

FTIR and AFM studies of the Ge on Porous Silicon/Si substrate hetero-structure obtained by molecular beam epitaxy

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Abstract

The single crystal Ge layers have been deposited by molecular beam epitaxy on porous silicon (PSi) substrate, with different thicknesses (40 nm and 80 nm) at the growth temperature of 500°C and 600°C. During deposition, the pore network of PSi layers has been filled with Ge. Fourier transformed infrared spectroscopy (FTIR) and Atomic force microscopy (AFM) have been applied for investigation of vibrational modes and morphological properties of the Ge on PSi layers. AFM investigation showed the surface roughness and pyramid like hillocks. It also confirmed the nanometric size of the crystallites. FTIR absorption measurements showed different vibrational modes present in the Si_{1-x}Ge_x structures. The observed vibrational frequencies depend strongly on the growth temperature.

Keywords: Germanium, porous Silicon, molecular beam epitaxy, AFM, nanocrystals, FTIR.

1. Introduction

The interest in porous silicon (PSi) is increased considerably by the observation of its room temperature visible photoluminescence (PL) [1] and electroluminescence [2, 3]. PSi shows different features in comparison to the bulk silicon such as shifting of fundamental absorption edge into the short wavelength and PL in the visible region of the spectrum. Analyses of PSi show that this material presents interesting properties [4-6] necessary for a wide area of potential applications such as waveguides [7], thermal [8] and optical [9-12] applications or for Silicon on insulator (SOI) technology [13]. However, PSi has good compatibility with existing silicon technology.

Many microelectronic devices incorporate Ge containing layers such as Si_{1-x}Ge_x [14]. To provide increased device performance, it is advantageous to have a relatively high Ge content in the Si_{1-x}Ge_x layer. Nevertheless, greater amounts of Ge increase the amount of strain which is due to the lattice mismatch (4.2 %) between Ge and Si. This problem is partially overcome by growing a relaxed SiGe buffer layer, called virtual substrate [15, 16], on top of which the active layers (Ge or Si) are deposited. PSi is a spongy material and could partially relax the epitaxial strain caused by the heteroepitaxy of SiGe layers because of the large density of pores. Then, it could be used as a stressor layer with Ge epitaxial layer grown on. This process has the advantage of low cost thin film solar

cells. Especially, when filling the pore network of a PSi with Si or Ge.

In our previous work [17], we reported the use of PSi as sacrificial layer to grow epitaxial planar and fully relaxed Ge membranes. The Ge layers were grown on PSi by molecular beam epitaxy (MBE) in ultra high vacuum atmosphere. The resulted Ge thin films could be used as relaxed pseudo-substrate in conventional microelectronic technology. However, further characterisation is needed to address the issue of the use of these samples on optoelectronic technology. In this study, we report the studies of morphological properties and vibrational modes of Ge layers grown on PSi as a function of the growth temperature and deposited thickness.

2. Experimental procedure

The main The Ge layers were grown on PSi substrate by MBE, in order to fill the pore network of a PSi layer with Ge. In this work, we used two samples with different Ge thicknesses $h=40$ nm and $h=80$ nm elaborated at 600°C and 500°C respectively. The fabrications of the PSi and Ge layers grown on PSi have been described in our previous work [17].

The surface morphology and roughness of prepared samples was obtained by Atomic Force Microscope (AFM), type PSIA XE-100, in the tapping mode.

Absorption FTIR spectra of the samples were measured using a Nicolet-Avatar-360 spectrophotometer. This technique can be used to evaluate the evolution of the chemical bond with growth temperature.

