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RadFET DOSE MONITOR SYSTEM FOR SOLEIL

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Abstract

SOLEIL is currently testing new dose measurement monitors based on RadFET transistors. This new monitor at SOLEIL will provide a measurement of the dose received by equipment that are damaged by the radiations in the storage ring, in order to anticipate their replacement. This monitor should be very compact to be placed in tiny areas, sensitive to all kind of radiation and low cost to install many of them around the ring. A readout electronic module is being developed in-house, and a first prototype has been built and installed on the machine. Description of the system and first results recorded on the machine are presented here.

INTRODUCTION

After more than ten years of operation, SOLEIL pieces of equipment in the storage ring are damaged by radiations. The damage level is strongly dependent on the tunnel localization [1]. In order to have a better knowledge of the deposited dose, and to anticipate the replacement of the equipment, a dose monitor system has to be deployed around the storage ring.

This system must:

- Have a compact sensor that can be installed as close as possible to the equipment, and sometimes in tiny areas.
- Be sensitive to all kind of radiation, including X-rays since we know that in some particular locations X-rays are responsible of damages.
- Be low cost to be able to deploy a large number of sensors around the ring.

RadFET sensors, which have already been used with success by the accelerator community [2, 3], fit those specifications. SOLEIL has tested one kind of RadFET during the last months. A dedicated multiplexed electronics has been designed to periodically and automatically read the dose measurements.

RADFET SENSORS

Description

RadFET are Metal Oxide Semiconductor Field Effect Transistors (MOSFET), optimized for radiation sensitivity. When ionizing radiations go through the gate oxide layer, they generate pairs of electron-hole, leading to a permanent modification of the layer with trapped positive charges (Fig. 1). As a consequence, the threshold voltage of the transistor is modified. The voltage shift depends on the amount of radiation that hits the device. By measuring the threshold voltage shift (forcing a fixed DC current in the device), the dose received by the RadFET can then be deduced.

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RadFETs are sensitive to all kind of radiations (X-rays, gamma, electrons…). They give a measure of the total integrated dose received.

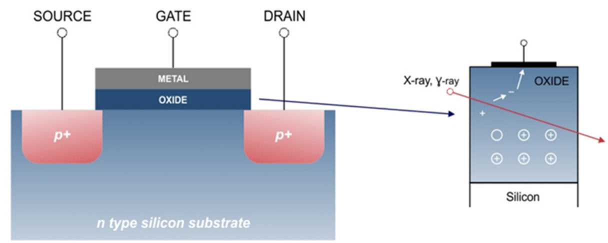

Figure 1: RadFET schematics (source Tyndall).

RadFETs used at SOLEIL are provided by Tyndall Works and manufactured by Tyndall National Institute in Ireland [4]. The TY1004 chip embeds two identical RadFETs with a gate oxide thickness of 400 nm. The active area (gate oxide surface) is very small: 300 µm by 50 µm.

Calibration

RadFETs TY1004 are given for a measurement range from 1 rd to 100 krd (1 cGy to 1 kGy). Since their response is non-linear with the deposited dose, calibration curves are provided by the manufacturer to retrieve the dose value from the measured voltage shift ΔV according to the following formula:

$$\Delta V = A * Dose^{B}$$

The A and B coefficients are obtained exposing one RADFET to discrete dose values using a Co60 source (see Fig. 2). It is then assumed that all RADFETs of a same batch follow the same calibration curve.

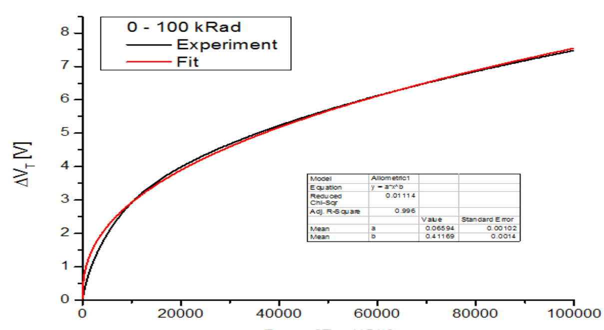

Figure 2: Calibration curve for dose range 0 – 100 krd / 1 kGy (Source: Tyndall).

A and B coefficients are not constant over the full measurement range. This is why a set of coefficients is given depending on the dose range (Table 1).

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Table 1: Calibration Coefficients (Source: Tyndall)

Dose Range	A	B
0 – 1 kRad	0.0014	0.8900
0 – 5 kRad	0.0052	0.6976
0 – 10 kRad	0.0090	0.6306
0 – 50 kRad	0.0478	0.4438
0 – 100 kRad	0.0659	0.4117

Sensitivity

The sensitivity of the RadFET to irradiation depends on:

- The gate oxide layer thickness: the sensitivity increases with the thickness of the gate oxide layer [5].
- The gate bias: by applying a constant DC voltage on the gate the electron-hole generation process is improved and following, the sensitivity of the device. Nevertheless, this improvement of the sensitivity is done to the detriment of the measurement range.

