High sensitive MOSFET-based dosemeter for application in space

M. Zamani[1], S. Stoulos[1], M. Fragopoulou[1]

[1] School of Physics, Nuclear and Elementary Particle Section
Aristotle University of Thessaloniki, 541 24, Greece

S. Siskos[2], T. Laopoulos[2], V. Konstantakos[2] G. Sarrabayrouse[3]

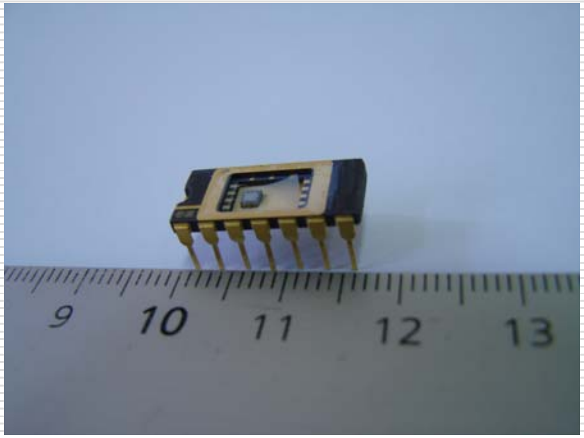
[2] School of Physics, Electronics and Computers Section
Aristotle University of Thessaloniki, 541 24, Greece

[3]CNRS; LAAS; 7 avenue du Colonel Roche, F-31077 Toulouse, France

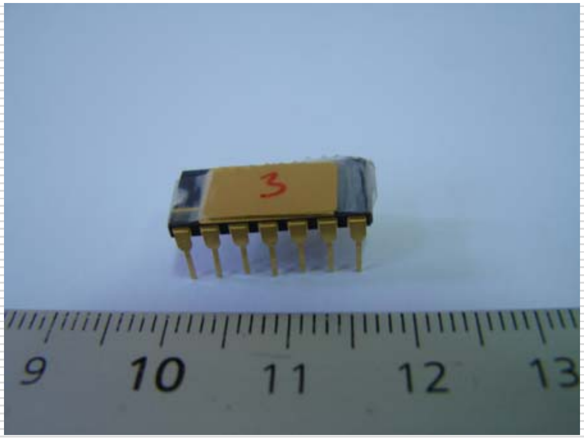
MOSFET dosemeters

A picture of the Metal-Oxide-Semiconductor Field Effect Transistor, MOSFET dosimeter, with neutron converter, manufactured at LAAS-CNRS Laboratory, Toulouse France. The dimensions of the detector are:

1 mm x 1mm



During measurement the MOSFETs were diode connected (gate and drain grounded) while the source was fed by a constant current of 100 μA.



MOSFET advantages

Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) dosemeters have numerous advantages such as:

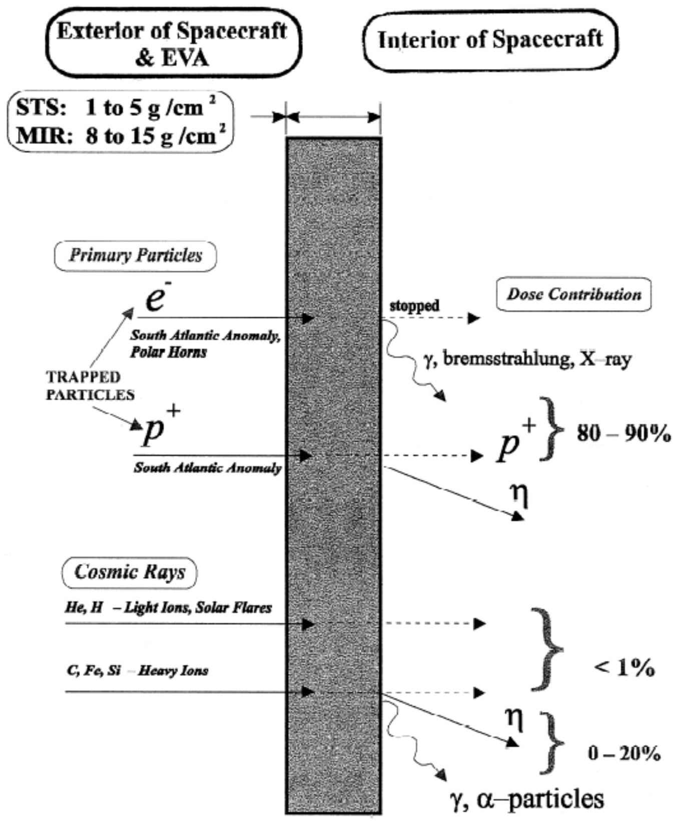
- Low cost
- Small size and weight
- Accuracy of measurement
- Simple operation
- New MOSFET can be used without power supply during irradiation i.e as passive dosemeters
- Low power requirements
- Possibility of integration with other sensors and/or circuitry
- New MOSFET can measure large dose ranges