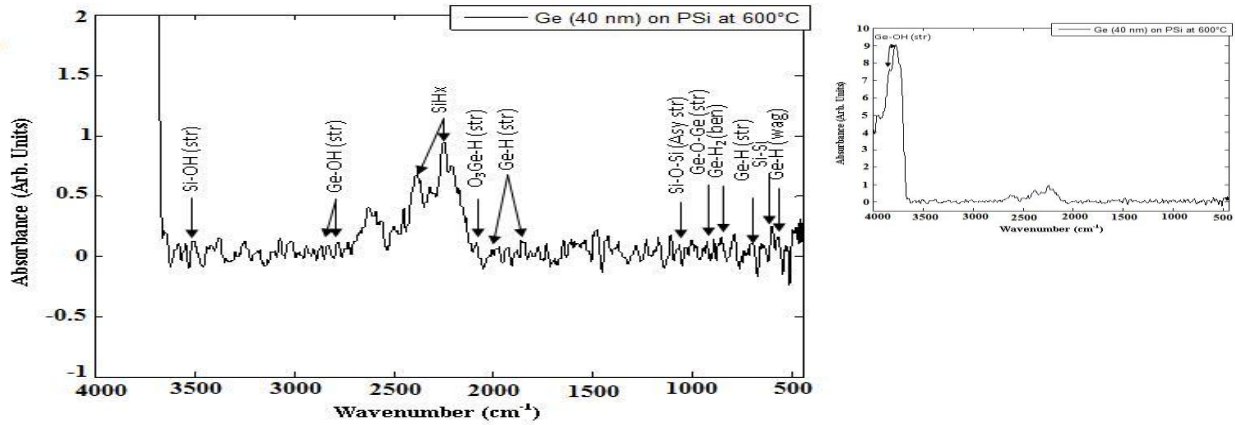


Fig. 1 FTIR absorption spectra obtained from Ge grown on PSi at 600°C for h=40 nm. Inset: FTIR spectra on large scale.

3. Results

The internal surface chemical composition of as-prepared PSi was characterized using FTIR technique. The different bonds are resumed in our work submitted and accepted for another conference [18], where a combined analysis of FTIR spectroscopy and PL spectra were applied to characterize the Ge/PSi structures.

The surface composition of Ge/PSi structures were characterized by FTIR absorbance analysis. The results are depicted in Fig. 1 and 2. FTIR absorption measurements on the Ge/PSi structures showed replacement of the Si-OH modes with Ge-OH related modes. Specifically, Ge-OH stretching modes at 2780, 3770 and 3830 cm^{-1} for 40 nm thick Ge grown at 600°C and at 2789, 2838, 2918, 3836 and 3305 cm^{-1} for 80 nm thick Ge grown at 500°C appeared in FTIR spectra [19, 20, 21, 22]. The FTIR absorbance spectra characteristic of the hybride-terminated surface, which consists of Si-H stretching modes at 2254 and 2351 cm^{-1} [23] for 40 nm thick Ge and at 2250 cm^{-1} for 80 nm thick Ge [23]. However, the peak at 3520 cm^{-1} is in general attributed to the stretching signal of the Si-OH bond [24]. The characteristic asymmetric stretching signals of Si-O-Si bridges between 1066 and 1184 cm^{-1} [25] and at 1070 cm^{-1} [23] are too weak. Also, we noticed the presence of the stretching points of O₂Ge-H and O₂Ge-H at 2035 and 2065 cm^{-1} [19]. In addition, Si-Si bonds are obtained at 609 and 613.5 cm^{-1} [23] for 40 nm thick Ge and 80 nm respectively. The above results indicate that FTIR spectra of

Ge/PSi samples contain vibrational modes arising from chemical compound of Ge, O and H.

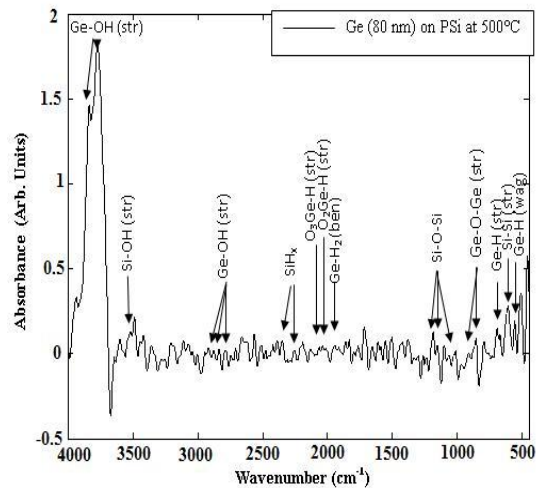


Fig. 2 FTIR absorption spectra obtained from Ge grown on PSi at 500°C for h=80 nm.

