PHOTON ASSISTED PARTICLE IRRADIATION OF SILICON

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Since radiation methods are widely used in microelectronics technology, tile problem still stand to govern the radiation defects behavior in the irradiated semiconductor, especially in silicon crystals. A method for incascade, real time manipulation with primary defects, i.e. self - interstitials and vacancies, and control the formation of stable defect complexes by the additional crystal ionization at the irradiation stage has been found experimentally and originally reported in [1]. This method is known as photon assisted implantation, i.e. the irradiation of semiconductors by energetic particles with in situ photoexcitation of the crystal electronic subsystem by photons whose energy only slightly exceeds semiconductor forbidden gap.

In the present report we survey experiments which have been done in our laboratory and demonstrate the method of the photon assisted implantation. In these experiments the photoexcitation was carried out by light of a high pressure mercury arc lamp or hehum-neon laser. RBS with ion channeling, TEM, SIMS, FTIR and DLTS techniques were used to analyze the irradiated samples.

We would mention following basic results.

I) First of all we consider the effect of the photoexcitation during electron radiation [2] because it is an easier case than ion implantation. Really, in this case the generation of defects is homogeneous across the specimen depth and the defects are simple in structure. The irradiation was carried out at the pulse electron accelerator with electron energy of 4 MeV, dose of 10^{14} cm^{-2} at room temperature. The power density of the in situ light on the sample surface was 50 mW cm^{-2}. Variations of the specimen temperature from room temperature were not more than 2 K in the conditions of the experiments. Estimations of the excitation level of the electron subsystem in silicon showed that the excess concentration of electron-hole pairs due to the light adjacent to the surface is equal to 10^{18} cm^{-3} and is four orders of magnitude above the concentration under electron excitation.

Figure I shows the DLTS data of the irradiated samples. The designation E_1 (86 K) stands for the peak associated with the deep level of A-centers (oxygen-vacancy complexes); the peak E_2 (125 K) is attributed to the level of the singly negative charge state of divacancies; the peak E_3 (192 K) depicts the level of K-centers, and the peak E_4 associated with a mixture of E-centers and divacancies in singly negative charge state. Note that in the spectra of the samples irradiated with light a maximum at 167 K (not shown on Fig. 1) appeared, but this maximum was not detected in the "ordinary' spectra.

The DLTS spectra on Fig.1 demonstrate that the photoexcitation during electron irradiation decreases the amount of all radiation defects, especially of divacancies (the concentration of divacancies was 1.5 times lower than for the "dark" irradiated sample, sec the peaks E_2 and E_4 on Fig.1) and causes the emergence of new type defects.

2) The photoionization. of silicon sample during ion implantation has a strong influence on the implanted layer despite high density and nonuniform depth profile of the ion induced damage [3]. Figures 2 and 3 show the reduced concentration of the radiation defects in the silicon samples implanted with He^+ and As^+ ions.

3) Figure 4 demonstrates that photoexcitation suppresses defect accumulation in the early stage of ion bombardment, when relatively simple types of defects dominate. Really, according to the experimental data of A.G.Italyantsev (fig.4) the action of light is detectable [4] even if the following inequalities holds

$$\Phi^*/\Phi = 0.1$$

where Φ^* is the dose of ion with photoexcitation, and Φ is the total ion dose.

It must be noted that in all our experiments the impact exerted by in situ light has athermal nature. As temperature is concerned there is the following result:

4) Figure 5 shows that the temperature of the irradiated sample and the in situ light affect the defect concentration in the opposite directions [5]. Namely, photon assisted irradiation at high temperature raises the defect concentration while high temperature alone usually reduces one.

UP to this point we consider some examples of low irradiation doses, approximately 10^{11}-10^{13} см$^{-2}$, which typical for silicon doping. However, in the region of significantly higher doses, about of 10^{15} - 10^{17} cm^{-2}, the light action is detectable too. It is the change in the oxygen and nitrogen redistribution as well as chemical reactions in the implanted Si - O - N system.

5) The data on the Figure 6 corresponds to the following experiments, where a two step implantation was carried out. In the first step, silicon was implanted with 160 KeV molecular oxygen ions at a dose 2.5 x 10^{16} cm^{-2}. In the second step, the molecular nitrogen ions were implanted at energy 160 KeV with a dose of 5 x 10^{16} cm^{-2} with and without in situ photoexcitation of the silicon sample. After the implantation the samples were annealed at 1200^{0}C for 1 h. Figure 6 shows that implanted oxygen is accumulated under the profile of implanted nitrogea provided that the nitrogen was implanted with tile silicon photoexcitation (compare curves 2 and 3 on fig.6).

