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Fast fabricated the high quality Ge nanodot arrays on Si substrate

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***Abstract-* The evaporated amorphous germanium (a-Ge) nanodot arrays transforms into high quality crystal-Ge (c-Ge) nanodot arrays are investigated to fabricate on the lattice mismatched Silicon (Si) substrate. Utilizing the laser annealing to improving the quality of a-Ge nanodot arrays on the Si substrate, and using the local stress of hole structure to affects the treated the Ge nanodot. Therefore, the a-Ge nanodot can be easier and faster crystallized and transforms into c-Ge nanodot. In addition, selective deposition of the Ge material is developed to obtain excellent regular Ge nanodot arrays. The quality of Ge nanodot arrays are significantly depend on laser energy, hole depth of the Si hole substrate, surface cleanliness of the Ge nanodot arrays. To evaluate the crystal quality of the Ge nanodot arrays were investigated by Raman signal measurement. Finally, the Raman spectrums are well fitted, whose narrow FWHM of the Ge nanodot arrays are 4.14 cm^{-1} and peak position at 300 cm^{-1} is approach the Ge bulk (FWHM is 3.86 cm^{-1}and peak position at 300 cm^{-1}). Those results show that the processed Ge nanodot arrays are crystalline Ge. The Ge nanodot arrays may be promising for use in nonvolatile memories (NVM).**

1. Introduction

Recently years, semiconductor Nano crystals (NCs) and quantum dots (QDs) have attracted much attention. In addition, there has also been a lot of interest to growing the high quality hetero-epitaxial semiconductor on the lattice mismatched substrates. Therefore, growing Ge NCs or 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 c-Ge material required, fast fabricated the high quality Ge without expensive equipment has much attracted research interest. Therefore, developed laser crystallization (LC) to crystallize (or re-crystallize) an amorphous film on a crystalline (c) substrate to solve problems.

In this paper, fast fabrication of uniformly sized and well-arranged high quality Ge nanodot arrays 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 hole depth of hole structure (Si hole substrate) and surface cleanliness of the Ge nanodot arrays are also three important factors to affect the crystallinity of the Ge nanodot arrays. The three important factors would make the *a*-Ge nanodot arrays faster transform to the high quality c-Ge nanodot arrays. Thus, the LC Ge nanodot arrays are fast formed on Si substrates and the quality of processed Ge nanodot arrays is very 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 arrays of the nanohole. The thickness of the resist is about 300 nm, and the entire nanohole diameter is about 100 nm, and the interval between the nanohole is 100nm. Then, etch the Si substrate. To follow, the Ge layer of 200 nm thick is deposited by E-Gun evaporator. The Ge atoms is filled the nanohole arrays. And then, all resist were removed, and using HF dip to clean the Ge surface, the result is shown in Figure 1(a). The size of the Ge nanocone arrays are 100 nm and the height is about 200 nm is shown in Figure 1(b). To follow, capping the SiO_2 layer to protect the Ge nanodot arrays and avoid vanished during laser anneal process is shown in Figure 1(c). Finally, the Ge nanocone arrays are formed on the Si hole substrate. Then, the three-layer (Si hole substrate/Ge nanocone/SiO2 layer) of sandwich structure is finished is shown in Figure 1(d).

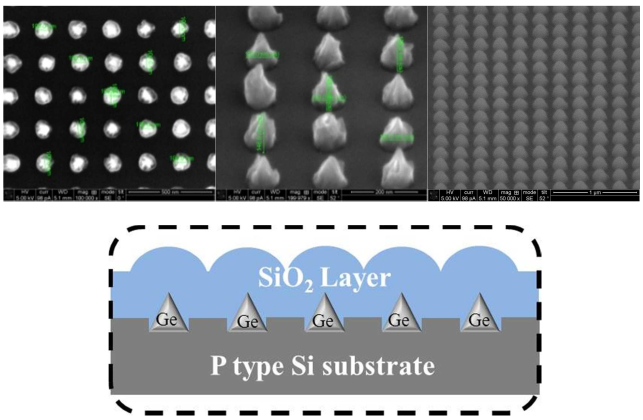

Fig.1 is sho the SEM image of the Ge nanocone arrays (a) top view and (b) tilt 52° is without the SiO_2 layer, (c) tilt 52° is with the SiO_2 layer, (d) is schematic cross section of the Ge nanocone arrays (sandwich structure) All of nanocone arrays are ordered arrangement.

Then, the Ge nanocone arrays were crystallized with single pulses from an excimer laser. Then annealed by laser annealing in a dry N_2 ambient at about 100 (mJ/cm^2). The structure of the crystallized Ge nanodot arrays was routinely investigated by Raman spectroscopy. Raman spectra of the Ge nanodot arrays were measured at room temperature with a micro-Raman spectroscope. The measurement mode was static while 3 times accumulation was used to improve the signal to noise ratio. Before measurement of the Ge nanodot arrays, 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.