In our case the thickness is fixed at 400 nm (by design), and we do not want to reduce the maximum possible measured dose value. Gate biasing is therefore not used, and all pins are grounded during irradiation.

Operating Modes

In order not to modify the sensitivity of the RadFET, the readout of a RadFET should be avoided during irradiation. As a consequence, RadFET sensors have two modes of operation:

- An exposure mode for which all pins are grounded.
- A readout mode for which a fixed current is forced between ground and source. This is preferably done without irradiation (no beam) or punctually during short time. We use the same current value (10 µA) than the one used during calibration by the manufacturer. This is the current giving the minimum temperature dependence of the threshold voltage.

READOUT ELECTRONICS

A dedicated electronics has been designed to perform the acquisition of the RadFET and to control the two modes of operation described previously. This electronics allows automatic and periodic measurements. For cost efficiency, a multiplexing system gives the possibility to connect up to seven RadFETs on a single reader.

Acquisition

The acquisition (among other tasks) is performed by a Red Pitaya board [6]. One of the two 14 bits ADCs is used in the extended range configuration (+- 23 V) providing a resolution of 2.8 mV (2 rd). The input impedance being of the same order of magnitude than the one of the RadFET (at 10V threshold), a unity gain buffer amplifier has been added in front of the Red Pitaya input.

This board was easily integrated into our Tango control system by embedding the generic Tango device server on the ARM processor.

Current Source

A DC stable current source is needed to provide the 10 µA to the RadFET accordingly to the manufacturer calibration data. The terminal adjustable current source LM334 from TI has been selected for its good stability. It gives the possibility (if needed) to cancel the thermal effects, even if the stability records in the lab revealed that it wasn't necessary four our need: the 24 hours stability is indeed below 7 pA rms (Fig. 3). The amplitude of the current provided by the source can be easily adjusted by a potentiometer knob on the front panel. This value is continuously monitored by the second ADC of the Red Pitaya when the RadFETs are not being read.

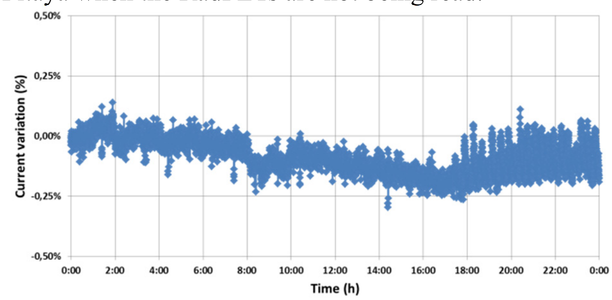

Figure 3: Stability (in % of variation) of the DC 10 µA current source over 24 hours.

Multiplexing

To be able to read several RadFETs with the same readout module (and minimize the costs), a multiplexing scheme has been set up. It is based on double poles power relays, and allows to switch the reading from one RadFET to the other on the same chip, or to switch from one chip to the other. The 16 digital I/Os from the Red Pitaya that is performing the acquisition are used to drive the relays through photocouplers for isolation and voltage adaptation (from 3.3V to 24V). One electronic module is thus able to read 7 chips, that is to say 14 RadFETs (Fig. 4).

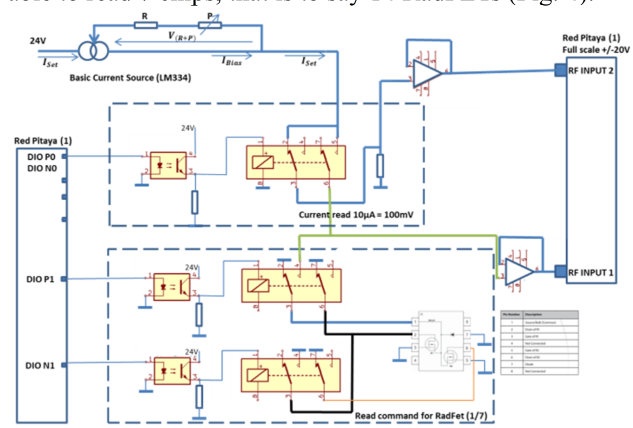

Figure 4: Simplified schematic of the RadFET readout electronics.

