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W.Hammer [1], Sl.Sterlinski [2], V.M.Nazarov,
Z.Bober [3]


# EXPERIMENTAL FINDINGS ON SELF-RECOVERY AND IMPROVEMENT OF REPRESENTATIVE PARAMETERS OF SOME SEMICONDUCTOR DEVICES AS IRRADIATED IN FAST NEUTRON FLUX


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[1] Institute for Nuclear Studies, Swierk-Otwock, Poland

[2] Institute of Nuclear Chemistry and Technology, Warsaw, Poland

[3] Institute of Nuclear Physics, Cracow, Poland



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The "self-recovery" term applied to the improvement of electric characteristics of the devices under test (DUT) at a room temperature in situations where the effects of other factors are not taken into consideration. The settling time for a parameter after the irradiation has been completed depends upon the type of the DUT and may vary from several minutes to weeks. Thus, the first test of the parameter is to be performed as soon as possible after the irradiation process has been completed. Such a condition makes difficult the testing of the self-recovery effects for these DUTs which are strongly activated in the neutron flux, e.g. low and medium power transistors in metal packages, and integrated circuits in the packages of TO-99 and TO-100 type, etc.

The term of the "improvement of electrical characteristics" of the DUT designates the process resulting from the irradiation, which leads to a change in the electrical characteristics in the positive direction. The experimental investigation of the improvement of characteristics requires two measurements at least: the first one before the irradiation process is started and the second one after correspondingly long time from the termination of the irradiation process to reach the saturation state of the self-recovery process.

The self-recovery effect for the long-base diodes (known also as PDN) irradiated in the fast neutron flux has been quite well known in dosimetry laboratories. One of the experimentators (W.H.) noticed this effect when a Si(Li) detector was used for measuring the fast-neutron fluence in a 14 MeV fast neutron generator[1]. The self-recovery effect should not be mistaken with the known procedure of recovery from the radiation damages in semiconductor detectors by soaking them at a high temperature or by means of redrift treatment[2-4].

The effect of improvement of electric characteristics resulting from irradiation of semiconductor devices is covered by the respective references but this applies only to small doses. The references available to us do not cover large neutron fluences.

For our experiments there were employed two fast neutron sources: the 14 MeV neutron generator (NA-2) and at IBR-2 Pulse Reactor (Channel K1) at the Joint Institute for Nuclear Research in Dubna (USSR)[5]. The neutron output from the NA-2 Generator was about $10^{10}$ $n \cdot s^{-1}$. The fast neutron flux density at the IBR-2 reactor (Channel K1) was $1.4 \times 10^{12}$ $n \cdot cm^{-2} s^{-1}$ ($E_n > 0.5$ MeV, average energy - 1.3 MeV).

Table 1

List of devices in which the effects of self-recovery (SR) and/or improvement of electrical characteristics (IEC) were observed while testing radiation damage in semiconductor devices

| Type of device | 14 MeV neutron generator | | Reactor IBR-2 | |
|---|---|---|---|---|
| | SR | IEC | SR | IEC |
| Si(Li) detectors | + | - | - | - |
| 7404 TTL | + | + | + | + |
| 7473 TTL | n.m. | n.m. | h.a. | + |
| 7493 TTL | n.m. | n.m. | h.a. | + |

"+" Effect observed at least for one device; "-" effect not observed; n.m. = not measurable with the use of our neutron generator due to excessively low neutron flux; h.a. = not measured due to high activity of the device irradiated.



The investigation of irradiation defects included 15 types of semiconductor devices. The tests of self-recovery effects and/or improvement of characteristics could be performed for four types (see table 1).

Si(Li) Detectors. The energy resolution FWHM (full width at half maximum) was tested for the line $\beta$-625 Cs and $\alpha$ - 5.5 MeV resulting from the reaction (n,$\alpha$) of $^{28}Si$ incorporated the detector. The measurement results obtained for the 14 MeV neutron generator are presented in table 2. Owing to the small density of neutron flux the irradiation process had to last for four months. The detectors were used to measure the fluence[1)].