MOSFET applications

MOSFETs have been used in several application fields such as:

- **Medical**
  - A. B. *Rosenfeld Rad. Prot. Dos. 101 (2002) 393*
  - *G. Sarrabayrouse S. Siskos 1998. IEEE Instr. Measur. Magaz.1 (1998)26*
- **Military**
  - *G. Sarrabayrouse S. Siskos 1998. IEEE Instr. Measur. Magaz.1 (1998)26*
- **personal dosimetry**
  - *S. Kroneberg and G. J. Bruker IEEE Tran. Nuc. Sci. 42 (1995) No 1,20*
  - *N. H. Lee, S. H. Kim, G. U. Youk, I. J. Park, Y. M. Kim Rad. Prot. Dos. 110 (2004) 277*
  - *F. Ravotti, M. Glaser, M. Moll, Gh. Ilgner, B. Camanzi and A. G. Holmes-Siedle IEEE Tran. Nuc. Sci. 52 (2005) No 4, 959*
- **Space radiation (mainly for protons and electrons)**
  - *L. Adams and A. G. Holmes-Siedle IEEE Trans. Nucl. Sci. 25(1978) 1607*
  - *I. Thomson Mutation Research 430 (1999) 203-209*

Application in Space



From I. Thomson, Mutation Research 430 (1999) 203

Neutrons contribute up to 30% of the dose equivalent of the intravehicular crew exposure [1,2]

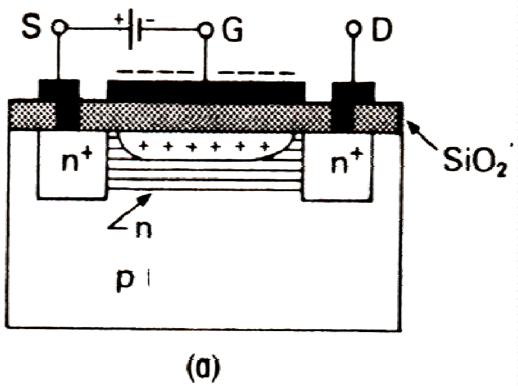
Shielding from the spacecraft structure and space suits changes the radiation environment reaching the astronauts body

The doses received during Extra Vehicular Activities have not been quantified to the same degree

[1]*J. E. Keith, G. D. Badhwar, D. J. Lindstrom Nucl. Tracks Radiat. Meas. 20(1992) 41*

[2]*V. E. Dudkin, Yu V. Potatov, A. B. Akopova, L.V. Melkumayan, E.V Benton, A.L. Frank, Rad. Meas. 17(1990) 87*

Detection with MOSFET dosemeters



- When ionizing radiation passes through the gate oxide in a MOSFET , electron-holes pairs are generated.
- The p-type MOSFETs with 1.6 μm thick gate insulator developed at LAAS-CNRS Laboratory Toulouse were irradiated by photons and neutrons.
- For neutron dose measurements a 3μm thick LiF converter was deposited on the surface of the MOS gate.

The alpha particles, produced via $^{6}Li(n,\alpha)^{3}H$ reaction cause electron-hole pairs in the insulator.

Threshold Voltage

- The **threshold voltage** shift, ΔV_T, which is the measured quantity, depends upon the incident particle type and energy, the ionizing particle penetration into the oxide, the absorbed dose, the gate insulator thickness and the gate bias during irradiation.
- In personal dosimetry an unbiased dosemeter is preferable and for that reason in those experiments the irradiated dosemeters were chosen to be unbiased.
- For that exposure mode, usually called zero bias mode, the expected response of the voltage shift ΔV_T follows a power-law :

