**

1. Introduction

There has been a lot of interest to growing the high quality hetero-epitaxial semiconductor on the lattice mismatched substrates. Growing Ge nanocrystals (NCs) or quantum dots (QDs) on Si substrates is one of the ultimate goals of hetero-epitaxial semiconductor. Because of Germanium (Ge) -based devices have both high performances on the electronic and optical properties [1, 2] and the compatibility with the existing CMOS technology. In addition, to reduce the cost of the material required, poly-crystalline Ge (poly-Ge) has attracted research interest in recent years. Therefore, laser crystallization (LC) has also been applied to crystallize (or re-crystallize) an amorphous film on a crystalline (c) substrate.

In this paper, the fabrication of uniformly sized and well arranged high quality Ge nanodot array structures formed on the lattice mismatched Si substrate is demonstrated. First, as to the Ge quality, the laser energy density E (mJ/cm^2) and the sandwich structure (Si substrate/Ge nanodot /SiO2 layer) are also two important factors to affect the crystallinity of the nanodot array. The two important factors would make the amorphous Ge (*a*-Ge) faster transform to the polycrystalline Ge (poly-Ge). Thus, the LC of Ge nanodot arrays is formed on Si substrates, and the quality of processed nanodot array would be pretty good and cost is relatively down.

2. Experiments

Through the process by the Electron Beam Lithography system to define the resist and form the two-dimensional array of the nanohole. Figure 1(b) show the SEM image of the resist is defined on the si substrate. The thickness of the resist is about 300 nm, and the pitch is 100nm, and the entire nanohole diameter is about 100 nm. Then, the Ge layer of 200 nm thick is deposited by E-Gun evaporator. The Ge atoms is filled the nanohole array. To follow, etch the Si substrate and lift off the resist. Finally, capping the SiO_2 to protect the Ge and avoid vanished during laser anneal process. The size of the nanorod is 100 nm and the thickness is about 200 nm. Finally, the Ge nanodot array is formed on the Si hole substrate. Then, the three-layer (Si substrate/Ge nanodot/SiO2 layer) of sandwich structure is finished. Figure 1(a) depicts the cross section sketch of the sample.

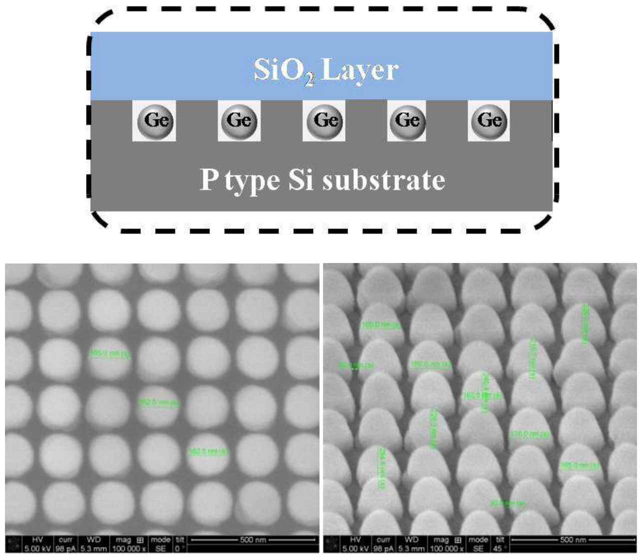

Fig.1 (a) is schematic cross section of the samples. (b) Top view and (c) tilt 52° of the SEM image to certify of the final structure. All of nanodot arrays are ordered arrangement.

Then, the samples were crystallized with single pulses from a excimer laser. A Gaussian-like laser beam profile with a diameter (ϕ = 4 mm) was obtained by using a vacuum spatial filter. The laser pulse energy within the crystallized spot was estimated from the measured pulse energy by assuming a Gaussian profile for the distribution of light intensity on the irradiated area. Then annealed by laser annealing in a dry N_2 ambient at about 100 (mJ/cm^2) for ten spots. The structure of the crystallized Ge nanodot arrays was routinely investigated by Raman spectroscopy. Raman spectra of the samples were measured at room temperature with a micro-Raman spectroscope Spatially resolved (lateral and energy resolutions of 2 μm and 1 cm^{-1}, respectively) in backscattering configuration, with a 50x optical microscope objective and using an Nd:YAG diode LASER with wavelength of 532nm as the excitation source. The measurement mode was static while 3 times accumulation was used to improve the signal to noise ratio. Before measurement of the Ge nanodot array, a single crystal FZ-Si wafer, which had a narrow peak at around 520 cm^{-1}, was used to calibrate the Raman system regarding wavenumber. A single crystal Ge bulk was measured as a reference.

