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Annealing a Ge layer embedded between the SiO_2 and patterned Si substrate into crystalline

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***Abstract*- To improve the quality of evaporated Ge film on Si substrate, a method of using nano-structure and thermal annealing is demonstrated. The Si substrate is patterned with nano-hole array. After evaporating the Ge thin film layer, SiO2 is capped on it and then thermally annealed. Raman spectrum is used to characterize the quality of the Ge layer. The Raman spectrum fit in with the Lorentz distribution with the FWHM is 3.77cm^{-1}, and peak position is 299cm^{-1}. This result shows that the quality of the processed Ge layer is very close to single crystal.**

1. Introduction

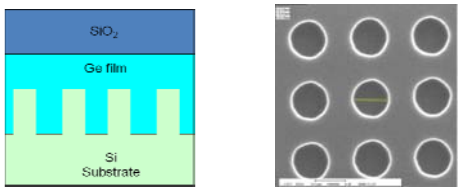
There is a tremendous interest in the field of growing the high quality hetero-epitaxial semiconductor layers on the lattice mismatched substrates. Because of the compatibility with the existing CMOS technology, the Si/Ge hetero-structure is of great interest. The high quality Ge layer growth on the Si substrate is always attracted a lot of attention. Ge-based devices have been considered for several different technology applications, because they have both high performance on the electronic and optical properties like strained Si and fiber communication application. However, because of the 4.2% lattice mismatch, there are some serious issues like threading and misfit dislocations. The threading dislocations will degrade the device performance or lead to premature device failure. Therefore it is very important to reduce dislocation densities and improve the quality of Ge layer. To date, there are several growth technology has been demonstrated to reduce the dislocation and boost the quality of the Ge layer. One is using patterned substrate, which is a very popular technology in the nano-devices [1] [2]. The pattern of nano-hole array modifies the surface strain and reduces the stress energy in the growth film. Thus, the layer grown on the patterned substrate has higher critical thickness than that on the flat substrate [3].

In this paper, Ge thin film layer is deposited on the Si patterned substrate with capping oxide on the top of structure. Fig. 1(a) depicts the cross section sketch of the sample. In addition to the patterned substrate, the temperature and pressure are also two important factors to affect the crystallinity of the growth layer. In this structure, the melting point of the Ge layer is lower than the other layers. As the structure is annealing, the Ge layer would be in melt phase and the above capping oxide will give extra pressure on it. Because the bottom layer of Ge layer is crystallized Si substrate, it will lead the crystallized direction of the Ge layer as it is re-grown from melt phase. Due to the high temperature, high pressure, and nano-structure, the quality of Ge layer on the patterned substrate will be better than on the flat substrate.

2. Experiments and results

Through the process by the Electron Beam Lithography system (Japanese Elionix ELS-7000), and Reactive Ion Etching, the two-dimensional array of the circle hole with the diameter of 240nm and the pitches ranged from 500nm to 1000nm, all with the depth about 120nm, are fabricated and uniformly distributed on the surface of the Si substrate. The SEM picture is shown in Fig. 1.

Before Ge deposition, the residual of the resist was cleaned by plasma O_2 treatment for 3 minutes followed by an HF dipping process to remove the native oxide on the surface of Si substrate. On the surface of the Si substrate, Ge layer of 300nm thick is deposited by E-Gun evaporation to form the thin film layer. A following 100nm capping SiO_2 layer was deposited by PECVD system. The three-layer (Si patterned substrate/Ge thin film layer/SiO_2 capping layer) structure was then heated by furnace annealing treatment in a dry N_2 ambient at 900^{0}C for 10 minutes.



(a) (b)

Fig. 1. (a) Schematic cross section of the samples. (b) The SEM picture. The hole size is 240nm.

Next, a micro-Raman spectrometer (Jobin Yvon T64000) was used to characterize the Ge layer quality. Light from the 532nm laser was focused through the 50x objective.

Raman spectroscopy is a powerful and non-destructive technology in the analysis of semiconductor material. It provides the information about the crystallinity, the degree of alloying, and stress effect of the material. Raman scattering spectrum would be broadened by the presence of amorphous phases, whose spectrum exhibit spectrum at lower wave numbers than bulk single crystal material [4]. As shown in Fig.2 (a), the as-grown Ge layer is amorphous phase whose Raman spectra peak position is at around 270cm^{-1} with a broad linewidth. After thermal annealing,

the spectrum become very symmetrically with the peak at 299cm^{-1}. Additionally, the peak position is red-shifted compared with the crystalline Ge.

To characterize the phenomenon, the spectrum is fitted with the Lorentz distribution, and the result displays a good fitting as shown in the inset of the Fig.2 (a). In spectroscopy, Lorentz distribution is the description of the line shape of spectral lines which are subject to homogeneous broadening in which all atoms interact in the same way. Furthermore the full width at half maximum (FWHM) of the sample is only slightly wider than that of single crystal Ge. This shows that the sample has a high degree of crystallinity [5].

The Raman scattering spectrum of the samples with different pitches are shown in Fig. 2(b). The "out" in the figure means that the laser spot is focused on the non-patterned area. The intensity of Raman scattering increases with the decrease of hole pitch, and the maximum intensity happens when the pitch is 500nm. The larger the intensity is, the better the crystallinity.