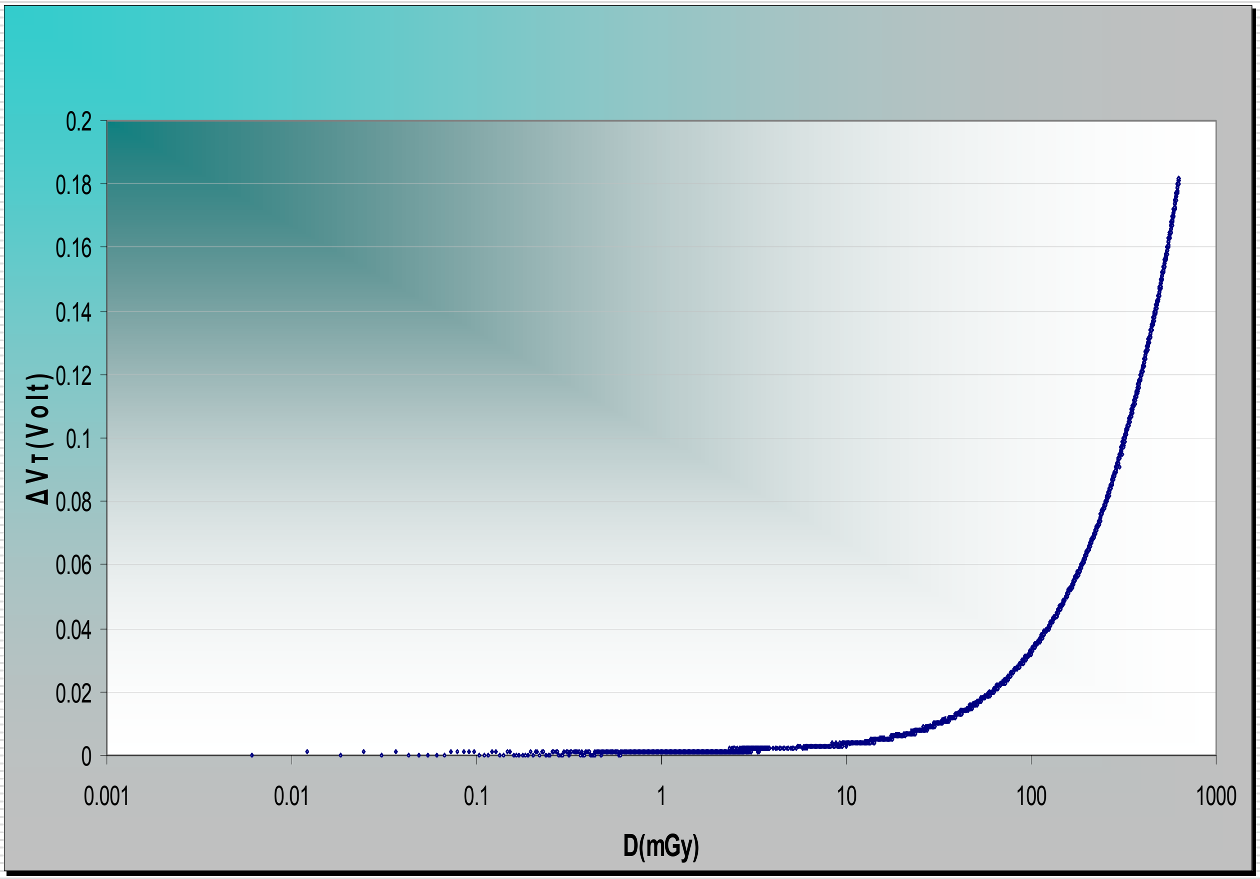
$$\Delta V_T = \alpha D^b \qquad (1)$$

- Parameters a and b were experimentally determined. Parameter b was found to be close to unity so the response of the MOSFETs was expressed by parameter a

MOSFET irradiations

- In order to measure **gamma rays**, **thermal neutrons** and **intermediate-fast neutrons**, 3 dosemeters were irradiated at the same position inside the sub-critical reactor.
- The first dosemeter was irradiated without converter so giving information about gamma ray dose.
- The other two sensors were in contact with LiF converter, while one was additionally covered by 1mm thick Cd layer.
- From Cd covered detector the response of the dosemeters to intermediate-fast neutrons can be measured.
- The response of the dosemeters to thermal neutrons can be obtained by subtracting the shift of V_T of Cd covered from Cd un-covered detector.