3. Results

The sample was also analyzed by SEM to certify of the final structure. The result of the SEM picture is shown in Figure 1(b) top view and (c) tilt 52°. The Ge nanodot array is formed obviously, and shows the Ge nanodot array is uniform without void during lithography process.

After laser crystallization, a micro-Raman spectrometer was used to characterize the Ge nanodot array quality. It provides the information about the crystallization. The Ge nanodot array structure of the laser crystallized depends strongly on the laser fluency. Usually, the coexistence of two phases occurs at low laser energy, leading to appearance of amorphous portion on the lower wave number side. Therefore, we develop a method of using local pressure for sandwich structure to affects the treated Ge nanodot at low laser energy. The results are shown in Figure 2, the sandwich structure and compare with only Ge nanodots on Si plane substrate after laser annealing 100 (mJ/cm^2) of ten laser spots. The sandwich structure shows the Raman spectrum intensity was obviously enhanced and the amorphous phase vanishes and a sharper symmetrical peak appears is compares with only Ge nanodots on Si plane substrate. In addition, the Raman spectra of the sandwich structure can fit well with Lorentz distribution.

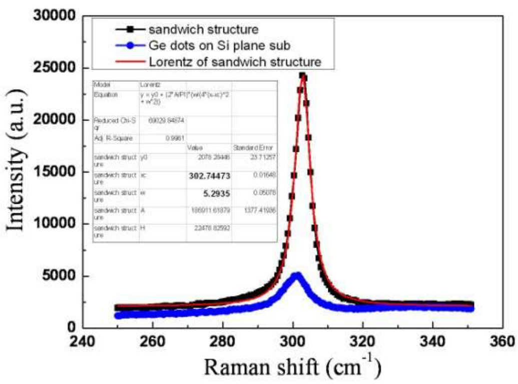

Fig. 2 is show the measurement result of Raman spectrum distribution of the sample after laser annealing treatment (E = 100 (mJ/cm^2 of ten laser spots).

The resultant of Lorentz fitted exhibits a sharp peak centered at 302.75 cm^{-1} and the FWHM is further reduced to 5.29 cm^{-1}, suggesting the Ge nanodot array was crystallized. Although a shift in peak position can also be due to stress and local pressure in the nanodot, these results clearly indicate increasing laser spot quantity and using sandwich structure to trend Ge nanodot arrays that the Raman signal peaks shift toward 303.79 cm^{-1} (reference Ge wafer position). The poly-Ge nanodot arrays were prepared by laser annealing of evaporator a-Ge nanorod. Utilizing the sandwich structure and increasing laser spot quantity can induce the Ge nanodot array faster transform from amorphous phase into polycrystalline phase.

Finally, the Ge nanodot arrays are clearly obviously ordered arrangement and uniformly sized. The result of the Ge nanodot arrays were confirmed that final structure by cross section SEM image is shown in Figure 3. All of Ge nanodot arrays are ordered arrangement and entire size is about 60nm. The SEM image shows the Ge nanodot arrays is uniformly without void during lithography process and laser annealing process.

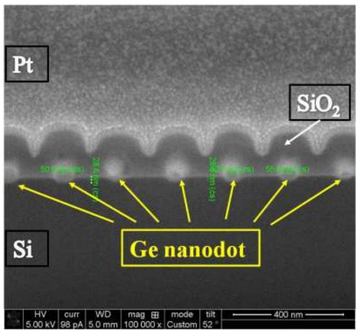

Fig. 3 is showed the cross section SEM images of Ge nanodot arrays. The nanodots size is about 60nm.

4. Conclusion

To fabrication uniformly sized and well arranged high quality Ge nanodot array structures is formed on the lattice mismatched Si substrate, a new method of using local pressure of sandwich structure by laser annealing treatment is developed. Utilizing the sandwich structure and low laser energy can induce the a-Ge nanorod faster transform to poly-Ge nanodot, further improve crystalline properties and enhance the Raman spectrum intensity. The hetero-material LC of poly-Ge nanodot arrays on the lattice mismatched Si substrates is demonstrated. Finally, all of poly-Ge nanodot arrays are ordered arranged and entire size is about 60nm.

References

[1] Cui Y and Lieber C M, *Science* 291 (2001) 851-3.

[2] Hsu B C, Chang S T, Chen T C, Kuo P S, Chen P S, Pei Z and Liu C W 2003 A high efficient 820 nm MOS Ge quantum dot photodetector *IEEE Electron Device Lett.* **24** 318–20.