Effect of $\gamma$ Radiation on Gate Trigger Current of Thyristors

Yasuhei Izawa* and Rintaro Katano**

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Experimental study on the $\gamma$-radiation effect in gate trigger current, $I_{GT}$, of small current thyristors (2A class) has been performed. The gate trigger current is sensitively increased by $\gamma$ radiation and the stability of the thyristor is improved. The increase in $I_{GT}$ is proportional to the $\gamma$-radiation dose and is not deteriorated by heat treatment at 200°C for 1000 h.

It is well known that many types of semiconductor devices are radiation sensitive. The radiation effect on semiconductor devices usually appears at $10^3$ R and by irradiation of $10^8$–$10^{10}$ R, they become out of use. The change in their electrical properties is caused by the structural defect produced by irradiations. Electron beams or $\gamma$ rays of about 1 MeV give rise to the Frenkel defect, i.e., one electron removes one atom in the crystal structure involved. This defect forms impurity levels in the forbidden band of semiconductor crystal, resulting in change in carrier concentration, in decrease in minority carrier lifetime and mobility, and in change of optical or other physical properties. Among these effects, the most sensitive one is the decrease of the lifetime of minority carriers, which is proportional to the irradiation dose.

In the present work, the $\gamma$-ray radiation effect on the electrical properties of thyristors was examined. The thyristor is the most practical $pnpn$ 4-layer switching device and the function is equivalent to a pair of $pnp$ and $npi$ transistors interconnected through the collectors.

In the actual use of thyristors, operations should be done at a certain standard value of $I_{GT}$. However, at the present stage of manufacturing process, it is rather difficult to produce thyristors with a desirable value of $I_{GT}$ for stable functioning. Since the thyristor operating with a small standard value of $I_{GT}$ is electrically too sensitive, misoperations may take place. Therefore, it is desired to get the thyristors with a large $I_{GT}$. The purpose of the present work is to obtain the thyristors with a large $I_{GT}$ without giving deteriorations to other electrical characteristics.

The principle of gate-turn-on of the thyristors ($p_i n_i p_i n_i$) is as followings; (a) when $p_i$ (gate) is plus-biased and $n_i$ (cathode) is minus-biased, there appears the current from $p_i$ to $n_i$, (b) then electrons flow in from junction $J_3$ and reach junction $J_2$, and (c) this leads to current of holes from junction $J_1$. When the thyristor is irradiated by $\gamma$ rays, recombination centers of carriers are produced in the layer $p_i$ making electrons from $n_i$ difficult to reach $J_2$ and resulting in increase of $I_{GT}$.

* New Nippon Electric Co., Ltd.
** Laboratory of Nuclear Radiation, Institute for Chemical Research, Kyoto University, Kyoto.
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The specimen used in the experiment is the diffused, glass passivated, mold-type thyristor (commercial name is 2P05M~2P4M, NEC). The base material is \( n \)-type (P-doped) silicon made by the Floating Zone method. The concentration of phosphor is about \( 10^{15} \) atoms/cm\(^3\). Ga is diffused in \( p_1 \) and \( p_2 \) layers and P in \( n_2 \). The sample was irradiated in a 2000 Ci \( \gamma \)-ray irradiation facility (6.7 \( \times \) \( 10^4 \) R/h) at room temperature.\(^5\) The irradiation dose was controlled by changing irradiation time. The method of testing electrical characteristics is JIS (c-7051).

In Table I are listed relative changes of items studied before and after \( \gamma \) radiation (2 \( \times \) \( 10^6 \) R). Numerical values are obtained by averaging values of 14 thyristors sampled at random. As seen in the table, the most sensitive item for \( \gamma \) radiation is \( I_{GT}/I_{GTO} \), where \( I_{GTO} \) and \( I_{GT} \) are the gate trigger current before and after \( \gamma \) radiation, respectively, but the others are not very much changed by \( \gamma \) radiation.

Table I. Relative Changes in Electrical Characteristics of Thyristors Caused by \( \gamma \) Radiation (2 \( \times \) \( 10^6 \) R). Suffix 0 means Initial Values

<table>
<thead>
<tr>
<th>( I_{GT}/I_{GTO} )</th>
<th>( I_{H}/I_{HO} )</th>
<th>( V_{GTO} )</th>
<th>( I_{D}/I_{DO} )</th>
<th>( I_{B}/I_{BO} )</th>
<th>( V_{D}/V_{DO} )</th>
<th>( V_{B}/V_{BO} )</th>
<th>( V_{T}/V_{TO} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.6</td>
<td>1.7</td>
<td>1.1</td>
<td>1.6</td>
<td>1.1</td>
<td>0.92</td>
<td>0.94</td>
<td>1.1</td>
</tr>
</tbody>
</table>

\( I_{GT} \) : Gate Trigger Current. \( I_{H} \) : Holding Current.
\( V_{GTO} \) : Gate Trigger Voltage. \( I_{D} \) : Forward Saturation Current.
\( I_{B} \) : Reverse Saturation Current. \( V_{D} \) : Forward Blocking Voltage.
\( V_{B} \) : Reverse Blocking Voltage. \( V_{T} \) : Forward Voltage Drop.

Fig. 1. Cross-sectional view of a glass passivated thyristor.

Fig. 2. Relative change in the gate trigger current, \( I_{GT}/I_{GTO} \), versus \( \gamma \)-irradiation dose.
The relation between $\gamma$-radiation dose and relative change in $I_{GT}$ was also studied, of which result is shown in Fig. 2. In this measurements, we used several decades thyristors divided into three groups with different $I_{GTO}$. However, the $\gamma$-radiation effect on $I_{GT}$ did not show appreciable dependence on the initial value of gate trigger current, $I_{GTO}$. From these observations, we concluded that the $\gamma$-radiation effect on $I_{GT}/I_{GTO}$ is proportional to the $\gamma$-radiation dose and does not depend on $I_{GTO}$.

It is of importance to know if the improved characteristics (increased $I_{GT}$) by $\gamma$ radiation do not deteriorate during actual use of thyristors. To see this, the thyristors treated by $\gamma$ radiation were annealed at 200°C for 1000 h. As shown in Fig. 3, reverse anneaing occurs within the first several hours, but after that, the improved characteristics are stable at that temperature. Since this temperature is higher than the operation temperature of thyristors, the $\gamma$-radiation effect can be considered to be useful to improve the characteristics of thyristors.

![Fig. 3. Relative change in the gate trigger current in annealing treatment. $I_{GTa}$ denotes the gate trigger current after the annealing.](image)

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REFERENCES