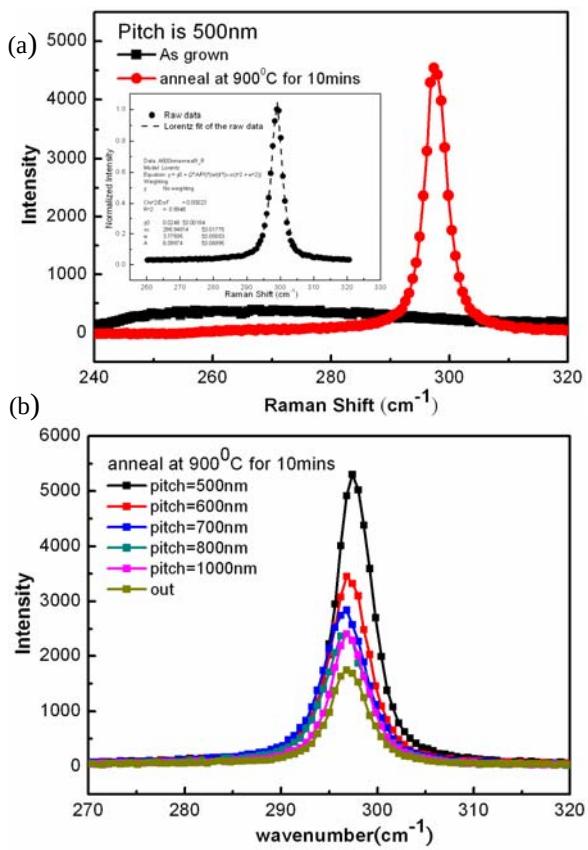
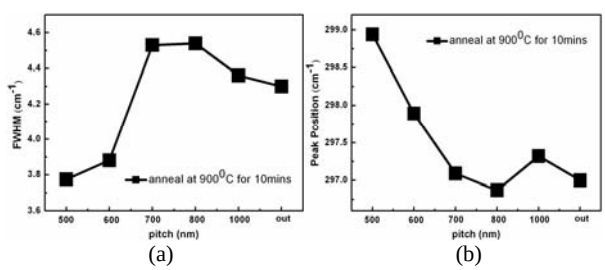


Fig. 2 (a) The Raman spectrum of the samples which are as-grown and annealing at 900^{0}C for 10 minutes. The inset image shows the Lorentz distribution fitting result of the sample with pitch is 500nm. (b) The Raman spectrum of the samples with different pitches and without nano-structure which are annealing at 900^{0}C for 10 minutes.

Fig.3 (a) and (b) show the FWHM and peak position of the samples with the different pitches and without nano-structure. In Fig.3 (a), the sample with the pitch of 500nm has the lowest FWHM which is only slightly higher than that of single crystal Ge [6]. The FWHM increases when a material is damaged or disordered, because these increase phonon damping or change the rules for momentum conservation in Raman process. The low FWHM shows that the Ge layer on hole-array with the pitch of 500nm is highly ordered. From Fig.3 (b), the peak position is closer to 300cm^{-1} as the pitch is smaller. The peak position of the sample with the pitch of 500nm is closest to that of bulk Ge. This indicates that the property of the material is close to the bulk property. From the above description, the hole-array with the pitch of 500nm has the best degree of crystallinity.

In addition to the high temperature annealing and high pressure given by the capping oxide, the nano-hole array modifies the surface strain and reduces the stress energy in the grown film. Furthermore, the nano-hole array would restrict the number of dislocation sources in a small range, thus the final dislocation and a degree of strain relaxation are much lower than that in the layers grown on flat substrates. Therefore, as the density of nano-holes increased, the crystallinity would be also increased. In this work, the sample with nano-hole pitch is 500nm, the FWHM is 3.77 cm^{-1} and peak position is 299 cm^{-1}. This implies that the quality of the Ge layer is very close to single crystal.



(a) (b)

Fig. 3 (a) The FWHM and (b) The peak position of the samples with different pitches and the sample without nano-structure.

3. Conclusion

The circle-hole array of the Si has been fabricated by the Electron Beam Lithography to modify the Ge/Si interface strain. Raman scattering spectrum are used to characterize the quality of Ge layer. Through changing the hole-array pitch, the crystalinity of Ge film can be improved. The result demonstrated that the hole array with the pitch of 500nm has the best degree of crystallinity.

References

1. T.A. Langdo, C.W. Leitz, M.T. Currie, E.A.Fitzgerald, A. Lochtefeld, D.A. Antoniadis, "*High quality Ge on Si by epitaxial neckingr*", Appl. Phys. Lett., 76, (2000), pp.3700-3702.
2. Yan-Ru Chen, Chieh-Hsiung Kuan, Yuen-Wuu Suen, Yu-Hwa Peng, Peng-Shiu Chen, Cha-Hsin Chao, Eih-Zhe Liang, Ching-Fuh Lin, Hung-Chun Lo, "*High-density one-dimensional well-aligned germanium quantum dots on a nanoridge array*", Appl. Phys. Lett., 93, (2008), pp.083101-1-083101-3.
3. Serge Luryi, Ephraim Suhir, "*New approach to the high quality epitaxial growth of lattice-mismatched materials*", Appl. Phys. Lett., 49, (1986), pp.140-142.
4. R. Loudon, " *The Raman effect in crystals*", ADVANCES IN PHYSICS , 50, (2001), pp.813-864.
5. H.S Mavi, K.P. Jain, A.K. Shukla, S.C. Abbi, R. Beserman, "*Raman study of cw laser-induced crystallization of a-Si:H film on quartz and sapphire substrates*" , J. Appl. Phys., 69, (1991), pp. 3696–3701.
6. Minoru FUJII, Shinji HAYASHI, Keiichi YAMAMOTO, "*Growth of Ge Microcrystals in SiO2 Thin Film Matrices : A Raman and Electron Microscopic study*", J.J.A.P., 30, (1991), pp. 687-694.