RF PLASMA EFFECT ON AMORPHOUS THIN ION-IMPLANTED LAYERS OF N- AND P-TYPE GERMANIUM: RAMAN AND AFM RESEARCH

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Effect of RF plasma treatment (RFPT) and rapid thermal annealing (RTA) on high-dose implanted n-type and p-type amorphous Ge layers has been studied by Raman scattering spectroscopy and AFM techniques. To recrystallize the amorphous thin n-Ge layer implanted by BF_2^+ ions needed higher RTA temperatures and power density of RFPA than in the case of p-Ge implanted by P^+ ions with a same dose. It was shown that the RFPT resulted in recrystallization of amorphous Ge layers at considerably lower temperatures than RTA, that it was associated with nonthermal effects. Low-energy ion and electron bombardment during RFPT resulted in formation of nanostructured Ge surface.

Introduction

The integration of Ge material has considerable advantages in comparison with Si due to the high electron/hole mobility and low temperature activation of implanted impurities [1]. However the donor impurities such as phosphorus possess a high diffusion coefficient [1] that does not allow us to form a super-shallow n^+/p junction. Therefore in this case a short time annealing has to be used, such as rapid thermal annealing (RTA) [2] or flash-lamp annealing (FLA) [3]. Additionally low-temperature RF plasma treatment (RFPT) can be used which was employed successfully for annealing of thin implanted Si layers [4] but up to now it was not applied to implanted Ge layers. Thus, the present paper considers effect of low-temperature RF plasma treatment on structural transformation and surface morphology of thin amorphous implanted Ge layers.

Samples and measurement techniques

The monocrystalline germanium wafers with <100> orientation were polished on the front side. The n-type Ge wafer with doping concentration about 10^{14} cm^{-3} was implanted by BF_2^+ ions with energy of 20 keV and dose of 1×10^{15} $ions/cm^2$. The p-type Ge wafer with doping concentration about $(7\pm2)\times10^{16}$ cm^{-3} was implanted by P^+ ions with energy 12 keV and same dose of implantation. Energies of the implantations were chosen so the projected range of the implanted profile was the same distance from the Ge surface, with a peak of the ion distribution at about 15 nm from the surface. The profiles simulation was performed by SRIM code.

For annealing of the implanted Ge layer RTA in nitrogen ambient for 15 sec in temperature range from 300 to 550 °C was used. The RF plasma treatment (13.56 MHz) was performed in diode type reactor in forming gas (90% N_2 + 10% H_2) atmosphere [4]. The samples were located on a heated RF electrode resulting in a temperature rise up to 200°C. The RF plasma power density was varied from 0.5 to 2.0 W/cm^2, the treatment duration was 10 min. The sample temperature for plasma treatment was monitored in situ using a special thermal paints deposited on the back side of the samples.

The sample phase composition was studied by Raman spectroscopy (RS) at room temperature. The RS spectra were studied with a double monochromator DFS-52 equipped with Andor CCD camera. For excitation a YAG laser (λ=532 nm, P < 10 mW) was used. Information on surface morphology was obtained by atomic force microscopy (AFM) technique (NanoScope IIIa Dimension 3000).

Results and discussion

The RS spectra of implanted and RTA treated n-Ge samples (Fig. 1(a)) and p-Ge ones (Fig.1(b)) are presented. The spectrum 1 corresponds to implanted Ge samples and consists in wide line with a maximum at 273 cm^{-1} associated with amorphous phase of the Ge and narrow asymmetric line at 300 cm^{-1}, which is associated with crystalline Ge phase. In our case when the amorphous Ge layer has a thickness about 20 nm (from the SRIM simulation), and penetration depth for a light with wavelength of 532 nm is about 25 nm, the crystalline component is always attended in the Raman spectrum. Asymmetry of the line can be caused by light scattering on Ge nanocrystals, and Ge layer in which tensile stresses are presented.

After RTA of implanted n-Ge at temperatures from 300 to 350°C the intensity of wide line, corresponding to the amorphous phase, decreases, and it totally disappears from the spectra at temperature of 400°C and above (Fig. 1a). It should be noted that a crystalline line in RS spectrum for RTA at 400°C has considerably larger half-width (~6.5 cm^{-1}) than in case of initial unimplanted sample (3.3 cm^{-1}) and small shift in low-frequency part. These features are associated with defectiveness of the recrystallized Ge layer, and the annealed layer has tensile stresses. After RTA at 600°C the half-width and position in the RS spectrum of the crystalline line is compared with that for the initial unimplanted n-Ge.

