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RADIATION EFFECTS ON CDF AC-COUPLED MICROSTRIP SILICON DETECTORS †.

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ABSTRACT

Radiation hardness of FOXFET biased ac-coupled microstrip detectors, foreseen for the upgraded version of the vertex detectors (SVX') of the CDF experiment, has been studied by Co^{60} γ irradiation. Integrated doses up to 1 MRad have been investigated which induce two basic effects on the measured devices: a variation of the switching voltage up to 100% due to oxide charge accumulation and Si/SiO_2 interface trap formation, and 12-fold increase of the total leakage current, likely deriving from surface damage. Moreover, a 10-fold decrease of the FOXFET dynamic resistence is observed at low gate bias as deduced from dc I-V characteristics at zero source current as a consequence of the leakage current increase.

Post-irradiation annealing effects at room temperature of the detector electrical parameters are currently under investigation, in particular on a single shot 1 MRad irradiated device. Recovery phenomena toward the pre-irradiation values are observed only for the switching voltage due to the annealing of trapped oxide charge.

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1. INTRODUCTION

A basic issue concerning the use of microstrip silicon detectors in high energy physics experiments is their degradation upon irradiation during their operational life. Thus, a large effort is devoted to identify the detector electrical parameters critically affected by radiation-induced degradation, and to develop new radiation hard technologies. These researches will become even more important, in the light of the current tendency toward high luminosity accelerators, posing stronger challenges to the duration of the detectors operational life[1].

The ac-coupled single-sided microstrip *Si* detector studied in this work, where the bias of the strips is given through a single Field Oxide FET (FOXFET) common to all the strips, will replace the two innermost layers of the present dc coupled vertex detector (SVX) of the CDF experiment[2] in the 1993 planned run.

We are reporting in this work the first results we achieved during Co^{60} γ irradiation tests of these devices. Electrical parameters have been monitored at different steps during irradiation, with particular attention to the FOXFET characteristics. Room temperature annealing effects have been observed on the FOXFET switching point and other annealing effects are currently under investigation.

2. EXPERIMENTAL

FOXFET biased microstrip detectors, with either 256 or 384 strips, have been fabricated by Micron Semiconductor on high resistivity ($\geq 4\ K\Omega \times cm$) 4-inches $n - Si$ wafers supplied by Wacker Co. The schematic layout and cross-section are reported in Fig. 1, showing mainly the FOXFET region. The ac and dc signals are monitored at the ac pad and source terminals, respectively.

The strip width is 12 μm, while the pitch is 60 μm, and the FOXFET channel length is 6 μm. The thin (0.2 μm under the *Al* strips) and the thick (1 μm under the FET gate) steam oxides are grown at different steps during the wafer processing.

The dc electrical characteristics of the detectors have been measured at room temperature by using a HP4142B modular source/monitor instrument in conjunction with a Wentworth microprobe station. Capacitance-Voltage measurements have been performed on both detectors and test patterns, processed along with the detectors, where a MOS capacitor and another FOXFET were available.

All the irradiations were performed at the FRAE Institute, Bologna, using two Co^{60} gamma irradiators Nordion Gammacell-220. The detector, inserted between two 3 mm thick polystyrene strips, was placed in the middle of the anular radiation field. No electrical field was applied to the detector. The irradiations were performed at a temperature of $(30 \pm 2)^0 C$ and the relative humidity inside the irradiation room was $40 - 50\%$ A first prototype was irradiated at cumulative steps up to 1 MRad at a dose rate of 0.35 kRad/min, while a second one was irradiated at denser steps up to 100 kRad at a dose rate of 7.6 kRad/min. A third device was irradiated in a single-step at 1 MRad at the higher dose rate. The measurements of the electrical parameters were made at a constant time interval (5 hours) after irradiation.

The dose rate delivered by the source at the detector location was determined by the Fricke chemical dosimeter[3] contained in 10 cc. glass vials and the cumulative radiation doses reported above are referred to the liquid dosimeter.

3. RESULTS AND DISCUSSION

The electrical characteristics of the FOXFETs and of the entire detectors have been measured with different setups schematically drawn in Fig. 1. For clarity we will refer to such setups during the presentation of the results of our measurements.

3.1 Leakage Current

The detector total leakage current has been measured by using setup B of Fig. 1: all sources are floating but one which is grounded.

