Enhanced Read-Out System for RADFET Dosimeters Research

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Abstract –**This paper proposes a novel system for RADFET read-out, which allows measuring its threhold voltage at varied current levels. The system has the distinctive ability to change the direction of the readout current. That way the characteristics of the reverse diode between the drain and the silicon base can be measured and the FET temperature can be determined. Te paper also presents experimental data from pMOSFET ZVP4424 dynamic characteristics measurements.**

Keywords – **RADFET, Read-Out System**

I. Introduction

The first research on the effects of ionizing radiation on semiconductor devices started at the beginning of the 60s of the last century. Initially the limits when the semiconductor circuits stop working properly due to irreversible damage were studied. Later a variety of efficient and highly sensitive semiconductor radiation detectors were developed. In the mid-70s was proposed the idea 0 to use the accumulated defects in semiconductors to estimate the total absorbed ionizing radiation dose.

A. Application of pMOSFET as dosimetry sensors

When a semiconductor is exposed to ionizing radiation electron-hole pairs are produced. The holes in the gate area of a MOSFET are trapped in the SiO_2 layer above the channel. That creates a slight positive charge at the gate which in turn increases the threshold voltage of the p-channel MOSFETs. This effect is used to determine the dose the semiconductor device has absorbed.

Usually the dose absorbed in the pMOSFET is determined by the change in the threshold voltage ΔVth 0,0,0, at a predefined point on the $I_D=f(V_{GS})$ characteristic. The dose is calculated empirically using (1):

$$\Delta V_{th} = A.D^n \tag{1}$$

where for a given MOSFET A is a coefficient of proportionality and n accounts for the nonlinearity.

Sometimes the absorbed dose is determined by the change of the slope of the I-V characteristics. This poses the requirement to measure more than one point on the characteristic $I_D=f(V_{GS})$. The absorbed dose is determined using 0 the equation (2):

$$\Delta D = a.(S_{D2} - S_{D1}) = a.\Delta S \tag{2}$$

where ΔS is the change of the slope of the I-V characteristic and a is a coefficient of proportionality. The slope is defined as (3):

$$S = \frac{dV_{GS}}{d(Log(I_D))} \tag{3}$$

It should be noted that the relation between the dose and the slope change ΔS is much more linear than between the dose and the threshold voltage ΔVth.

Because of their small size, ease of use (dose can be accumulated without power and/or external circuitry) and relatively simple measurement circuit pMOSFET are becoming a popular dose measurement solution in radiotherapy, for dosimetry control in industry and nuclear facilities and for radiation exposure monitoring in space ships.

B. Problems, research and solutions

Nowadays special transistors have been created, popular as RADFET, designed specifically for dosimetry 0. Their parameters are highly repeatable and have been thoroughly studied. The DDGAA RADFET 0 can be used as an example. They are distinguished for their unique design and excellent linearity over a wide dynamic range but their price is very high which prevents their widespread use. This is a motivation for many research teams to study the possibility to use cheap, widespread general purpose p-channel MOSFETs for the same purpose.

Some of the most commonly studied transistors are BS250F, ZVP3306 and ZVP4525 0,0. The ZVP3306 for example have shown excellent sensitivity and very good linearity. In 0 the possibility to use the pMOS inside CD4007 has been studied. They have achieved very good results – high sensitivity and easy temperature compensation due to the Zero Temperature Coefficient (ZTC) region occurring at low drain current - I_D value of about 140 μA.

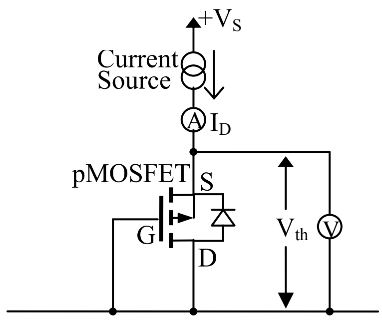

Fig. 1

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Various circuit solutions have been used 0, 0 to measure the threshold voltage V_{th}. The gate of the pMOS is connected to the drain and a current source is applied at the source (fig. 1). The drain-source voltage and the source current are measured to determine the threshold voltage or the transfer function. This circuit has positive output voltage and is compatible with practically every existing ADC, either stand-alone or integrated in a microcontroller.

The temperature dependence of the pMOSFET parameters may pose a serious problem when determining V_{th} or S. Its value may be of the same magnitude or even greater than the change caused by the absorbed dose. The most elegant solution when measuring V_{th} in only one point is to choose is so it coincides with I_{ZTC} (zero-temperature coefficient drain current). Unfortunately this can't be done for power MOSFETs as I_{ZTC} can be as high as a few amperes. For those cases a temperature sensor is used (usually a thermistor) which measures the MOSFET temperature. After making the measurements the data is corrected for the temperature dependence.