The RTA of p-Ge implanted by P^+ ions is significantly different from the RTA for BF_2^+ ion implanta-

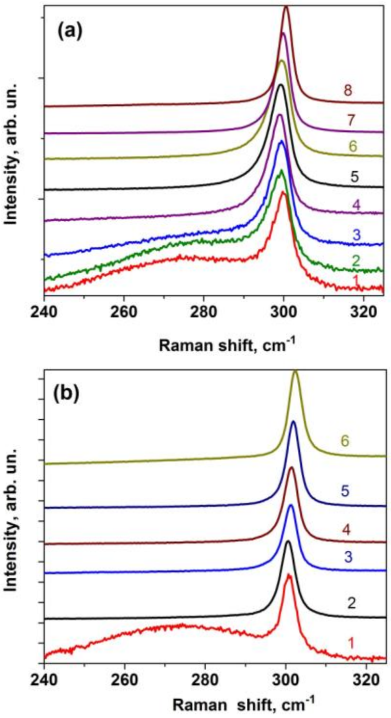

Fig. 1. Normalized RS spectra for n-Ge implanted by BF_2^+ ions (a) and p-Ge implanted by P^+ ions (b). The implanted samples with following RTA: 1. Initial without RTA; 2. T=300°C; 3. 350°C; 4. 400°C; 5. 450°C; 6. 500°C; 7. 520°C; 8. 600°C (t=15 sec).

tion of n-Ge. The RTA at 300°C results in total crystallization of the amorphous phase in the Ge thin layer (Fig. 1b). Besides, a half-width of the line at 300 cm^{-1} is relatively small (Γ = 4.2cm^{-1}) that is evidence of the good quality crystalline layer formation with low defect concentration.

RF plasma treatment of implanted n-Ge resulted in annealing of amorphous phase in thin implanted layer at 200 °C with power density 1.75 W/cm^2 (Fig. 2a), at which the sample can heated up to 320°C [4]. A half-width of “crystalline” line in the RS spectrum is about 6 cm^{-1} that can be associated with different mechanical stresses in the surface and the bulk of Ge layers.

RF plasma treatment of the P^+ ion implanted p-Ge led to crystallization of the implanted surface layer at considerably lower temperature and power than in the case of the implanted n-Ge. At a temperature of 100°C and power density 0.9 W/cm^2 the thin implanted amorphous layer is totally recrystallized (spectrum 2, Fig. 2(b)). A temperature of the samples at such RF plasma treatment is about 200°C [4]. RF power density rise at this temperature resulted in a reduction of a half-width of the “crystalline” line that associated with decrease of defect concentration in the implanted layer. Increase of additional heating of the samples during the RF plasma treatment up to 200°C changes the situation. An increase of the RF plasma power results in an increase of half-width of the “crystalline” line that could be associated with superposition of stresses in implanted and underlying Ge layers.

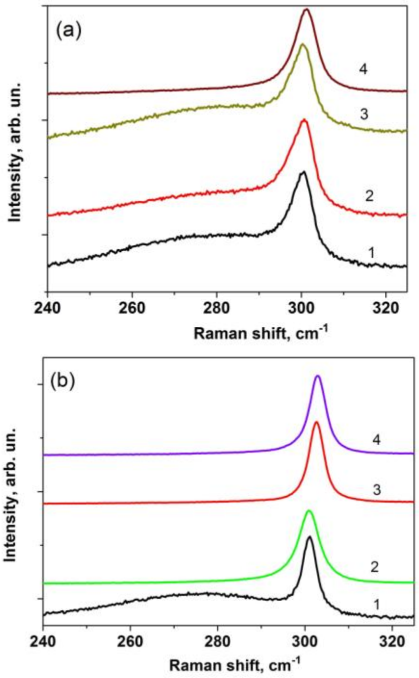

Fig. 2. Normalized RS spectra for n-Ge implanted by BF_2^+ ions (a) and p-Ge implanted by P^+ ions (b). The implanted samples with following RFPT: 1. T=100 °C, P=0.55 W/cm^2; 2. T=100°C, P=0.90 W/cm^2; 3. T=200 °C, P=0.75 W/cm^2; 4. T=200 °C, P=1.75 W/cm^2 (t=10 min).

To extract nonthermal factors which can lead to a reduction of the crystallization temperature of the implanted Ge samples, the control experiments with treatment of the samples by RF plasma discharge from the implanted side and the back side in the same process were carried out [5]. Fig. 3 demonstrates that RF treatment from the implanted side results in enhanced crystallization of amorphous implanted layer and annihilation of wide RS line at 273 cm^{-1}, a decrease of mechanical stresses of the crystalline Ge lattice that is determined from a shift to ideal position of the “crystalline” RS line (Fig. 3).

Under RF plasma treatment the front side of the implanted samples can be affected by the following factors: temperature; UV and soft x-ray irradiation, alternating electric field, proton injection from plasma; low-energy electron and ion bombardment [4]. Under RF plasma treatment from back side of the sample, the main effects are temperature, soft x-ray irradiation and alternating electric field. The low-energy electron and ion bombardment usually results in destruction of thin surface layer that can be shown from AFM experiments (Fig. 4). Thus the main effects which can enhance the ordering and crystallization of our amorphous layers are UV irradiation with the combination of alternating electric field and protons as catalyst of defect transformation reactions [6].