Table 2

Self-recovery of Si(Li) detectors irradiated on the 14 MeV neutron generator ($t_c$ - cooling line)

| Detector (volume) | Fluence $n \cdot cm^{-2}$ | FWHM (keV) | | | |
|---|---|---|---|---|---|
| | | $\beta$ - 625 keV | | $\alpha$ - 5.5 MeV | |
| | | $t_c = 0$ | $t_c$ = 2 weeks | $t_c = 0$ | $t_c$ = 2 weeks |
| 1 | 0 | 15.7 | | 192 | |
| (0.48 $cm^3$) | $3 \cdot 10^9$ | 25.0 | 17.2 | 290 | 210 |
| | $2.2 \cdot 10^{10}$ | 35.0 | 28.5 | 410 | 240 |
| | $5 \cdot 10^{10}$ | 41.0 | 30.0 | n.m.[1)] | 290 |
| 2 | | | | | |
| (0.27 $cm^3$) | 0 | 16.7 | | 200 | |
| | $4 \cdot 10^9$ | 30.2 | 20.8 | 310 | 220 |
| | $4.5 \cdot 10^{10}$ | 38.0 | 31.0 | n.m. | 280 |

1) Not measurable.

7404 TTL-Compatible Integrated Circuits. There were eight 7404 integrated circuits (i.e., 6x8 = 48 NOT gates) irradiated in the neutron generator, while 16 integrated circuits (96 NOT gates)

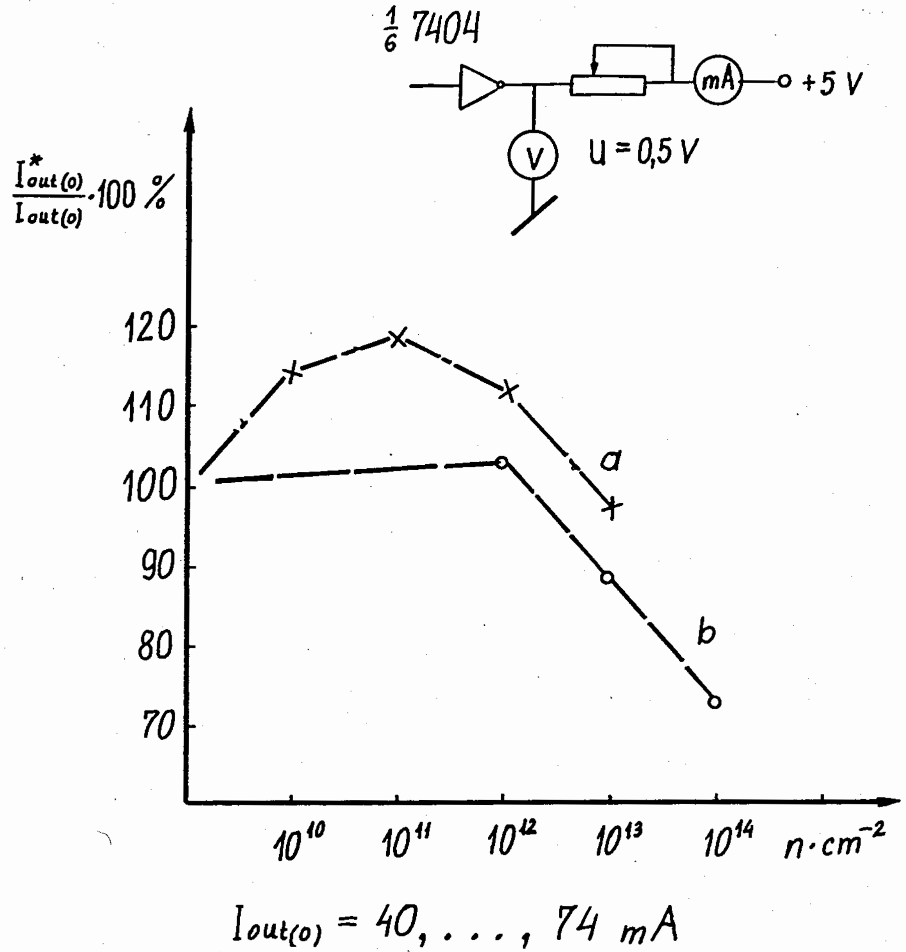


Fig.1. The improvement of electrical characteristics ($I_{out(0)}$) for 7404 TTL-compatible Integrated Circuits irradiated at neutron generator (a) and reactor IBR-2 (b) versus fast neutron fluence ($E_n >$ 0.5 MeV for the reactor flux). The values of $I^*_{out(0)}$ were measured after 2 week cooling time.