FTIR spectra on Figure 7 demonstrate the difference in the concentration of the silicon oxide phase in the samples implanted by oxygen ions with and without photoexcitation.

One more point should be mentioned to close the experiments discussion.

6). Comparing two profiles on the figure 8 of the range distributions of silicon ions in GaAs, everyone may see that they are different: an algebraic value of the profile skewness (third normalized moment of a distribution) is increased in the case of photon assisted implantation. It may be a result of one of two following processes: a) the change in the ion inelastic (electronic) energy losses during slowing down under the target photoionization, or; b) the redistribution of the thermalized silicon atoms which usually are immovable in the GaAs matrix at the room temperature.

Thus, the experiments considered above allow to conclude that the in situ photoexcitation of the electron subsystem of semiconductors changes not only the amount of radiation defects but the defect type. For practice, it is very important the effect of the suppression of the divacancy formation in the irradiated silicon. Aiming to explain this effect we are developing a kinetic model of the evolution of the ensemble of radiation defects taking into account the charge state of the point defects and the possibility to change this charge due to the interaction between point defects aud free electrons or holes. The simplified version of this model [6] allowed to explain the suppression of the divacancy formation due to the photo-induced Coulomb barrier between equal (in average) charged vacancies accumulated in the local area of the implanted semiconductor layer.

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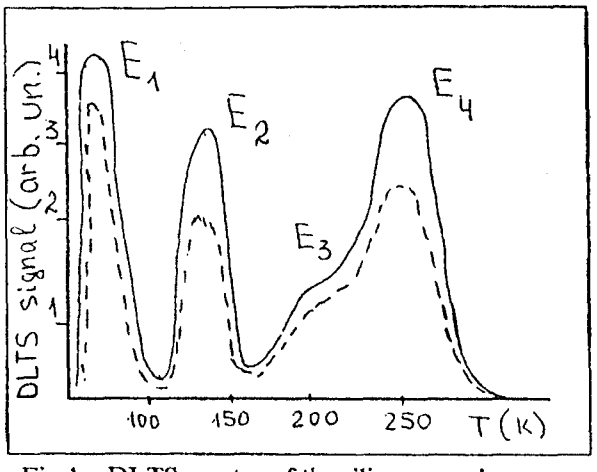

Fig.1. DLTS spectra of the silicon samples irradiated by electrons with (-------) and without (——) photoexcitation.

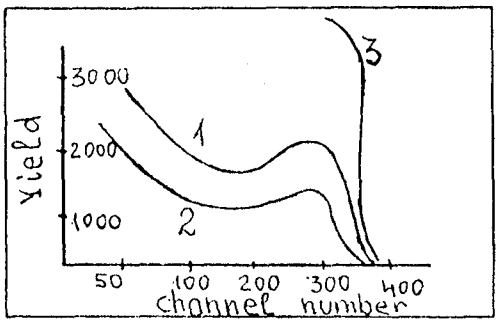

Fig.2. RBS-C spectra (800 keV He^+) of (100) Si samples implanted with 90 keV P^+ ions to a dose of $3x10^{14}$ cm^{-2} without (1) and with (2) illumination by light. Curve 3 is non-aligned spectrum.

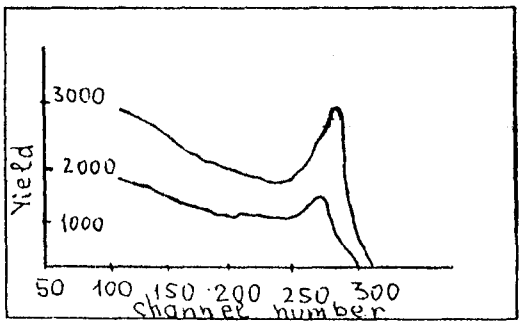

Fig.3. RBS-C spectra (1.4 keV He^+) of (100) Si samples after irradiation with 300 keV As^+ ions to a dose of $6x10^{13}$ cm^{-2} with (1) and without (2) additional photoexcitation.