Mechanical Integration

The different elements (power supply, Red Pitaya and PCB for multiplexing and current source) are integrated

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into a 2U 19' crate, with a set of diodes on the front panel to know if and which RadFET is being read (Fig. 5)

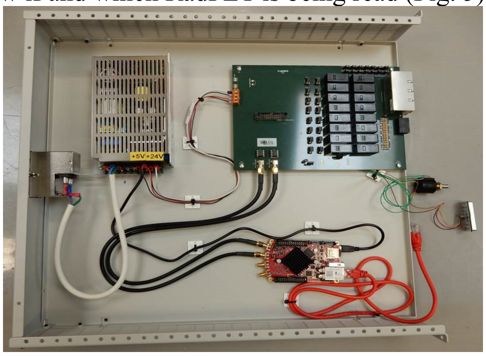

Figure 5: RadFET Electronic rack.

The chip is mounted on a small PCB equipped with a RJ45 connector (Fig. 6). The resulting size is 18x32x15 mm making the device very easy to install on the machine even in confined areas. If it is required, the chip and the cables can be soldered directly on the PCB to reduce further the thickness.

Figure 6: RadFET chip mounted on its PCB with RJ45 connector.

FIRST MEASUREMENTS WITH BEAM

CCD Survey

The first location where RadFETs have been installed is in the optical box of the two pinhole cameras (Fig 7). Indeed, despite appropriate shielding, the CCD camera installed in cell 02 shows a significantly faster degradation (to be replaced every year) compared to the one in C16 (although very close to the injection section).

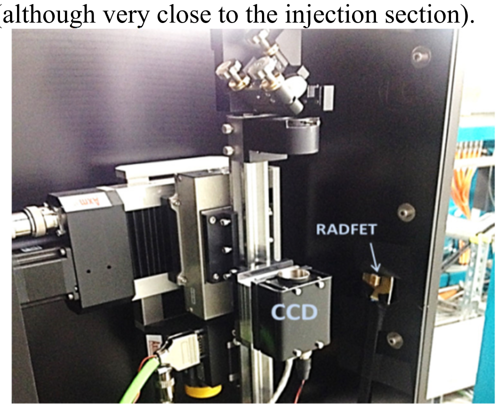

Figure 7: RADFET installed in the C02 pinhole camera optical box to monitor the dose received by the CCD camera.

The two RadFETs on a same chip give dose values that are in very good agreement. Measurements showed that the recorded dose in the optical boxes is linear with the integrated current in the machine and is not correlated to beam losses. It also confirmed that the dose received in the C02 optical box is three times higher than in C16 (Fig. 8).

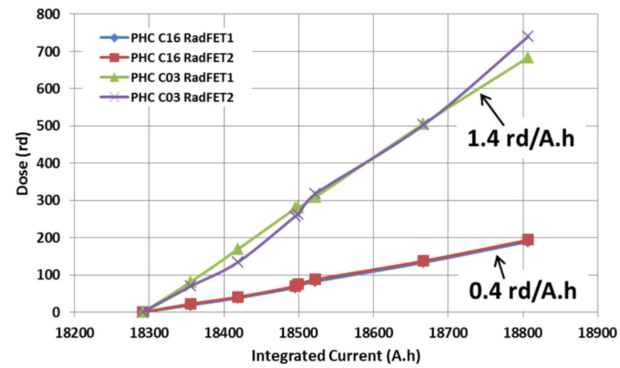

Figure 8: Dose measurement in the pinhole camera optical boxes confirming that the CCD in C02 is more exposed to radiation than the one in C16.

Recently, and for independent reasons, the pinhole crotch absorber has been modified (reduced horizontal aperture) and the optical box realigned. Since then, RadFET measurements show a drop in the dose rate inside the box (Fig. 9). Likewise, the new CCD camera installed at the same time in the box is not damaged as fast as the previous ones. We suppose that part of the X-rays where hitting an unexpected element in the box creating reflected or secondary emitted X-rays.

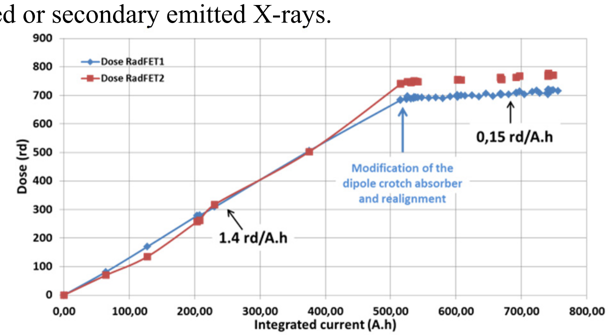

Figure 9: Dose measurement in the C02 pinhole camera optical box. The change in the slope is correlated with modification of the upstream crotch absorber (reduced aperture) and a realignment of the box.

Insulator Survey

SOLEIL equipment located around aluminium vacuum chambers located downstream dipoles are suffering from radiation with faster damages compared to other locations. In particular, cable insulators that become brittle and backing film glue that is reduced to dust, have to be replaced periodically (Fig. 10). The radiation at those locations consists of X-rays that originate from the interception of synchrotron radiation from upstream dipole by the vacuum chamber. When the vacuum chamber is in aluminium, X-rays are not damped significantly (compared to other materials like stainless steel or copper).