A detailed discussion of the detector operations is beyond the scope of this work: nevertheless a brief summary seems helpful and is given[4]. The $p-$channel FOXFET, fabricated on a n^- substrate, features a common p^+ drain diffusion and 256 or 348 source p^+ contacts, according to the number of microstrips. They span the entire detector length, acting as the p^+ terminals of the front-back $p^+n^-n^+$ diode. A positive gate oxide charge, deriving from the fabrication process, enhances the conduction threshold between drain and each source contact.

The leakage current derives from the integrated contributions of single strips, each strip contributing approximately the same current, as measured grounding a single strip through an ammeter. At increasing backside bias, the space charge region surrounding the p^+ implant of each strip grows up, thus increasing the generation-recombination leakage current. The current supplied by the backside contact through the strips is totally collected at the drain terminal, indicating that FOXFET is operating in the punch-through regime, and no current dispersion occurs between strips and guard-ring.

Co^{60} γ irradiation effects on leakage current are shown in Fig. 2, where the current value was measured at the operating point $V_B = 30$ V (full depletion) for a 256-strip detector, up to an integrated dose of 1 MRad. Leakage current increases with sublinear dependence on γ dose, without any evident saturation effects. The main contribution to the increase of I_B should derive from surface damage at the Si/SiO_2 interface[5,6].

In the same figure, corresponding results obtained on another 256-strip detector irradiated at the higher dose rate are shown. No dose rate effect appears from the comparison of the two data sets.

Leakage current has been also monitored at different times after irradiation on a detector irradiated at 1 MRad in one single step. No variation has been observed on a 60-day time period, indicating that the radiation induced damage enhancing the leakage current is not recoverable at room temperature.

3.2 FOXFET Switching Voltage

The FOXFET switching voltage V_{SW} (also referred as threshold) is another important parameter whose variation with the radiation dose has been investigated. It has been measured by using the configuration C shown in Fig. 1, and typical results are shown in Fig. 3 for different backside bias values.

The rapid increase of the source current over 20 V corresponds to the onset of punch-through conduction in the FOXFET. The switching voltage is obtained by extrapolating at $I_S = 0$ the quasi-linear region of the curves shown in Fig. 3. We notice that these curves tend to overlap when V_B increases, i.e., when substrate is driven in full depletion.

The effect of substrate biasing is similar to the well-known results obtained in the case of enhancement type MOSFETs[7], with the basic difference that in this case a larger gate bias is needed not in order to invert the surface, but to allow the source and drain space charge regions to merge.

Variations of V_{SW}, measured at $V_B = 30$ V, induced by γ irradiation, are shown in Fig. 4 to be linearly correlated with the square root of the total dose at different dose rates. Again no saturation effect is observed.

Changes on V_{SW} are due to two well-known basic effects: accumulation of positive charges in the oxide, and trap formation at the Si/SiO_2 interface. The dose dependence of the V_{SW} variations is similar to the results found at high doses in positively biased MOS capacitors[8]. Dose enhancement of V_{SW} shows non-negligible annealing phenomena also at room temperature, already noticeable on a few hour time period, which affect the results shown in Fig. 4, as no correction procedure was applied.

Instead, we are currently monitoring the variations at room temperature of V_{SW} on a single-shot 1 MRad irradiated device, whose corresponding results are shown in Fig. 5. They can be attributed to a decrease of the oxide positive charge, due to annealing of trapped holes through electron tunneling from silicon substrate, as indicated by the linear dependence of V_{SW} to $log(time)$ shown in Fig. 5[9]. In fact, annealing of radiation-induced traps is not expected at room temperature[10].

An increase of Si/SiO_2 interfacial traps is known to reduce the slope of subthreshold characteristics od MOSFETs[11]. A similar effect is observed also by comparing the characteristics of FOXFET at bias lower than punch-through ("subpunch-through") at different integrated doses, as reported in Fig. 6, measured on the FOXFET fabricated on the test pattern. The slope of the linear region of the "subpunch-through" curves decreases at increasing radiation doses indicating that a larger gate voltage swing is required to reach punch-through conditions, according to the increased density of interfacial traps.

No slope variation of "subpunch-through" characteristics has been observed on detectors up to 60 days after the end of irradiation, confirming that no annealing process of interfacial states has taken place at room temperature.

