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# Electron and γ-irradiation of ion implanted MOS structures with different oxide thickness

S. Kaschieva [a,*], S.N. Dmitriev [b], Ch. Angelov [c]

[a] Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tzarigradsko Chaussee, Sofia 1784, Bulgaria
[b] Joint Institute of Nuclear Research, Flerov Laboratory of Nuclear Reactions, Dubna, Moskow region 141980, Russia
[c] Research Center for Materials Science at Extreme Conditions, Osaka University, 1-3 Machikaneyama-cho, Toyonaka, Osaka 560-8531, Japan

## Abstract

Effects of high-energy electrons or gamma irradiation on the interface states of ion implanted MOS structures have been investigated by thermally stimulated charge method. The n-type Si–$SiO_2$ samples with oxide thickness of 20, 200 and 300 are implanted with 50 keV boron ions to a dose of $1.5 \times 10^{12}$ $cm^{-2}$. Formed MOS structures are irradiated with 11 MeV electrons or $^{60}Co$ γ-rays. The energy position and the concentration of the radiation-induced interface traps are determined. It is shown that the kinds of radiation-induced interface traps and their concentration depend on the disposition of the maximum of the previously implanted boron ions with respect to the Si–$SiO_2$ interface.


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## 1. Introduction

The radiation-induced defects in dually treated MOS structures have been extensively studied over the last years [1–4]. The investigation of a secondary irradiation of pre-implanted MOS structures shows a variety of processes depending on the kind of post-irradiation, its energy and dose as well as the ion implantation parameters. Irradiation experiments with high-energy electron beams are expected to offer important information about the irradiation effects in MOS structures. For a certain absorbed dose the amount of radiation damage induced by electron irradiation is very small compared with that for ions or neutrons. As compared with γ-ray irradiation, parameters of electron-beam irradiation can be changed more widely [5].

The present paper is a continuation of our previous work where the effect of high-energy electron irradiation on implanted Si–$SiO_2$ structures has been studied by deep-level transient spectroscopy [6] and thermally stimulated charge (TSC) measurements [7]. The influence of gamma irradiation on the property of implanted MOS structures with oxygen or boron ions (located close to the Si–$SiO_2$ interface) has also been investigated [8].

* Corresponding author. Tel.: +359-2-714-4513; fax: +359-2-975-3632.
*E-mail address:* kaschiev@issp.bas.bg (S. Kaschieva).

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In this paper n-type Si–$SiO_2$ samples with oxide thickness of 20, 200 and 300 nm are implanted by 50 keV boron ions with a dose of $1.5\times10^{12}$ $cm^{-2}$. It will be shown that 11 MeV electrons and γ-rays increase the concentration of ion-implanted defects in different way. It has been also demonstrated that the kinds of radiation-induced interface traps and their concentration depend on the disposition of the maximum of the previously implanted boron ions with respect to the Si–$SiO_2$ interface.

## 2. Experimental details

The n-type ⟨1 1 1⟩ Si wafer samples are oxidized in dry $O_2$ at 1000 °C to a different thickness of 20, 200 and 300 nm. After oxidation the Si–$SiO_2$ samples are implanted by 50 KeV boron ions with a dose of $1.5\times10^{12}$ $cm^{-2}$. To form MOS structures Al gates with thickness 150 nm are deposited onto the implanted surface of the wafers. The thickness of each layer was determined by ellipsometry technique. The samples were exposed to γ-rays or to 11 MeV electrons. Gamma irradiation was carried out by $^{60}Co$ with dose of $10^6$ rad. Electron irradiation with a flux of about $10^{15}$ el/$cm^2$ was carried out in Microtron MT-25, in FLNR, JINR Dubna, Russia. The irradiation in vacuum was performed under a pressure of about $1\times10^2$ Pa. The beam current was about $I_e = 10$ μA.

In order to determine the parameters of the radiation induced TSC characteristics are measured. Some of the traps are directly evident from the peaks in the spectrum. But since some of the peaks of the TSC curves overlap, "thermal" [9] and "field cleaning" [10] of the spectra are used in order to determinate their characteristics. The energy positions of trap levels evaluated from both methods (the initial rise plot method and Grossweiner's technique [11]) prove to be in a good agreement.

## 3. Results and discussion

Fig. 1 shows typical TSC curves obtained on implanted and gamma or electron irradiated MOS structures with oxide thickness of 20 (Fig. 1(a)), 200 (b) and 300 nm (c) respectively. About 50 KeV boron ions create radiation defects manifesting in almost the same temperature range of the TSC spectra (80–190 K) for all MOS samples. Additional irradiation with γ-ray or electrons of $B^+$ ion implanted MOS structures leads to the formation of a set of electrically active centres with the same parameters as the centres formed by ion implantation only.