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(a) top view and (b) tilt 52° is without the SiO_2 layer, (c) tilt 52° is with the SiO_2 layer. Figure 1(d) depicts the cross section sketch of the Ge nanocone arrays. The Ge nanocone arrays are formed obviously, and shows the Ge nanodot arrays is uniform without void during lithography process.

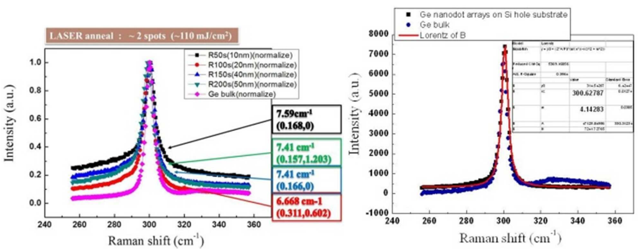

Fig. 2 is show the measurement result of Raman spectrum distribution of the Ge nanodot arrays (a) with different hole depth, (b) the Ge nanodot arrays with moderate hole depth is after laser annealing treatment (E = 100 (mJ/cm^2 of sixteen laser spots).

After laser crystallization, a micro-Raman spectrometer was used to characterize the Ge nanodot arrays quality. To characterize the phenomenon, the spectrum is fitted with the Lorentz distribution. The full width at half maximum (FWHM) and peak position of the Raman spectrum by Lorentz fitted can be the index of the crystallization. It provides the information about the crystallization. The Ge nanodot arrays structure of the laser crystallized depends strongly on the laser energy. Usually, the coexistence of two phases occurs at very low laser energy (~50mJ/cm^2), leading to appearance of amorphous portion on the lower wave number side. Therefore, we develop a method of using local stress of hole structure for sandwich structure, and suitable to modulate the hole depth to affects the treated Ge nanodot arrays at low laser energy. The FWHM results are shown in Figure 2(a), the hole structure with different hole depth will produce different stress has affects the treated Ge nanodot arrays, and the FWHM was obviously changed. Next, we are using laser anneal treatment the Ge nanodot arrays in the same laser energy density E = 100 (mJ/cm^2) and sixteen laser spots. The resultant of Lorentz fitted exhibits a sharp peak centered at 300.63 cm^{-1} and the FWHM is further reduced to 4.14 $cm^{-1}$is show in figure 2(b), suggesting the Ge nanodot arrays were crystallized. These results clearly indicate moderate laser energy and using hole structure to trend Ge nanodot arrays that the Raman signal peaks shift toward 300 cm^{-1} (reference Ge bulk position). The high quality Ge nanodot arrays were prepared by laser crystallization of evaporated a-Ge nanocone arrays.

Finally, utilizing the hole structure and moderate laser energy and spot quantity can induce the Ge nanodot arrays faster transform from amorphous phase into crystalline phase. The shape of the Ge nanocone arrays has transformed into the Ge nanodot arrays. The high quality Ge nanodot arrays are clearly obviously ordered arrangement and uniformly sized. The result of the Ge nanodot arrays were confirmed that final structure by the 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.

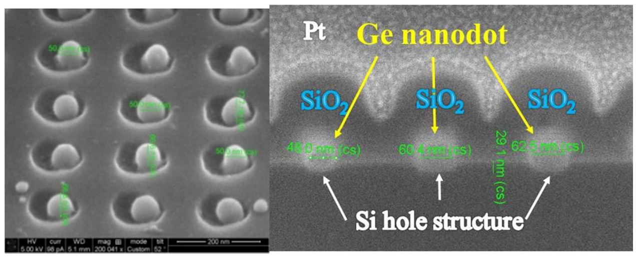

Fig. 3 is showed (a) tilt 52° without the SiO_2 layer and (b) the cross section SEM images with the SiO_2 layer of the high quality Ge nanodot arrays, and entire Ge nanodots size is about 60nm.

4. Conclusion

A new method of using local stress of hole structure by laser annealing treatment is developed to fabrication uniformly sized and well-arranged high quality Ge nanodot arrays structures on the lattice mismatched Si substrate. The shape of the Ge nanocone arrays has transformed into Ge nanodot arrays. Utilizing the hole structure and moderate laser energy can induce the a-Ge nanocone arrays faster transform to c-Ge nanodot arrays, further improve crystalline properties and enhance the Raman spectrum intensity. Finally, the hetero-material LC of high quality Ge nanodot arrays are clearly obviously ordered arranged and entire size is about 60nm and fabricated on the lattice mismatched Si substrates is demonstrated.

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.