3.3 Dynamic Resistance

Proper operations of the read-out electronics are determined by the detector dynamic resistance R_d, defined as $R_d = \delta I_S/\delta V_S$, when the device characteristics are measured by using the setup C shown in Fig. 1.

R_d has been evaluated as the slope of V_S vs I_S curves for various gate bias at $V_B = 30$ V and $I_S = 0$, i.e., in the operational conditions adopted in the CDF experiment.

Typical results on as received and irradiated samples are shown in Fig. 7. The dose rate was 0.35 kRad/min. The main radiation effects are the increase of the transition voltage from high to low resistance regions, and the decrease of R_d at low gate bias.

The first effect is correlated with the modifications of V_{SW} reported in Section 3.2, while the second one is related to the increase of the leakage current[4].

Two suitable regions can be identified for operating the detector, depending on the R_d values, (see Fig. 7):

- at the highest R_d values, which occur at low gate bias: R_d cannot be controlled by the applied gate bias, and is determined eventually by the degradation of the detector leakage current at increasing γ doses, without recovery at room temperature;
- at lower R_d values, around 1 $M\Omega$, which can be obtained in the high-low R_d transition region: R_d is directly controlled by the gate bias, but is strongly sensitive to radiation effects and recovery phenomena. Controlling R_d by continously adjusting the gate bias in a radiation harsh environment appears a critical task.

Variations with time of R_d on the single-shot 1 MRad irradiated detector are shown in Fig. 8. A recovery of the transition voltage is observed as in the case of V_{SW} (see Section 3.2). No clear variation of R_d at low gate bias is observed, in agreement with the absence of annealing effects on the leakage current reported in Section 3.1.

4. CONCLUSIONS

Preliminary results illustrating the basic effects of ionizing radiation from a Co^{60} γ source on ac-coupled FOXFET biased microstrip detectors have been reported.

An increase of the total leakage current of the detector and a shift of the FOXFET switching voltage with γ dose have been measured. We have also observed a decrease in the value of the dynamic resistance at low gate bias due to the increase of the leakage current.

At room temperature only a recovery of switching voltage has been observed, due to the decrease of the oxide positive charge, while no annealing effect has been detected on leakage current and, consequently, on maximum dynamic resistance values.

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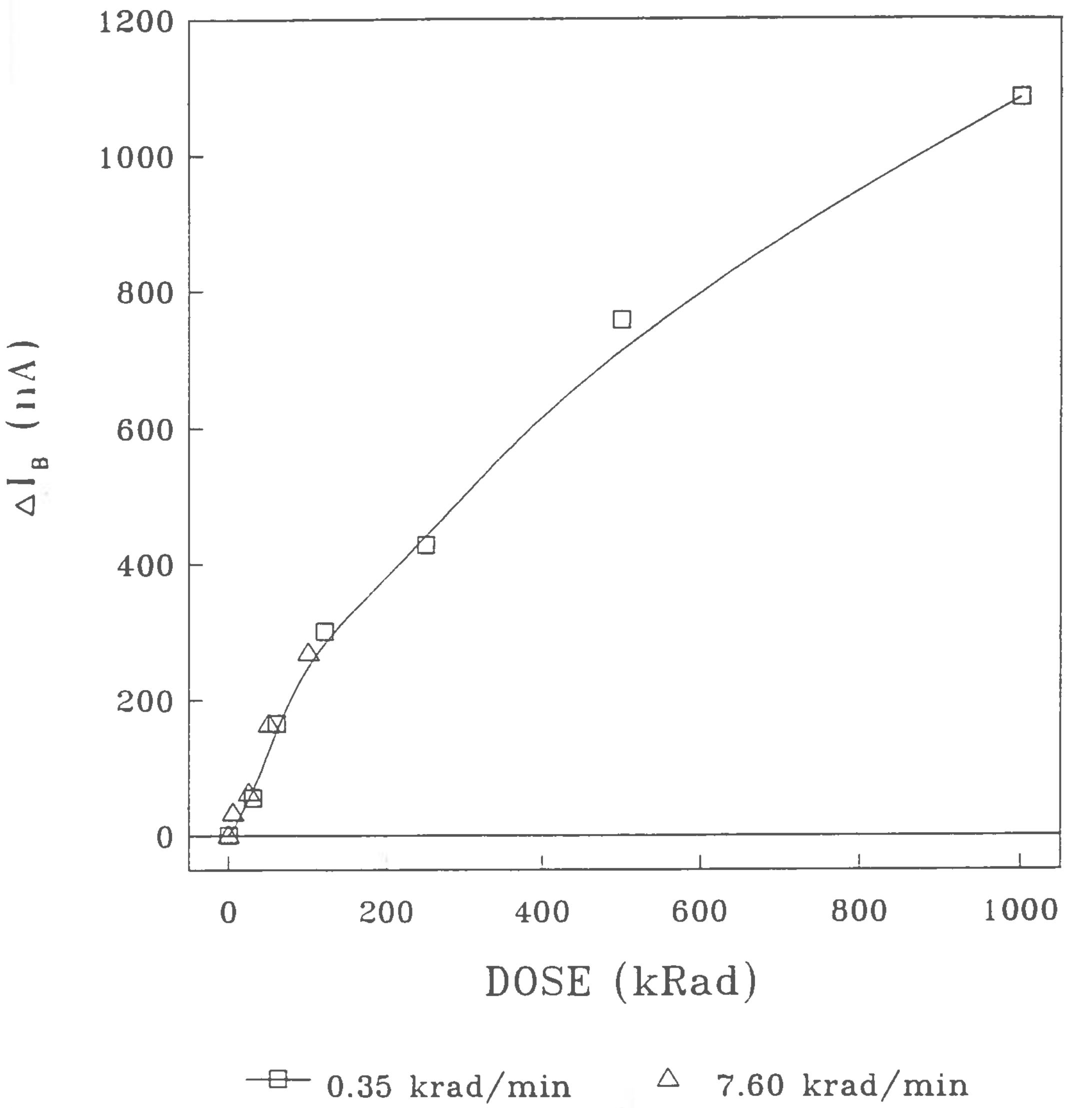