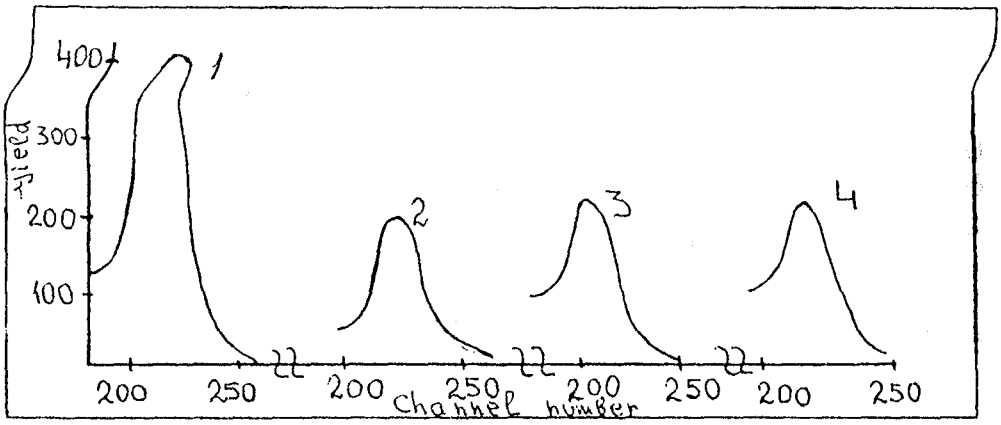

Fig.4. RBS spectra (1.4 MeV He^+) of Si samples implanted with 100 keV P^+ ions to a dose of $4x10^{14}$ cm^{-2} with different rations of "light" Φ^* and "dark" Φ ion doses: "dark" implantation (curve 1), $\Phi^* / \Phi = 0.1$ (curve 2);$\Phi^* / \Phi = 0.5$ (curve 3), and "light" implantation (curve 4).

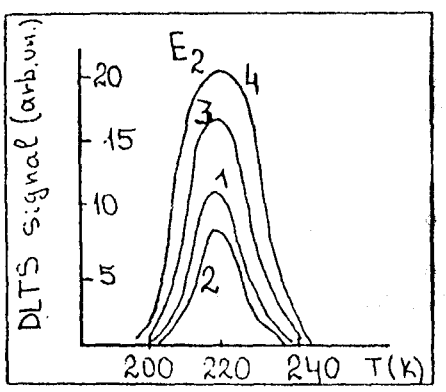

Fig.5. Amplitudes of E_2 peak from the DLTS spectra of n-Si samples irradiated with 150 keV Ar^+ ions to a dose of $7x10^{10}$ cm^{-2} at different sample temperatures and illumination conditions : T=300 K without (curve 1) and with (curve 3) illumination; T=600 K without (curve 2) and with (curve 4) illumination.

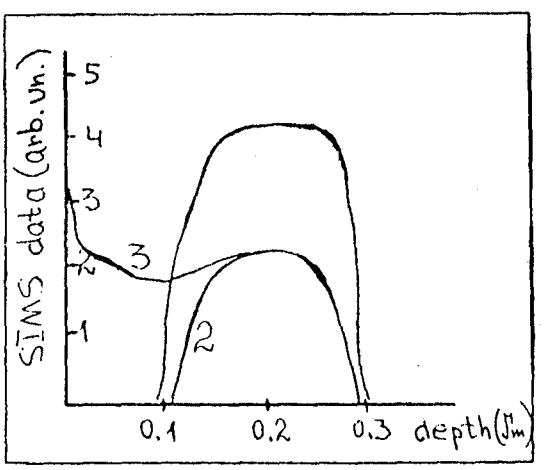

Fig.6. Changes in the shape of the oxygen profile: curve 1 is photoexcitation-independent N profile; curve 2 is oxygen profile corresponding to the "dark" oxygen implantation but "light" nitrogen irradiation; curve 3 - "dark" O and N implant.

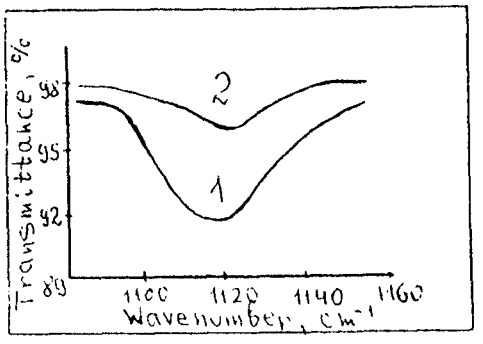

Fig.7. FTIR spectra of (100) Si samples implanted with 150 keV O^+ ions to a dose of 1.7×10^{16} cm^{-2} with (curve 1) and without (curve 2) photoexcitation.

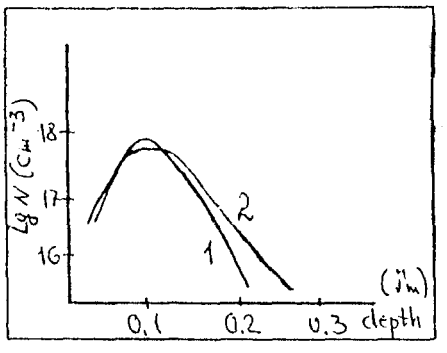

Fig.8. SIMS profile of 70 keV Si^+ implanted into GaAs to a dose of 8×10^{12} cm^{-2} with (curve 1) and without (2) photoexcitation.