Surface morphology of the implanted n-Ge is determined with a root mean square (RMS) roughness which equals in this case to 74.2 pm (Fig. 4a). The RFPT with power density 1.25 W/cm^2 and additional temperature heating of 100°C results in structured surface with RMS = 229 pm (Fig. 4b).

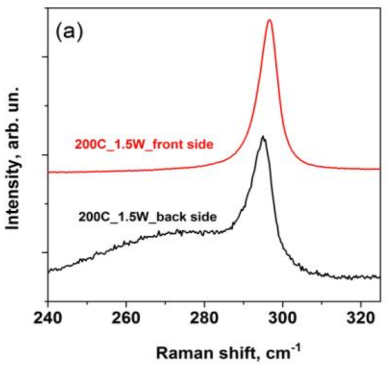

Fig. 3. Raman scattering spectra for n-Ge implanted by BF_2^+ ions and RF plasma treatment (T=200 °C, P=1.50 W/cm^2, t=10 min) of front side and back side of the samples:

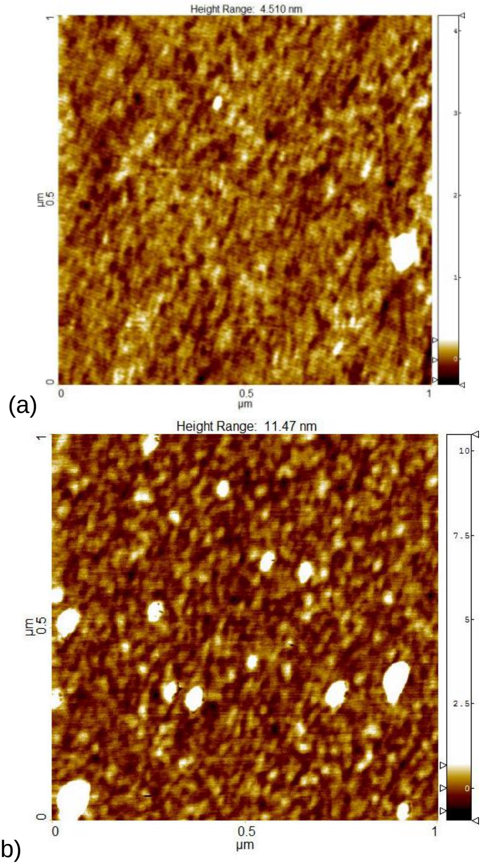

Fig. 4. AFM surface topography maps of n-Ge implanted by BF_2^+ ions (a) and with following RF plasma treatment (T=100 °C, P=1.25 W/cm^2, t=10 min) (b).

The RTA at 500°C increases also roughness with comparison with untreated surface and the RMS in this case equals to 213 pm (Fig. 5a) that is a bit smaller than at the RFPT. However a slight temperature rise up to 550°C leads to deep holes formation with depth up to 500 nm (see Fig. 5b).

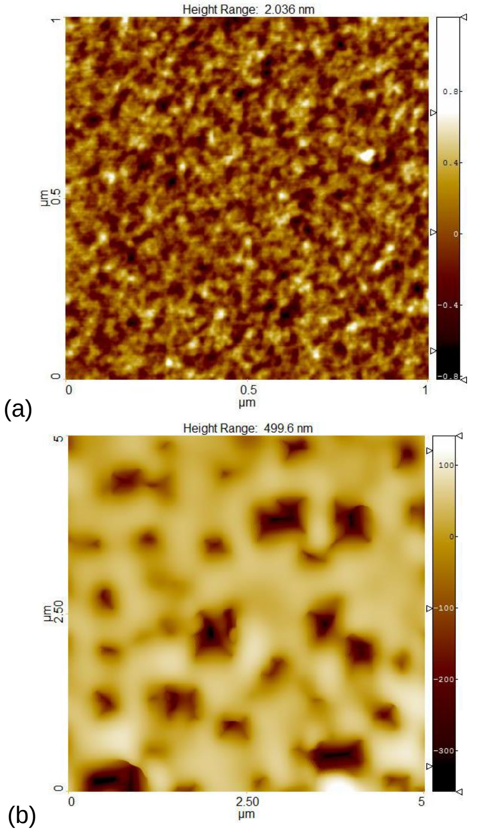

Fig. 5. AFM surface topography maps of n-Ge implanted by BF_2^+ ions and with following RTA with different temperature: (a) T=500°C, (b) T= 550°C (t=15 sec).

Conclusion

Using of RF plasma treatment to high-dose implanted shallow Ge layers results in their crystallization at temperatures considerably lower than in case of rapid thermal annealing. Observed effects associated with nonthermal processes, which affect the material during RF plasma treatment, include UV and soft x-ray radiation together with alternating electric field and protons.

References

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