Fig. 2 Variation of the detector leakage current at $V_B = 30$ V, $V_D = V_G = 0$ V with sources disconnected, as a function of the total irradiation dose.

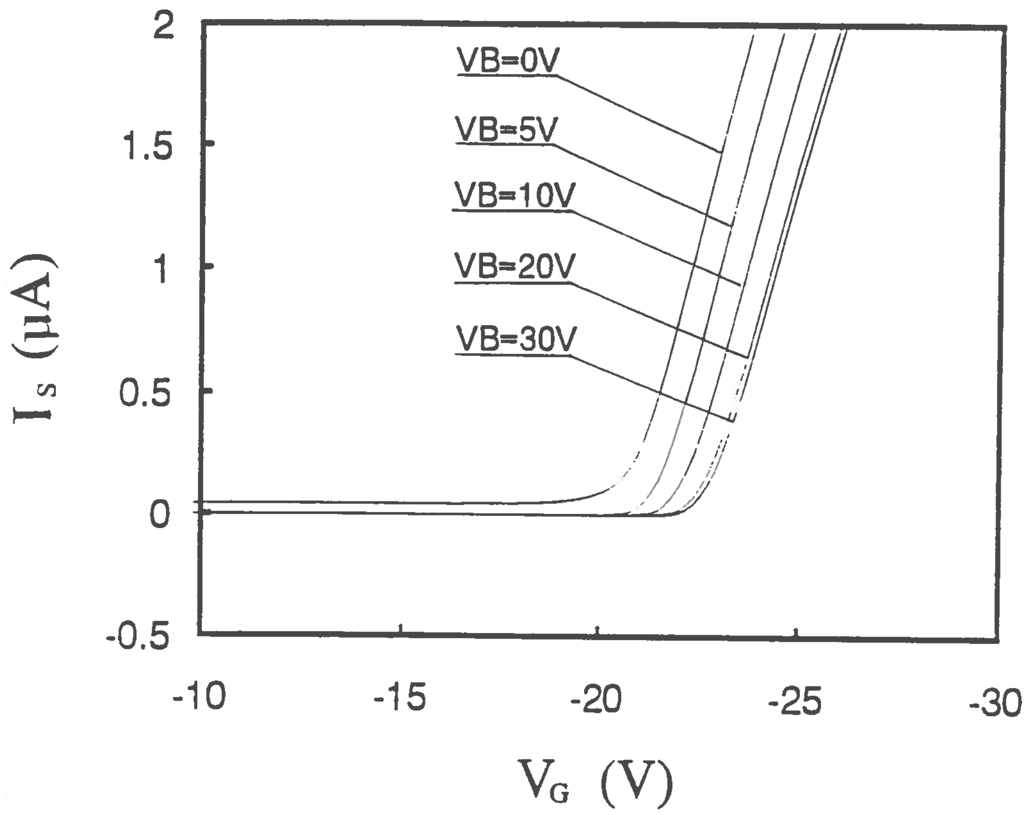

Fig. 3 FOXFET output current on a single source strip measured at $V_D = 0$, $V_S = 0.1$ V and at different backside bias V_B.