C. Reasoning behind the read-out system research

The need to determine the suitability of a growing number of general purpose pMOSFETs to be used as absorbed dose sensors is increasing. Their sensitivity and temperature instability have to be determined. As a side task the limits for stable operation of the devices when exposed to ionizing radiation can be determined.

The compensation of the thermal instability is an especially important topic. We believe the change, due to the absorbed dose, of the I-V characteristics of the reverse diode between the drain and the silicon base haven't been thoroughly studied. In case this change is sufficiently small the reverse diode can be used to measure the temperature of the semiconductor. That would allow for precise compensation of the thermal effects in the MOSFET and eventually allow for more precise measurement of the dose.

D. Research tasks

The main task of the research is to create an enhanced read-out system for measurement of the characteristics (V_{th} and S) of pMOSFET transistors after they have been exposed to ionizing radiation. It should also be able to measure the I-V characteristics of the reverse diode between the drain and the silicon base. The read-out system must support measurements at varied values of the current through the MOSFET. It must also be able to reverse the current direction in order to measure the diode characteristics.

II. System Design

A system has been developed that allows performing the measurements required for the research tasks. It measures the initial values of the threshold voltage V_{th} of the chosen pMOSFETs as well as the *I-V* characteristics of the transistors and their reverse diodes at different preset temperatures. The system also allows offline measurement of the parameters after the MOSFET has been irradiated.

A. Experimental setup

Figure 2 shows the experimental setup. It contains a thermostat that allows keeping the pMOSFET at a predefined temperature for the duration of the measurement. The temperature can be varied in the range 20 to 65 ^{o}C with an accuracy of at least ±0.5 ^{o}C. The temperature value is measured by the DAQ system.

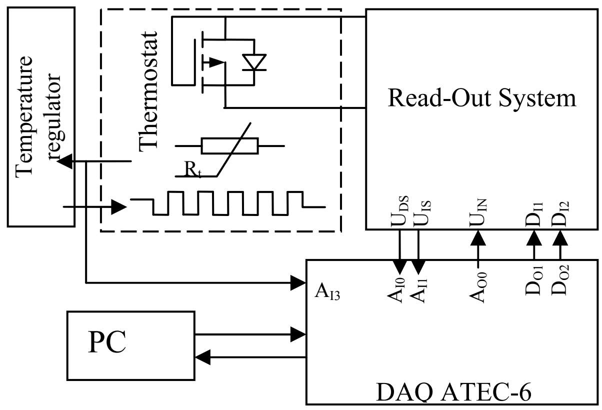

Fig. 2

The specially developed read-out system allows measuring the forward and reverse *I-V* characteristics of the pMOSFET. The output of the read-out system is a positive voltage for both forward and reverse currents, which allows easy coupling to the data acquisition system DAQ. The DAQ used is a 6 channel mixed signal system ATEC-6+1 0. It links to a PC by an RS232 serial interface.

B. Structural diagram of the read-out system

At the heart of the system is a bipolar voltage-to-current convertor that is connected to the pMOSFET (Fig. 3). The measurement point (current) is setup by the DAQ. A series of successive settings allows scanning the *I-V* characteristic of the device.

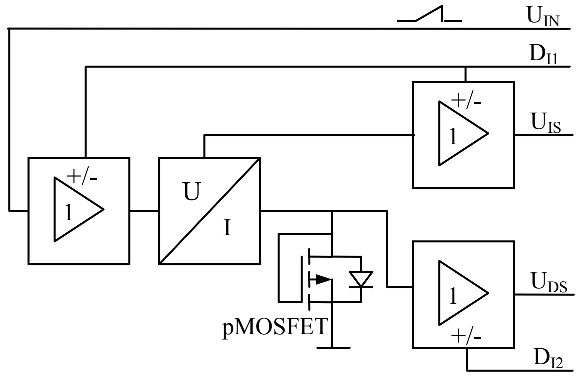

Fig.3

A digitally controlled inverting amplifier allows inverting the setting. That way the current direction can be reversed and allows measuring the reverse diode characteristic. That would output negative voltages to the DAQ (U_{DS} and U_{IS}), that's why the output digitally controlled inverting amplifiers are used to change the sign of the output. The U_{DS} voltage equals the voltage of the reverse diode or the V_{th} of the MOSFET. The U_{IS} voltage is proportional to the current through the device.

C. Read-out system schematic

Figure 4 shows the read-out system schematic. The operational amplifier U1B and the analogue switch S1A make up the setting input digitally controlled inverting amplifier. When the switch is open it repeats the U_{IN} voltage from the DAQ. When the switch is closed the amplifier has an amplification coefficient of -1 and inverts the voltage. Its output voltage controls the voltage-to-current convertor.

