Dear editor,

We like to express our appreciation to the reviewers for their comments. We are resubmitting the revised version of the paper number SSE-2019-316. We have studied the comments of the reviewer carefully, and have changed the text according to the comments they have listed. Below we refer to each of the reviewers comments.

Response to Reviewer #1

Comment 1. *The main conclusions (and the highlights) were in fact drawn before and according to more consistent studies.*

Reply:

The reviewer is correct and our work is not pioneering observations of acoustically induced annealing of defects. In particular, a whole number of References are cited in Introduction. However, not all radiation defects are acoustically active and annealed by ultrasound treatment (UST). To the best of our knowledge, only Parchinskii *et al.*[1,2] investigated UST influence on γ–modified Si–SiO$_2$ structure and there is no published paper which describes an UST effect on charge transfer in irradiated Si–SiO$_2$. In our case using of high–resistance substrate allowed to clearly mark out both current components, concerned with radiation defect, and UST effect on them. Basing on known typical radiation defects in Si–SiO$_2$ and obtained results it was concluded about low temperature annealing of P_b centers and E' centers. It is not previously reported about acousto–activity of P_b centers and E' centers.

In addition, it is well known that irradiation leads to increase in leakage current. It is well known that the majority of leakage current mechanisms in MOS structures deal with a defects, located at the near interface region. But there is a wide variety of such mechanisms: the thermionic trap-assisted tunneling, the space–charge limited current, the thermally–assisted variable–range–hopping conduction, the phonon–assisted tunneling etc. The global decision about nature of irradiation induced current is absent and the concrete charge transfer mechanism depend on type of irradiating particles, doze, properties of semiconductor and oxide layer. This work has decided such task for the case of $5 \cdot 10^7$ rad γ–irradiation of Si–SiO$_2$ with high–resistance substrate and native oxide layer. The main conclusions and the highlights were corrected in accordance with aforesaid.

To conclude, we believe strongly that the paper is an important addition to the literature and is not a variation but rather expansion of preceding studies.

Comment 2. *The claimed study of carrier transport is very poor, the investigations being reduced to the measurement and fit of a few Current-Voltage (I-V) characteristics recorded on Au-SiO2-Si MOS capacitors at room temperature (295K?!, for all the cases the same?): as grown, as irradiated with Co60-gamma and irradiated followed by ultrasound treatments of 30 and 60 minutes.*

Reply: Really, the claimed study is consist of following steps.

- Au-SiO_2-Si structure on high–resistance substrate with native oxide layer was formed. I–V characteristic of initial structure was recorded at room temperature. It is generally accepted that bias dependence of current is used to determine carrier transport mechanism. In the case of initial structure, the I–V curves corresponded to current mechanism, being typical for MOS–structure, and additional investigation were not seem necessary.

- Au-SiO_2-Si structure was irradiated by ^{60}Co–gamma particles and I–V characteristic was recorded at room temperature. The change of bias dependence of current allowed to conclude about carrier transport mechanism alteration. I–V curves were fitted in line with known current mechanisms. Basing on best fitting results, the availability of SCLC and TAT was assumed. The known data about radiation defects in SiO_2-Si were taken into account and the conclusion about an important role of P_b centers and E' centers in charge transfer was done. I–V characteristics was recorded over a temperature range of 300-340 K. The temperature dependencies of fitting parameters confirmed assumptions.

- The irradiated structure was treated by ultrasound wave and I–V characteristics were recorded at room temperature. It was revealed that i) UST did not affect type of bias dependence of current therefore the current mechanisms were changeless and the measurement over wide temperature range was not so necessary; ii) UST leaded to change in current value therefore the defects, taking part into carrier transfer, were influenced by acoustic loading. Data, extracted by fitting of curves, measured at same temperatures, allowed to estimate ultrasound influence on radiation defects. The repeated treatment corroborated the features of ultrasound influence.

The main highlights are aforesaid in reply to the comment 1 (above). It should be noted that using of high–resistance substrate makes possible an clear observation of space charge limited current, caused by (radiation) traps. In turn, it allows to investigate ultrasound influence on P_b centers by a easy way.

In our opinion, the study is not so wide but is sufficient to achieve declared goal.

In addition the manuscript title was slightly modified and we have revised the text.

Comment 3. *The temperature dependence was measured only in a tiny range and only for fw biases (between 304K and 320K in Fig.3, although the fit of the I-V, shown in Fig.1, seems to be for 295K!).*

Reply: The fit of the I–V curves, shown in Fig. 1, was done for 300 K. We apologise for mistake in figure caption. The correction was done. The revised Fig.3 includes data over a temperature range of 300-340 K. This range is not huge as well, but following defence should be taken into account if possible. On the one hand, the lower temperature limit is restricted by setup sensitivity, the upper temperature limit is restricted by desire to avoid an annealing of defect. On the other hand, the current value at 340 K is 5 times as much as one at 300 K and the activation energy can be estimated precisely enough.

The temperature dependence of current in the case of trap–assisted tunneling is sufficiently tangled[3–5] and measured reverse biased curves do not used to illustrate results.