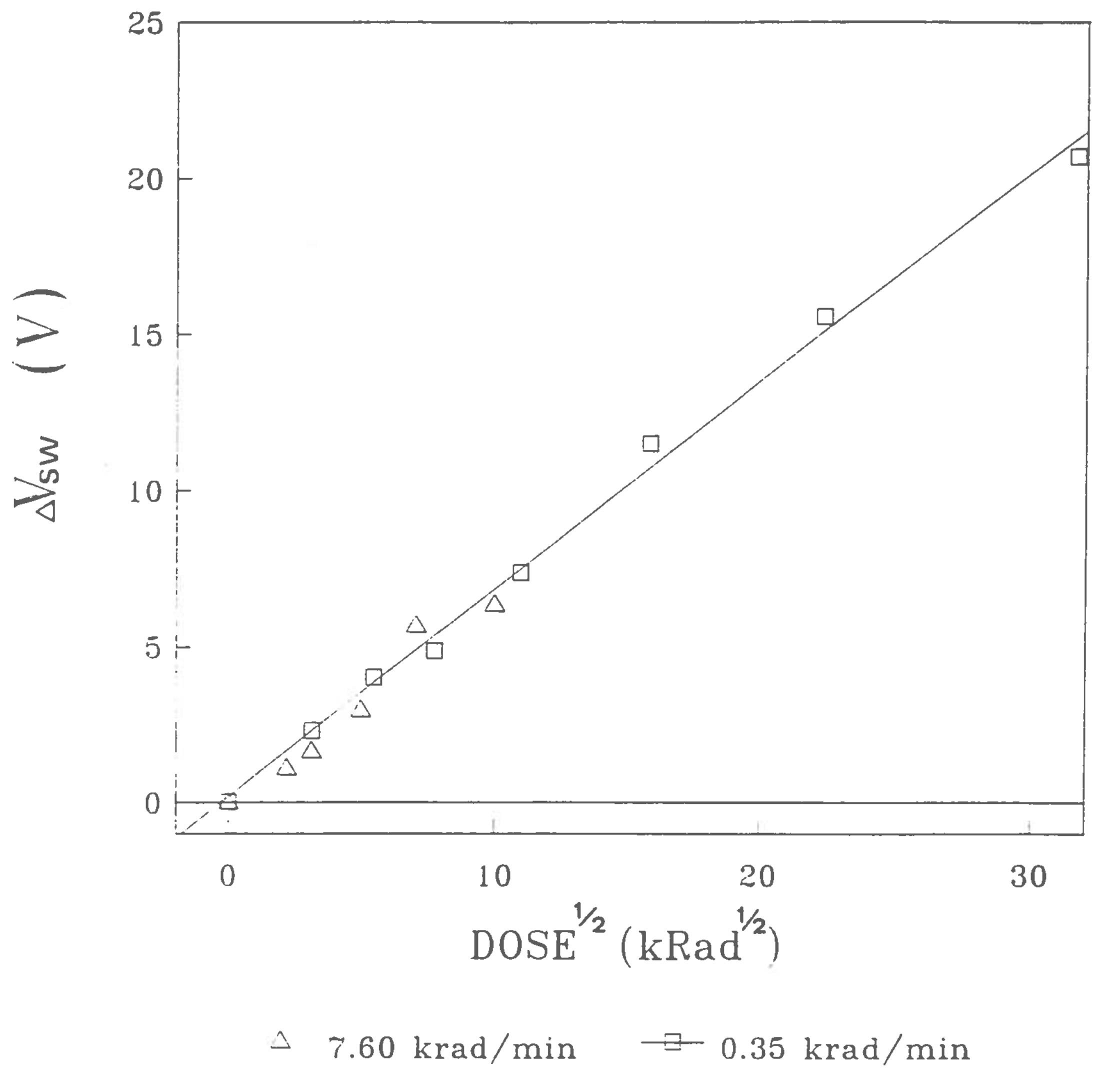

Fig. 4 Variations of the FOXFET switching voltage measured at $V_B = 30$ V, as a function of the square root of the total γ dose. The extrapolated