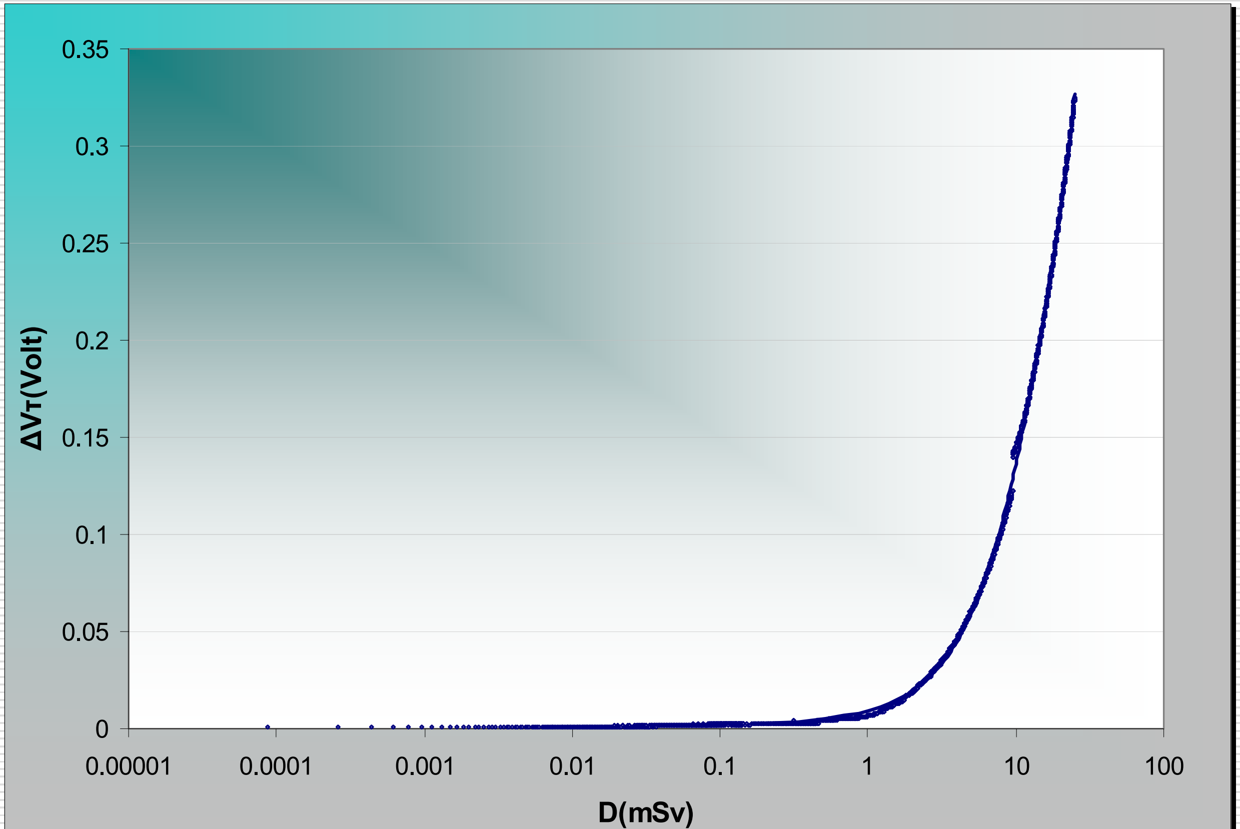
Response to gamma rays



In personal dosimetry the first part of the response curve, corresponding to low doses (up to mGy), is of special importance.

In this part of the response curve a linear function was applied, with R^2 equal to 0.99.