Comment 4. *The possible dependencies on the oxide thickness are neglected (the thickness of the oxide and of the depletion layer in Si are not even mentioned in the manuscript) as well as on the defect distribution (mentioned as nonhomogeneous for E-center at page 8). A positive charge in the oxide would move the flat band voltage, shifting and disturbing, when nothomogeneous, the shape of the I-V curves.*

Thus, it is hard to understand how relevant are the fit formulas for the device I-V characteristics.

Reply: The reviewer is correct and not only positive charge in the oxide but also negative charge at interface must be under consideration[6,7]. The presence of both type traps is taken into account in manuscript.

It is known[8,9] that the expression for thermionic emission current

$$I = I_s \left\{ \exp\left[\frac{q(V - IR_s)}{nkT}\right] - 1 \right\} , \qquad (1)$$

can be used in the case of inhomogeneous barrier as well. The inhomogeneity causes the specific temperature dependencies of both barrier height and ideality factor. In our case forward I–V characteristics at low bias cannot be fitted by Eq.(1). Therefore other current mechanism is expected. The observed bias dependencies of current were used to identify charge transfer mechanisms.

On the other hand, according to Reference[11], the E'-centers are non-homogeneously distributed over oxide layer depth and no data about non-homogeneous layer surface is present. Therefore the disturbing of the shape of the I-V curves is unlikely. Clarifying correction was done in manuscript.

The reviewer is correct and a current in MOS structure depends on the oxide thickness. But to the best of our knowledge, there is no published paper which describes a significant change of oxide thickness, resulting from γ–irradiation or ultrasound treatment. And the oxide thickness is considered constant when analyzing current changes. Data about the thickness of the oxide and of the depletion layer were added in manuscript.

Comment 5. *Also, the English is poor.*

Reply: The text was revised.

Response to Reviewer #2

Comment 1. *The paper is about influence of gamma-irradiation on carrier transport in Au-SiO2-Si structure. However, gamma-irradiation mainly influences on bulk Si rather than its surface, which is too thin. I feel that the discussions regarding the Si surface passivation are not relevant to main focus of the article.*

Reply: The reviewer is correct and gamma-irradiation mainly influences on bulk Si. But irradiation leads to creation of defects both at Si/SiO_2 interface and in thin oxide layer as well. In fact, total concentrations of P_b centers and E' centers are about 10^{18} cm^{-3} in the case of 10 Mrad dose of ionizing radiation[10,11]. Our work focuses on current mechanisms in MOS structure. These mechanisms are mainly determined by near interface region. Our results testify to the annealing of defects, located at interface region. In turn, it is generally accepted[6,12] that P_b centers (broken interfacial $\equiv \mathrm{Si}-\mathrm{H}$ bonds) and E' centers (broken $\equiv \mathrm{Si}-\mathrm{O}$ bonds) anneal by the trapping of some diffusing molecular species such as O_2, H_2, ... Therefore we are forced to discuss regarding passivation of near interface dangling bonds.

Comment 2. *The idea about ultrasound-induced hydrogen diffusion is interesting, however,* *there is no discussion about hydrogen source. The only source could be the hydrogen used in surface treatment, but that concentration of that hydrogen is not enough to cause drastic influence on electrical properties of bulk Si irradiated by gamma particles. This part of the discussions is speculative.*

Reply:

Indeed, the native oxidation of Si surface is a hydrogen source. The both dry and wet oxidation processes take place in this case:

$$\mathrm{Si} + \mathrm{O_2} \to \mathrm{SiO_2}\,,$$
$$\mathrm{Si} + 2\mathrm{H_2O} \to \mathrm{SiO_2} + 2\mathrm{H_2}\,.$$

Second reaction leads to rather high concentration of hydrogen in oxide layer. For instance, it is shown[13] that the appearance of the first monolayer of silicon oxide causes a strong increase in both interface states density D_{it} and surface charge. The further native oxide growth is characterized by significant decrease of D_{it} (down to about 10^{12} cm^{-2} in 1 nm layer). On the other hand, it is demonstrated[10] a rough one–to–one correspondence between interface trap density and P_b–center density. Therefore significant decrease of D_{it} indicates about passivation of broken interfacial $\equiv\mathrm{Si-H}$ bonds by hydrogen. In addition, according to Pershenkov *et al.*[11], the SiO_2 layers, which are grown by non–chemical oxidation, are rich in an atomic hydrogen. Thus hydrogen is enough to cause drastic influence on processes, occurring in interface region.

According to Pintilie *et al.*[14], the electrical properties of bulk gamma–irradiated Si are mainly influenced by interstitial defect $I^{0/-}$. In our case, the electrical properties of Si bulk have an effect on series resistance value predominantly. And increase in R_s value was detected after gamma-irradiation.

Comment 3. *Some important References are not cited, such as, e.g., A Davletova, et. al. J. Phys. Chem. Solids 70 (6), 989-992; J. Phys. D: Appl. Phys. 41 (16), 165107.*

Reply: The list of references was expanded.

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