straight line refers to the lower dose rate.

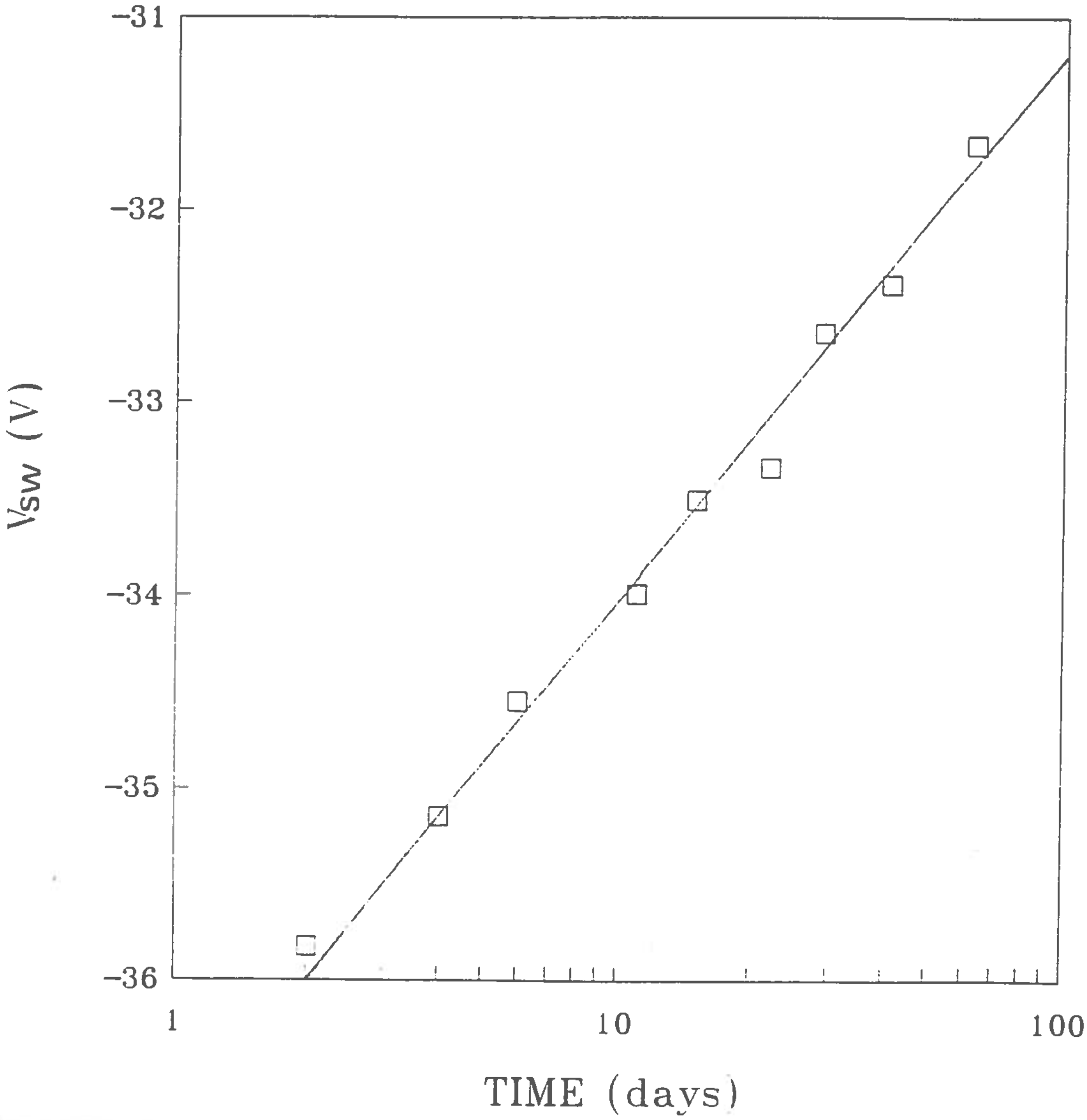

Fig. 5 Time recovery of the switching voltage, at $V_B = 30$ V, after one single-shot 1 MRad irradiation.