were irradiated at the IBR-2 reactor. The output current $I_{out(0)}$ from the NOT gate at its logic "0" state was the tested parameter. The termination of the self-recovery process was observed after 24-hour cooling from the termination of irradiation process on



Table 3. The improvement of electrical characteristics (limit frequency $f_T$) for 7473 and 7493 TTL-compatible integrated circuits irradiated at the reactor IBR-2 versus fast neutron fluence ($E_n >$ 0.5 MeV). The cooling time amounted to above 2 months

| Fluence n/cm$^2$ | $f_T$ (MHz) for 7473 IC | $f_T$ (MHz) for 7493 IC |
|---|---|---|
| o | 20.2 | 19.0 |
| 1.4x10$^{13}$ | 22.2 | 20.4 |
| 1.4x10$^{14}$ | 14.2 | 16.4 |
| 2.8x10$^{14}$ | 8.0 | 8.8 |

the neutron generator and 50-minute cooling from the termination of irradiation process at the reactor. The self-recovery effect was observed in all the gates that had been irradiated in the neutron generator and the reactor provided that their excited activity allowed for measuring the $I_{out(0)}$. The values of growth in the self-recovery effect (increase in the current $I_{out(0)}$) were estimated as 15% and 10% for the NOT gates irradiated in the neutron generator and the reactor, respectively. The $I_{out(0)}$ improvement was observed in 30 gates for the 48 tested gates which were irradiated at the neutron generator, but only in 12 gates for the 96 tested gates which were irradiated at the reactor. It was noticed that the improvement in the $I_{out(0)}$ output characteristics of the gates which had been irradiated on the neutron generator occurred mainly in that portion of the gates for which the $I_{out(0)}$ output parameter had been lower (before irradiation) than the average value of the $I_{out(0)}$ for the total population under test. Figure 1 shows the average percentage value of the improvement in the ratio of $I^*_{out(0)}/I_{out(0)}$ vs. fast neutron fluency for the samples irradiated in the neutron generator and the reactor($I_{out(0)}$

and $I^{*}_{out(0)}$ are the equivalents of the readings for the currents before and after the irradiation process, respectively).

<u>7473 and 7493 TTL-Compatible Integrated Circuits.</u> There were eight 7473 integrated circuits and eight 7493 integrated circuits irradiated at the IBR-2 reactor. Owing to the high activity (of Au mainly) excited in these devices it was impossible to measure the self-recovery effect. The limit frequency ($f_T$) for both IC types was measured by means of the electronic counter and oscilloscope.

The improvement of the limit frequency for 7473 integrated circuits was estimated as 8% and 18.8% (from 20.2 MHz up to 24 MHz) for the average value and maxiumum one, respectively. The suitable figures for 7493 integrated circuits were equal to 6% and 13% (from 19 MHz to 21.6 MHz). The results are represented in table 3. The improvement effect was not observed for some devices under test (20% and 37% for 7473 and 7493 integrated circuits, respectively). In a few instances the limit frequency of the tested devices became worse.

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Экспериментальные результаты измерения самoрегенерации и улучшения основных параметров некоторых полупроводниковых приборов после облучения потоком быстрых нейтронов

Исследовались полупроводниковые приборы /детекторы Si-Li, диоды, транзисторы и микросхемы/ после облучения в ядерном реакторе при интегральном потоке до $2{,}8\cdot 10^{14}$ $н\cdot см^{-2}$ /$E_n > 0{,}5$ МэВ/ и нейтронном генераторе при интегральном потоке до $10^{13}$ $н\cdot см^{-2}$. При измерении радиационных повреждений у детекторов Si-Li и некоторых микросхем были обнаружены эффекты саморегенерации и улучшения их электрических характеристик.

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Experimental Findings on Self-Recovery and Improvement of Representative Parameters of Some Semiconductor Devices as Irradiated in Fast Neutron Flux

Semiconductor devices /Si-Li detectors, diodes, transistors and integrated circuits/ were irradiated at a nuclear reactor up to $2.8\cdot 10^{14}$ $n\cdot cm^{-2}$ /$E_n > 0.5$ MeV/ and a 14 MeV neutron generator up to $10^{13}$ $n\cdot cm^{-2}$. While testing radiation damage it was seen that some Si-Li detectors and integrated circuits showed the effects of self-recovery and improvement of electrical characteristics.

The investigation has been performed at the Laboratory of Neutron Physics, JINR.

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