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Effect of low dose γ-radiation on the annealing temperature of radiation defects in ion implanted MOS structures

S. Kaschieva *, S. Alexandrova

Institute of Solid State Physics, Bulgarian Academy of Sciences, Boulevard Tzarigradsko Chaussee 72, Sofia 1784, Bulgaria

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Abstract

The effect of previous low dose (10^3 rad) gamma irradiation on the annealing temperature of the radiation-induced defects in ion implanted MOS samples is studied by means of thermally stimulated current (TSC) method. In the work presented here two groups of samples (first—without any additional treatment and second—gamma irradiated after oxidation samples) are used. Then both groups are implanted through the oxide with boron ions with energy 15 KeV and dose of 1.2×10^{12} cm^{-2}. Thermal treating of the samples at different temperature is carried out. Full thermal annealing of the radiation defects introduced by ion implantation in the samples from the first group is observed after 15 min annealing at 700 °C. It is shown that gamma irradiation leads to a lowering of the annealing temperature—after 15 min annealing at 500 °C, TSC spectra of the double treated samples is not observed. A possible explanation of the results is proposed.

Keywords: MOS structures; Annealing; γ-Irradiation; Implantation

1. Introduction

In the last 30 years, the radiation defects introduced by ion implantation have traditionally been removed during high-temperature thermal processing. The method of high-temperature annealing removes the radiation damages and activates the implanted impurities. In the last years, this method is still used to anneal Si nanoclasters in SiO_2 fabricated by high dose ion implantation [1]. But high-temperature annealing does not lead to full restoration of the electro-physical characteristics of the Si–SiO_2 interface to their initial values [2] as redistribution of the impurities takes place. Laser annealing of these radiation-induced defects has also been effectively used [3,4]. The current investigations trend towards lower temperature processing for annealing of the defects associated with ion implantation. On the other hand a particular interest has been paid to the annealing processes stimulated by different kind of irradiation [5,6], which is a way to lower annealing temperature of radiation-induced defects.

In our previous investigation on the influence of X-ray irradiation on boron-implanted MOS structures it was shown that preliminary X-ray treatment reduces the temperature of thermal annealing of the radiation induced defects by ion implantation [6]. Our results also showed that X-ray irradiation anneals some of the interface states introduced by ion implantation (the deepest levels in silicon band gap) [7].

In this work, we show that the preliminary treatment with low dose (10^3 rad) gamma irradiation decreases the annealing temperature of radiation defects introduced in MOS structures by boron ion implantation with energy 15 KeV and dose of 1.2×10^{12} cm^{-2}.

2. Experimental details

Experimental investigation was performed with n-type ⟨1 0 0⟩ oriented Si wafers, with a resistivity of 4.7 Ω cm. Following the standard cleaning process thermal oxidation at 1050 °C in dry oxygen+6% HCl ambient

* Corresponding author. Tel.: +359-2-7144-513; fax: +359-2-975-3632

E-mail address: kaschiev@issp.bas.bg (S. Kaschieva).

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was performed to produce a 34-nm thick oxide. The oxide thickness of the samples was determined by ellipsometry. Some of the samples (the first group) were prepared without any additional treatment after oxidation and they were left as a reference. Part of the samples (the second group) after oxidation was gamma irradiated by Co^{60} with dose 10^3 rad. Then both groups were simultaneously implanted through the SiO_2 with boron ions with energy of 15 KeV and dose of 1.2×10^{12} cm^{-2}. After that the samples were thermally treated at a different temperature in the range of 300 up to 700 °C for 15 min. After temperature treatment aluminium gate electrodes were photolitographycally defined and ohmic contacts were formed on the entire back side of the samples. All of the samples were measured by thermally stimulated charge method before and after different temperature treatment. The obtained thermally stimulated current (TSC) spectra were composed of several overlapping peaks, so that the thermal and differential field 'cleaning' were applied to reveal the main peaks [8]. The state parameters (activation energy, capture cross-section and concentration) were determined.

3. Results and discussion

Fig. 1 presents TSC spectra of the both groups of the samples, (which are boron ion implanted with dose 1.2×10^{12} cm^{-2}) before and after annealing at different temperature. Fig. 1a shows TSC spectra of the samples without any additional treatment after oxidation. As-implanted sample is presented by curve 1. Implanted and thermal annealed samples at 300, 400, 500 and 700 °C for 15 min are presented by curves 2, 3, 4 and 5,