However, we display in fig. 1 and 2 a low presence of SiH_x for a 80 nm thick Ge, compared to the other sample grown at 600°C. Some authors correlated the presence of SiH_x with the strain of PSi materials [26, 27], this explanation is supported by our results obtained from FTIR spectra with in addition the results reported in our previous work [17] obtained by high resolution X-ray diffraction.

Figure 3 shows the 2D and 3D views of different samples. From the AFM measurements, we find that the root mean square (RMS) roughness decreases with the deposited thickness from RMS= 15.2 nm for h=40 nm to RMS=3 nm for h=80 nm, and is estimated to be 2 Å for PSi [17]. From fig. 3, the formation of pores can be clearly seen in 3D images, it is observed that there is a condensation point which forms the skeleton of PSi and pyramid like hillocks surfaces. These can

be regarded as a condensation point to form skeleton clusters which play an important role for the strong visible luminescence. The lateral sizes of the nanocrystals are found to be in the range of 3-5 nm. Despite this, it is difficult to differentiate nanocrystals sizes but it is expected that their sizes are smaller for a 80 nm thick Ge which leads to an intense PL, especially since we found that Ge thicknesses have no effect on PL properties [18].

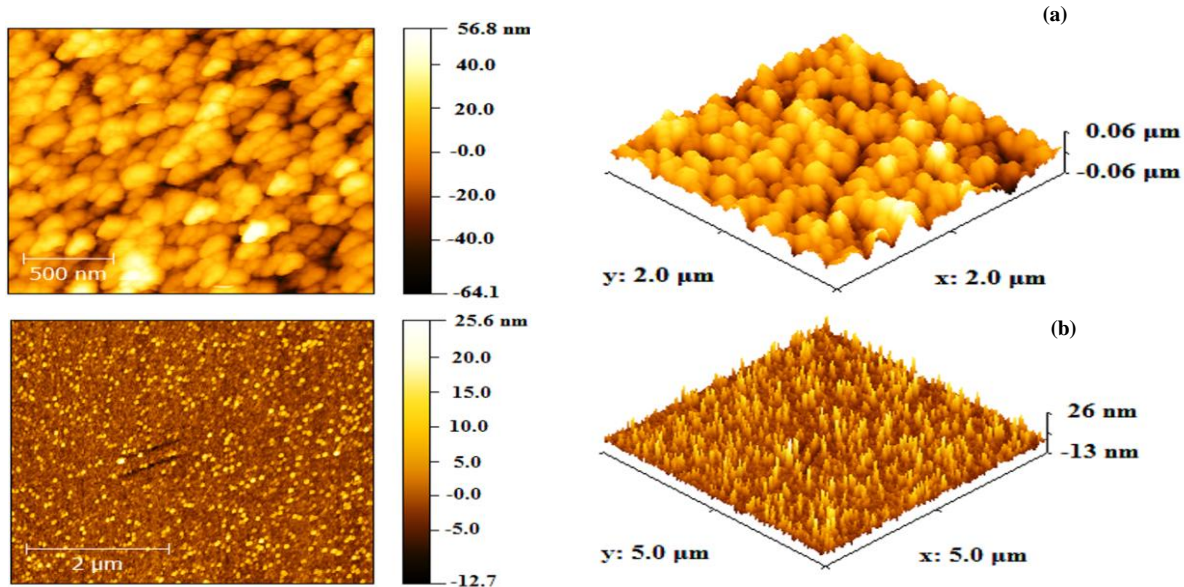


Fig. 3 AFM images of Ge grown by MBE on PSi for; (a) h=40 nm at 600 °C and (b) h=80 nm at 500 °C

4. Conclusion

A combined study of FTIR and AFM was conducted on PSi and Ge/PSi structures with different thicknesses and growth temperature. The AFM investigation shows the rough Si and Ge/PSi surfaces, which can be regarded as a condensation point for small skeleton clusters which play an important role for the PL. Also, we have deduced the size of Si nanocrystals from AFM measurements. Furthermore, FTIR absorption results of the Si_{1-x}Ge_x layers depend on the growth temperature and show the emergence of Ge-O-Ge, Ge-H and Ge-OH stretching modes.

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