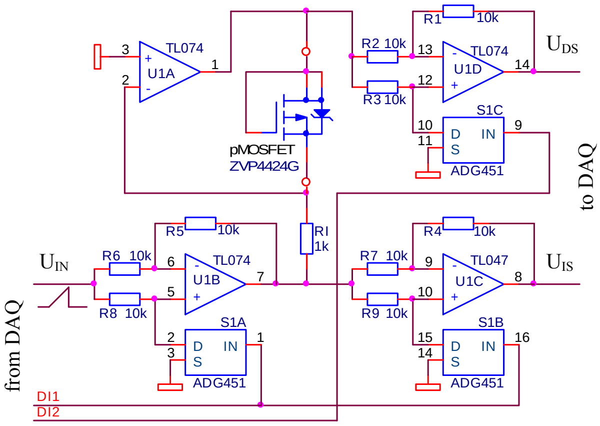

Fig.4

The bipolar voltage-to-current convertor consists of the *U1A* operational amplifier and the R_I resistor. The source is always connected to a virtual ground. The drain is driven by the op-amp in an opposite polarity to the setting voltage. The current is proportional to the voltage across R_I.

The output digitally controlled inverting amplifiers consist of *U1C* and *U1D* and the *S1B* and *S1C* analogue switches respectively. They use the same schematic as the input amplifier. The U_{DS} voltage equals the voltage of the reverse diode or the V_{th} of the MOSFET. The U_{IS} voltage is proportional to the current through the device.

The readout system allows a unipolar DAQ to make bipolar measurements of pMOSFET (or other) devices.

D. Measurement sequence

In order to measure the p-channel MOSFET a positive voltage has to be applied to R_I. The DAQ sets logical "1" on *DI1* which configures *U1B* and *U1C* as repeaters. The drain voltage is negative. The *U1D* is configured as an inverting amplifier by setting *DI2* to logical "0".

The DAQ then applies a range of setting voltages from 0V to 5V which corresponds to current values from 0 to 5mA. Both output voltages U_{DS} and U_{IS} are measured for each current setting. The data is used to determine the *I-V* characteristic of the pMOSFET.

To determine the characteristic of the reverse diode the current direction has to be reversed. *U1B* и *U1C* are configured as inverting amplifiers by setting *DI1* to logical "0". The anode voltage is positive so *U1D* is configured as a repeater by setting *DI2* to logical "1". The characteristic is measured the same way as for the MOSFET.

III. Results and Discussion

A series of experiments have been carried out with the Enhanced Read-Out System. The characteristics of

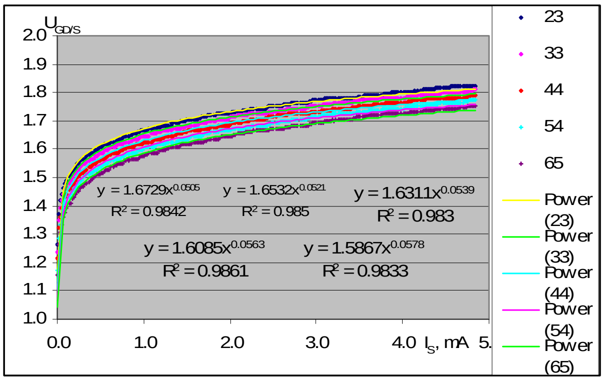

Fig.5

pMOSFET ZVP4424 as well as those of the reverse diode have been measured at different temperatures.

Figure 5 shows the pMOSFET ZVP4424 characteristics at different temperatures. Their change with temperature can be seen easily. In the measured range of currents no zero-temperature coefficient drain current has been observed.

Taking this into account:

a) the measurements should be carried out in multiple points of the characteristic;
b) the transistor temperature should be measured;
c) the compensation of the thermal shift should be carried out using digital processing.

Figure 6 shows the characteristics of the reverse diode at different temperatures. Again their temperature dependence can be clearly seen.

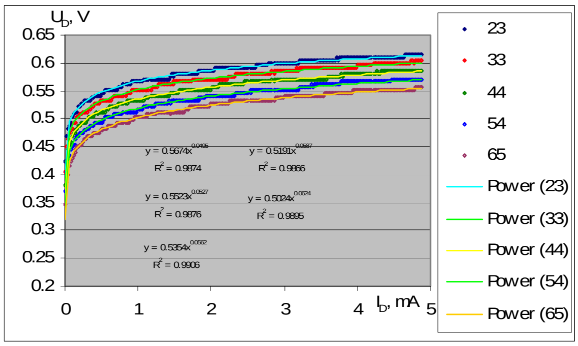

Fig. 6

IV. Conclusion

As a result of the analyses of the measurement conditions when measuring p-channel MOSFETs to determine their absorbed dose a special Enhanced Read-Out System has been developed and studied. It allows measuring the pMOSFET temperature using the reverse diode as well as multi-point measurements. That allows making measurements with pMOSFETs whose zero temperature coefficient is well outside the system's current range. The ability to reverse the current polarity allows for a wide range of studies that would be inaccessible otherwise.

ACKNOWLEDGEMENT

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