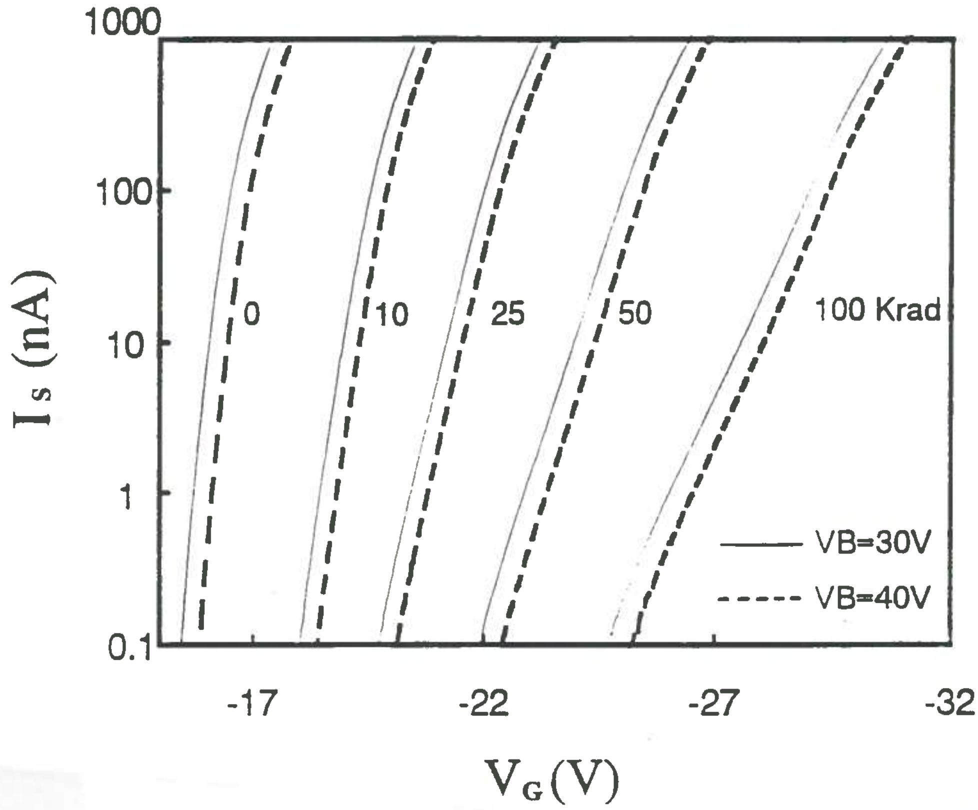

Fig. 6 FOXFET output current on a single source strip measured at $V_D = 0$, $V_S = 1$ V, for different total γ doses.