Fig. 1(a) shows that when implanted boron ions locate deep in the Si matrix one kind of defects is induced – only one peak of TSC spectrum at 175 K is observed. The activation energy of these defects in silicon forbidden gap is estimated as $E_c - 0.40$ eV. This electron-trapping centre attributed to the ion implantation is a lattice vacancy trapped at a substitutional phosphorus atom–phosphorus-vacancy pair or E-centre. γ-rays with doses of $10^6$ rad increases the density of the defects created by ion implantation and besides centre $E_c - 0.40$ eV manifest two more kinds of defects. They are connected with the levels $E_c - 0.25$ and $E_c - 0.31$ eV. The $E_c - 0.25$ eV level can be related to divacancies. The $E_c - 0.31$ eV level can be correlated with high-order defects [12]. The concentration of these defects increases more intensively after gamma irradiation.

Additional electron irradiation of ion implanted MOS structure with oxide of 20 nm also increases the concentration of all kinds of defects created by ion implantation. About 11 MeV electrons preliminary increase the concentration of the deepest centre $E_c - 0.40$ eV. After electron irradiation, the concentration of the shallower defects with energy position $E_c - 0.31$ eV is almost the same as after gamma irradiation.

Fig. 1(b) shows that when maximum concentration of the implanted boron ions locates close to the Si–$SiO_2$ interface several kind of defects are demonstrated. The two peaks (located about 165 and 185 K) in the spectra are clearly revealed after additional gamma irradiation with doses $10^6$ rad. The shallow level $E_c - 0.16$ eV has been attributed to a vacancy trapped by an interstitial oxygen atom or 'A' center. The levels $E_c - 0.21$ and $E_c - 0.25$ eV probably are correlated with double acceptor levels of divacancies [13]. The last two kinds of traps

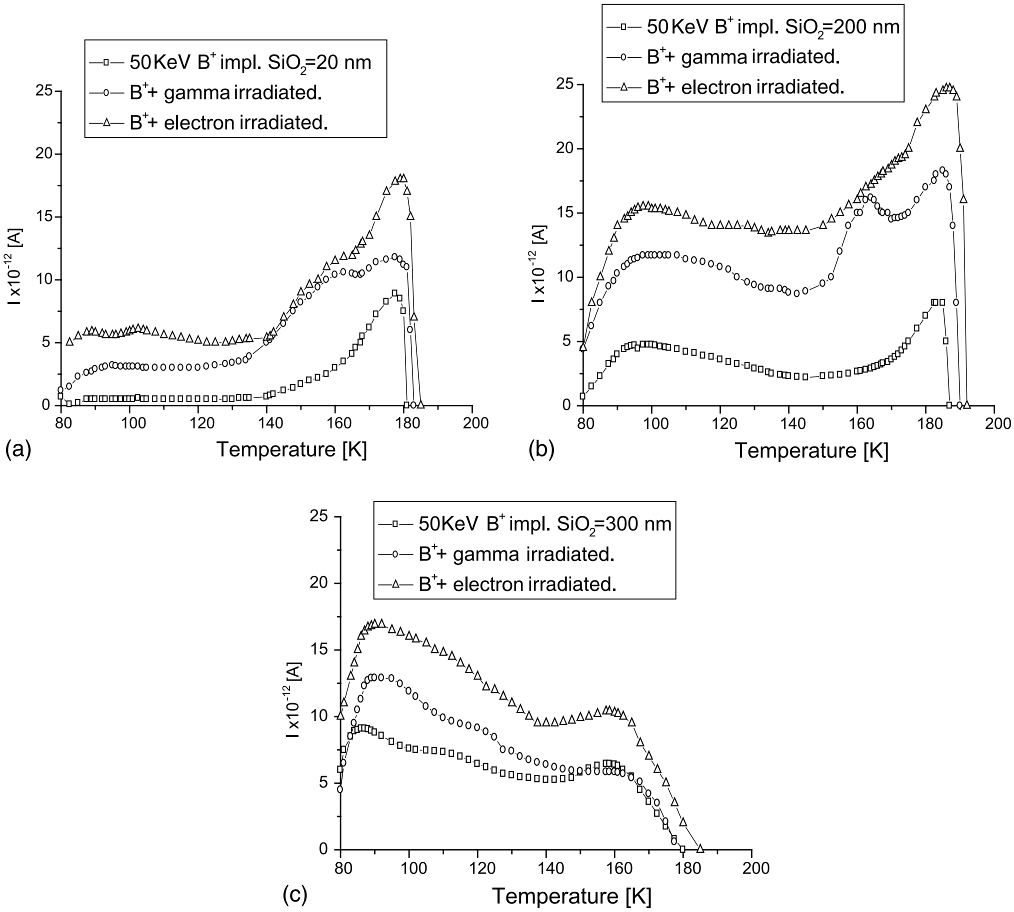


Fig. 1.