Response to thermal neutrons

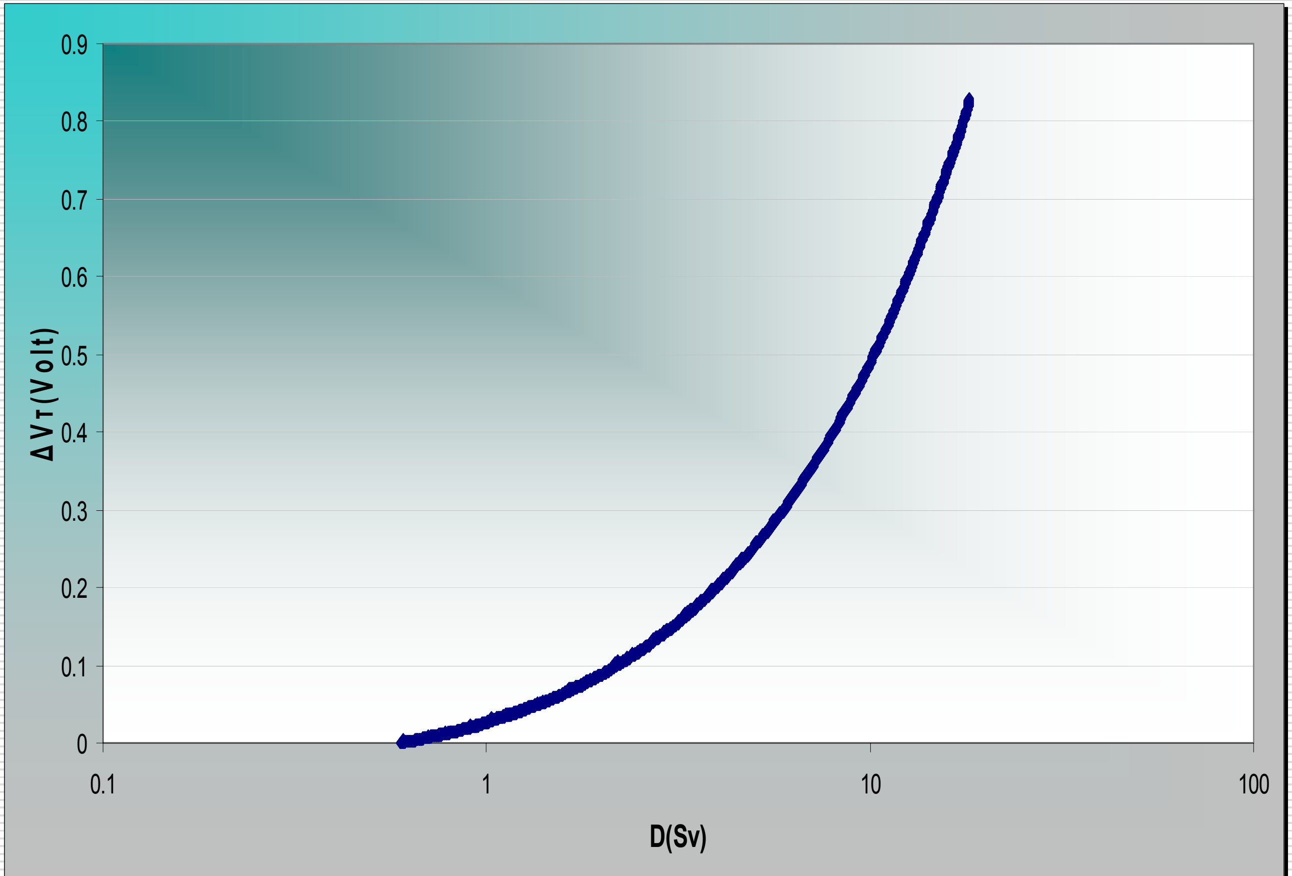


Parameter b for thermal neutrons was found to be close to 1, (1.01 ± 0.001).

In case of intermediate - fast neutrons parameter b was less than 1, (0.937 ± 0.001)

which was very close to the behavior of irradiated MOSFETs by gamma rays.

Response to intermediate-fast neutrons



Their response to intermediate-fast neutrons is

about two orders of magnitude lower to that measured for thermal neutron

and similar to that for gamma rays.

Characteristics of the new p-MOSFET dosemeters

<table>
<tr><th>Type of radiation</th><th>Response (mV/mSv)</th><th>Response (mV/mGy)</th><th>Lower detectable limit</th></tr>
<tr><td>Gamma rays</td><td></td><td>0.5 ± 0.1</td><td>Of the order of μGy</td></tr>
<tr><td>Thermal neutrons (10^{3} neutrons/cm^2.s)</td><td>11 .04 ± 0.05</td><td>56.6 ± 0.3</td><td rowspan="2">Of the order of μSv</td></tr>
<tr><td>Thermal neutrons (10^{4} neutrons/cm^2.s)</td><td>10.00 ± 0.07</td><td>51.5 ± 0.4</td></tr>
<tr><td>Intermediate-fast neutrons</td><td>0.045 ± 0.001</td><td>0.59 ± 0.02</td><td></td></tr>
</table>

Conclusions

- New MOSFET response to thermal neutrons is about 50-55 mV/mGy i.e., about two orders of magnitude higher than that measured for intermediate-fast neutron as well as of that for gamma rays.
- New MOSFET response is higher than previously reported in the literature with different neutron converters such as Gd in which the sensitivity to thermal neutrons was found to be 1.5-.1.6 mV/mGy.
- The new p-MOSFETs present a linear response for a wide dose ranges.
- Influence of dose rate on the dose response curve was negligible
- New MOSFETs are promising devices for their use in space radiation.