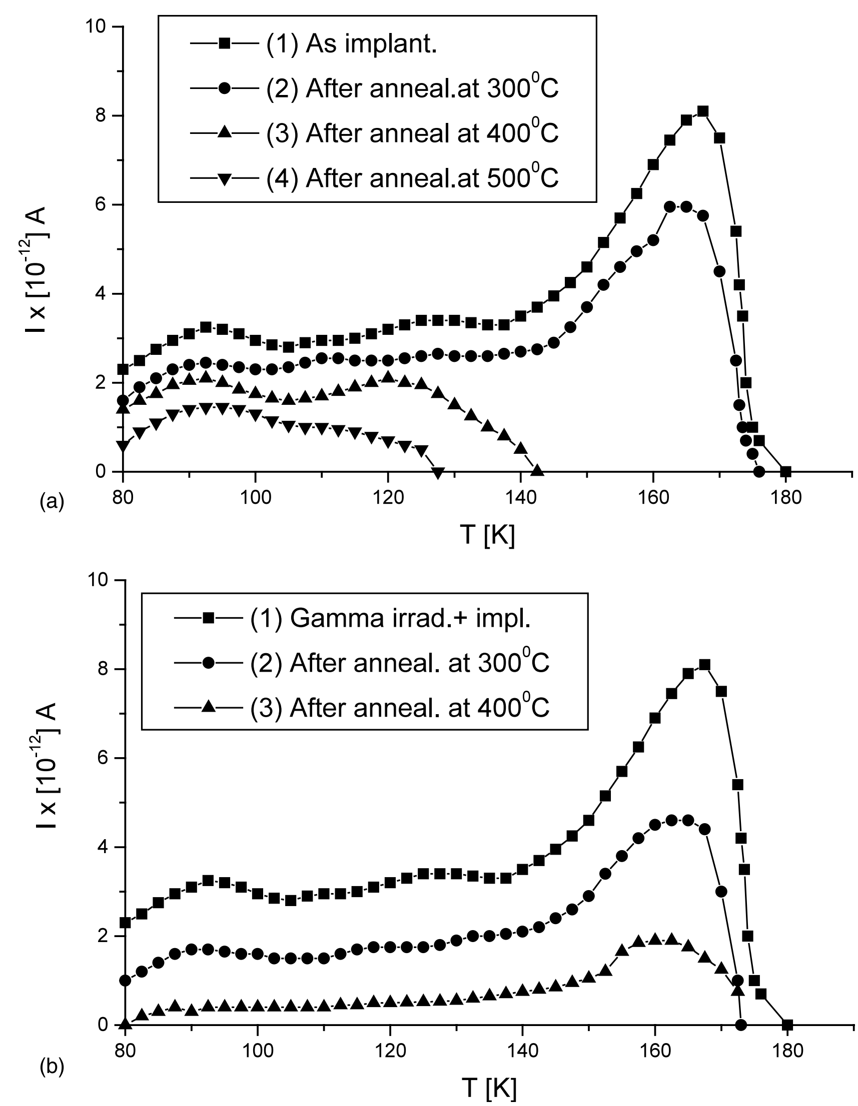

Fig. 1. TSC spectra of both group B^+ ion implanted samples with dose 1.2×10^{12} cm^{-2} before and after annealing. (a) Presents the samples without any additional treatment after oxidation. (b) Presents the samples previously gamma irradiated and then implanted at the same conditions as the first group.

respectively. TSC spectra of as-implanted sample is composed of several overlapping peaks and one distinct peak located at about 170 K. After thermal or differential field 'cleaning' of this spectrum, five peaks are distinguished. They are located at about 90, 110, 125, 160 and 170 K, respectively. The most intensive peak is the last one. The state parameters (the energy location in silicon band gap) derived from curve 1 are $E_c = 0.17$, $E_c = 0.22$, $E_c = 0.26$, $E_c = 0.32$ and $E_c = 0.45$ eV. The maximum of the last peak and the area enclosed by the curve decrease smoothly after first thermal annealing at temperatures of 300 °C (curve 2). Further thermal annealing of the implanted samples (at higher temperature) causes disappearance of the last peak. A decrease in the total density of defects, and narrows of the temperatures range of the spectra to the lower temperature also can be seen from the curves 3 and 4. The disappearance of the last peak, demonstrates that defects corresponding to it anneal out first. These defects can be connected with vacancy–phosphorus complex. The lower temperature peaks, corresponding to the lower energy traps in silicon band gap $E_c = 0.17$ and $E_c = 0.22$ eV are connected with defects like oxygen–vacancy and di-vacancies, respectively. These defects anneal finally. After thermal annealing of the samples at 700 °C for 15 min no TSC spectra is observed. Obviously this temperature contributes for complete annealing of the radiation defects introduced by ion implantation in the $Si–SiO_2$ structures.