$E_c - 0.31$ and $E_c - 0.40$ eV have already been discussed above. Our results show that in this case the concentration of all levels related to the ion implantation increases after gamma irradiation. An increase in the area enclosed by the TSC spectrum is observed after gamma irradiation.

After electron irradiation of the samples with the same ion profile at the interface the concentration of the defects – corresponding to the peaks located at 95 and 185 K increases more intensively. This means that electron irradiation creates mainly defects, associated with A-centre and E-centre complexes. The intensive increasing of trap concentration of these complexes possibly is due to the easier creation of interstitial atoms and vacancies near ion implantation complex defects [14,15]. After electron irradiation, the concentration of the defects with energy position $E_c - 0.31$ eV is almost the same as after gamma irradiation.

Fig. 1(c) shows that not all of the above mentioned defects introduced by ion implantation at the Si–$SiO_2$ interface are present in the case when the maximum of the implanted ions is located in the $SiO_2$ bulk. In this case, the last peak in TSC spectra, corresponding to the deepest level $E_c - 0.40$ eV was not observed. This means that the defects like P–V are not created, as an insignificant number of the implanted ions reach close to the Si–$SiO_2$ interface. The dominant electron trapping centres attributed to implantation is the A-centre. In this case gamma rays increase in a high degree the concentrations of the A-centres

Table 1
Defect concentration ($\times 10^{11}$ cm$^{-2}$) of ion implanted MOS samples with different oxide thickness of 20, 200 and 300 nm, which are gamma irradiated (with dose of $10^6$ rad) or 11 MeV electron irradiated (with a flux of about $10^{15}$ el/cm$^2$)

| Sample | Oxide thickness (nm) | | |
|---|---|---|---|
| | 20 | 200 | 300 |
| $B^+$ ion implanted | 5.2 | 9.8 | 13.5 |
| $B^+$ + gamma irradiated | 14.1 | 29.3 | 19.1 |
| $B^+$ + electron irradiated | 20.1 | 41.8 | 27.3 |

and to a certain extent the divacancies concentration, while the concentration of the defects with energy $E_c - 0.31$ eV does not change. When ion implanted MOS structure are irradiated with electrons, the concentration of defects created by ion implantation increases in a similar way.

Our results shown that when maximum concentration of boron-implanted ions locates close to the Si–$SiO_2$ interface, the total concentration of gamma or electron irradiation induced defects at the Si–$SiO_2$ interface is the largest. The implanted boron ions, located at the Si–$SiO_2$ interface create a suitable condition for a more intensive increase of radiation defect concentration close to the Si–$SiO_2$ as the result of the additional $\gamma$-ray or electron irradiation.

Table 1 shows the defect concentrations of the implanted and double treated samples: after additional gamma irradiation or electron irradiation for different oxide thickness 20, 200 and 300 nm. Total defect concentration of ion implanted samples with 20 and 200 nm oxide thickness increase about 3 times after gamma and about 4 times after electron irradiation. For the samples with thicker oxide (300 nm) this increase is about half and 2 times respectively. Obviously, this total defect concentration is the largest in the case when maximum concentration of boron-implanted ions locates close to the Si–$SiO_2$ interface (oxide thickness of 200 nm).

It could be assumed that the previous ion implantation breaks the strained bonds near the Si–$SiO_2$ interface and besides radiation defects creates favourable conditions for creation of additional radiation defects introduced by the subsequent irradiation. A possible explanation of the observed results (in the implanted and irradiated structures) should be the recombination-enhanced-defect reaction (REDR) mechanism proposed by Ma and Chin [16]. 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 generation process more effectively at the Si–$SiO_2$ interface after additional gamma or high-energy electron irradiation.

## 4. Conclusions

The experiments described here are performed on boron ion implanted Si–$SiO_2$ structures with different oxide thickness. Our results have shown that the concentration of gamma or high-energy electron induced defects in ion implanted MOS structures depends on the spatial distribution of implanted ions. Three important conclusions can be drawn from our results: (1) high energy-electrons and $\gamma$-rays increase the concentration of ion-implanted defects in different way; (2) the kinds of radiation-induced interface traps and their concentration depend on the disposition of the maximum of the previously implanted boron ions with respect to the Si–$SiO_2$ interface and (3) the total concentration of gamma or electron irradiation induced defects at the Si–$SiO_2$ interface is the largest when the maximum concentration of implanted boron ions locates close to the Si–$SiO_2$ interface.

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