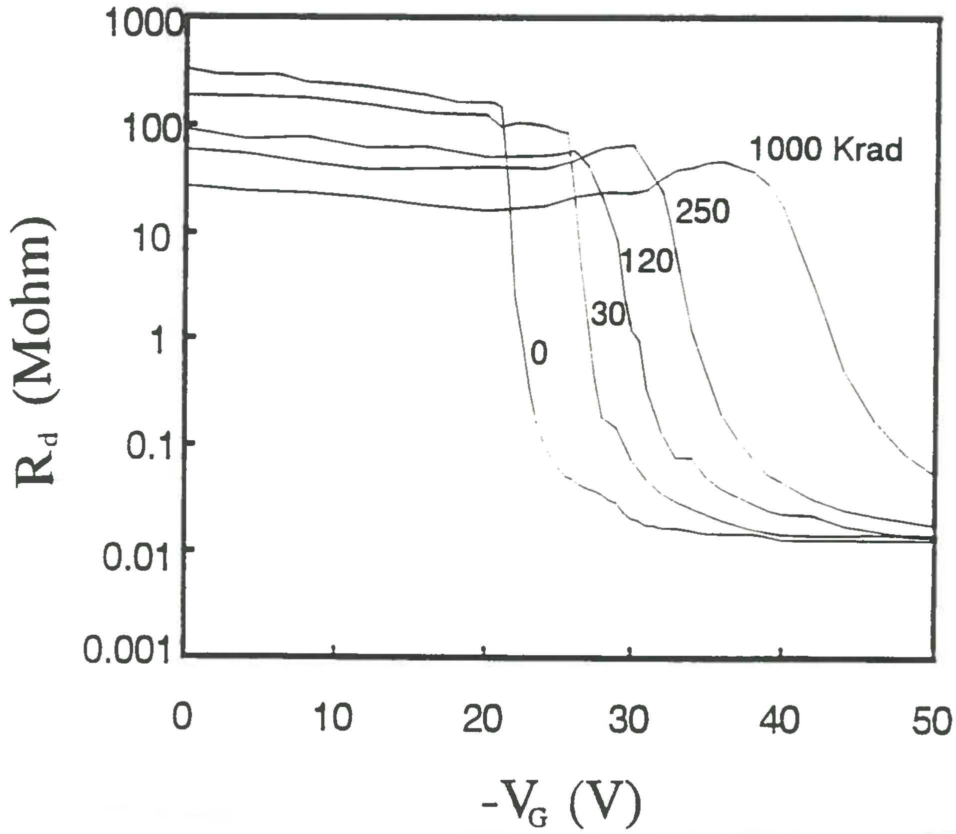

Fig. 7 FOXFET dynamic resistance measured at $I_S = 0$, $V_B = 30$ V, for different cumulative γ doses.

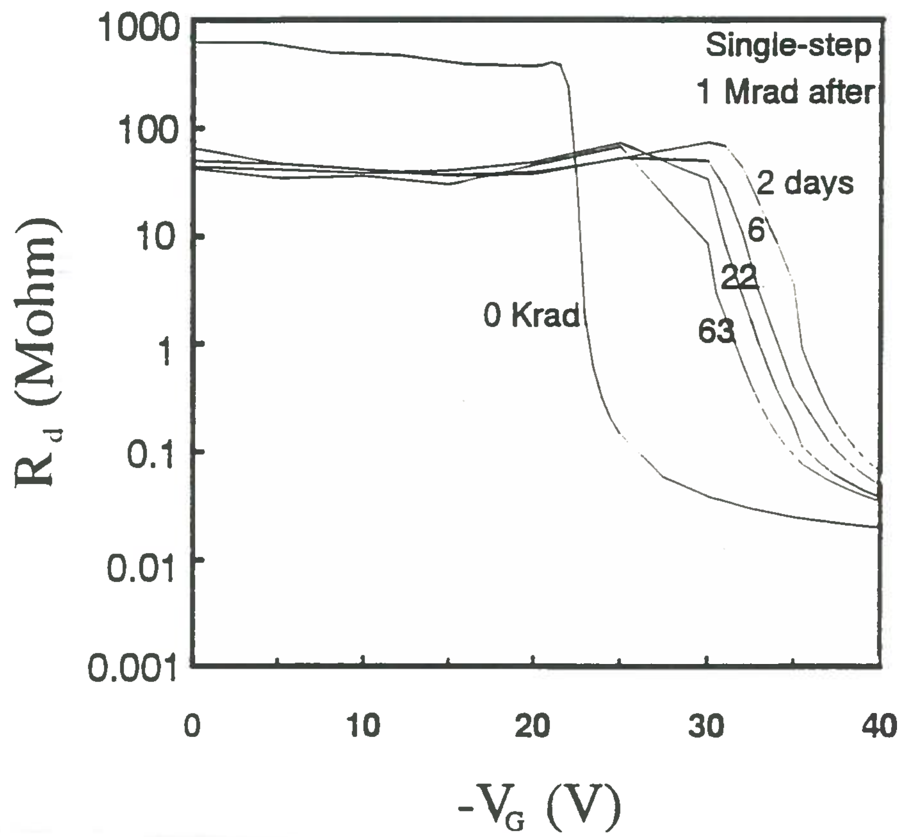

Fig. 8 FOXFET dynamic resistance before and at different times after one single-shot 1 MRad irradiation.