Fig. 1b presents the second group of the samples, which were previously gamma irradiated and then implanted at the same conditions as the first group of the samples. TSC spectra of the samples are seen in the same temperature range 80–180 K, as the first one. Gamma irradiation of the samples with dose 10^3 rad is low enough to introduce measurable density of defects and after this irradiation no TSC spectrum is observed. TSC spectrum of gamma irradiated and ion implanted samples (Fig. 1b—curve 1) does not differ considerably from the spectrum of the as-implanted samples (Fig. 1a—curve 1). Obviously as a result of the preliminary gamma irradiation, the shape of TSC spectrum of the ion implanted samples does not change. Therefore, the total concentration of radiation induced defects by ion implantation in gamma irradiated samples and the total concentration of radiation-induced defects in as-implanted samples is almost the same. But the behaviour of the spectra of these samples after the same thermal treatment considerably differs. After thermal annealing of double treated samples at 300 °C, the concentration of all kinds of defects decreases, which is demonstrated by the reducing area enclosed by curve 2. This process continues after annealing at 400 °C as it is demonstrated by Fig. 1b—curve 3. After thermal treatment at 500 °C for 15 min all defects of the samples are fully annealed. It can be suggested that the defects introduced by gamma irradiation interact with those from the following implantation and the last ones easily anneal. To summarize, as a result of previously low dose gamma irradiation two kind of effects are observed: first—a simultaneously annealing of all kind of defects introduced by ion implantation and second—a radiation-stimulated annealing of defects introduced by ion implantation (all of them anneal at considerably lower temperature).

Fig. 2 shows the total defect concentration of the implanted samples (curve 1) and defect concentration of double treated samples (curve 2) before (shown on the Y-axis) and after thermal annealing as a function of annealing temperature. It is obvious that before annealing the total concentration of as-implanted and the double treated samples are almost the same. It is well

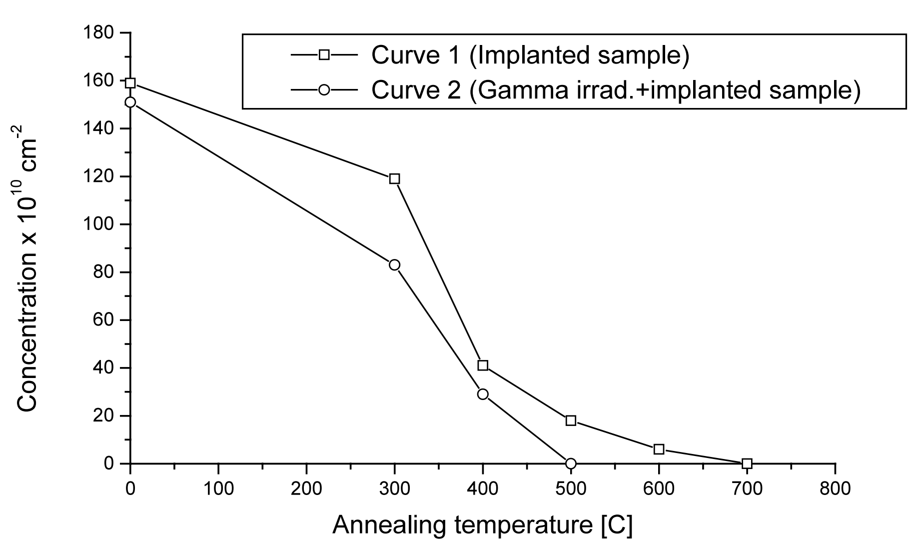

Fig. 2. Total defect concentration of the both groups of the samples as a function of annealing temperature.

known that gamma irradiation creates only one kind of defects, (with energy position $E_c = 0.17$ eV in silicon band gap) like oxygen/vacancy. But, as it was mentioned before, gamma irradiation with dose 10^3 rad is sufficiently low to introduce measurable concentration of defects in the samples. It is believed that the lowering of the annealing temperature described is due to the interaction of gamma rays and interface states at Si–SiO_2 interface, which structurally changed by gamma irradiation. This low dose gamma radiation breaking of strained bonds near the Si–SiO_2 interface only creates favourable conditions for lowering the annealing temperature of radiation defects introduced by subsequent ion implantation. A possible explanation of the observed gamma ray enhance-annealing effect in the double treated structures, should be the recombination-enhanced-defect reaction (REDR) mechanism proposed by Ma and Chin [9]. This REDR mechanism consists in recombination of electrons with holes, which could deposit substantial energy to the recombination sites if proper conditions are met. This deposited energy could promote the defect annealing process.

4. Conclusion

In conclusion it can be noted that the behaviour of the radiation induced by ion implantation defects in Si–SiO_2 structures during thermal annealing process depends on the preliminary treatment of the samples. Previous low dose (10^3 rad) gamma irradiation of the samples, in which following ion implantation introduces radiation defects, leads to complete annealing of these defects at a considerably lower temperature. The REDR mechanism as a possible explanation of this effect is proposed.

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