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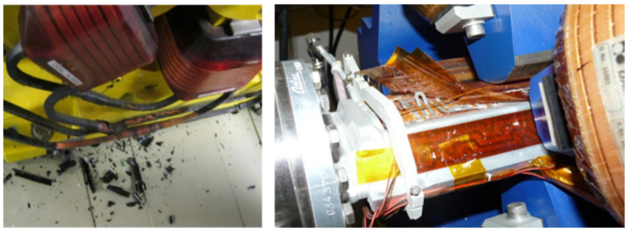

Figure 10: Damages caused by radiation around aluminium vacuum chamber located downstream bending magnets.

A set of 5 RadFETs have also been installed in cell 03: two on BPM cables (Fig. 11) (one upstream and one downstream a dipole), one close to damaged sextupole insulators, and two on the tunnel wall (on internal and external side of the machine).

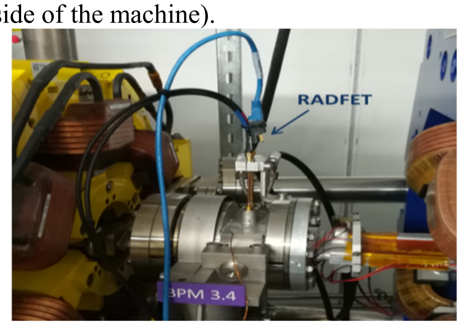

Figure 11: RadFET installed on BPM cables downstream bending magnet.

Here again, the measurements are in very good accordance with the damages observed on the machine, with a very high dose deposition (20 krd/A.h) nearby the aluminium vacuum chamber downstream bending magnets whereas doses recorded upstream the dipole (0.4 rd/A.h) or on the wall (24 rd/A.h) are more reasonable (Fig. 12).

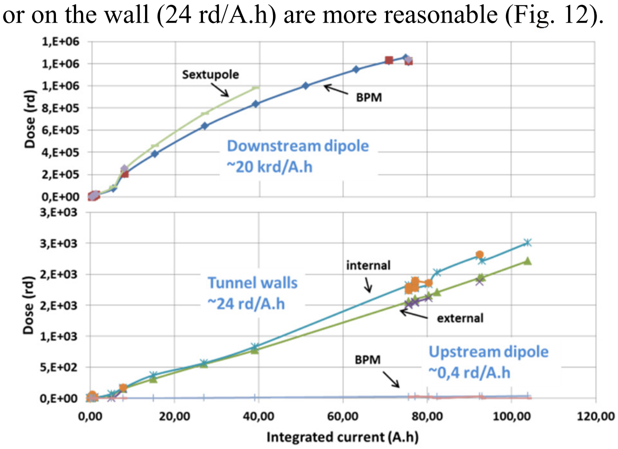

Figure 12: Doses recorded by RadFET sensors in C03.

Nevertheless absolute dose values recorded in this case with X-ray radiation are probably overestimated since the RadFET sensitivity is not the same for X-rays and gamma-rays, whereas the calibration has been done with a gamma source. Measurements made in 2013 [1] with Gafchromic films showed a dose rate a factor two lower (9.4 kRad/A.h). A dedicated calibration of the RadFETs for X-rays will be done in the future.

Fading

Spontaneous electron-hole annealing in the RadFET degrades the threshold voltage when irradiation stops. This fading effect has been measured on two RadFETs exposed at ~11 krd below 3% during the 4.5 weeks after the stop of irradiation (Fig. 13). This decay is small enough to avoid any compensation of the fading.

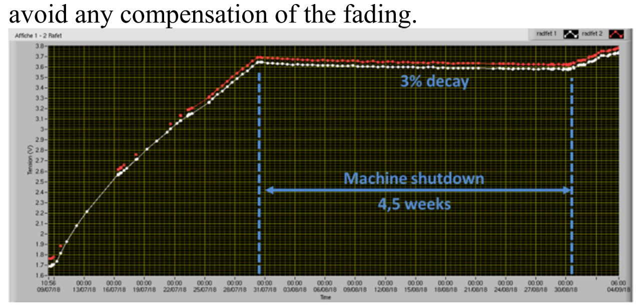

Figure 13: Fading measurement.

CONCLUSION

RadFET sensors have been tested and used with success at SOLEIL to monitor the deposited dose around equipment damaged by radiations. The dependence of the calibration curves with respect to the type of irradiation (X or gamma) has to be measured.

A dedicated electronics has been designed and a prototype tested to read up to 7 RadFET chips. The low cost of this system will give us the possibility to install several monitors in every cell of the storage ring depending on our needs.

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