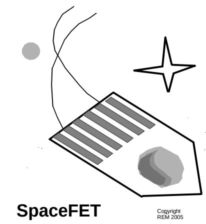
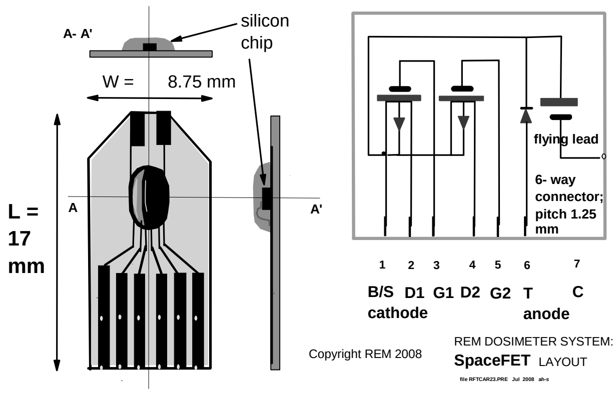


Type **RFT300-CC10G1**
REM LOW-FADE SILICON MOSFET DOSIMETER
Two RADFETs, Diode & Capacitor / Lid technology: "glob"



Key features

- measures ionising radiation doses in the rad to megarad range
- applications include
  - space and military missions
  - high-energy physics experiments
  - nuclear power
  - radiotherapy
- microscopically small sensor volume, measured in cubic micrometres, enables radical new designs of miniature radiation sensing systems
- low-Z epoxy packaging and small silicon chip make a rugged sensor

REM TOT600 chip, mounted on a CC10 carrier is the latest silicon sensor from REM, available in a variety of encapsulations and sensitivity values. There are several variants but the standard one , normally in stock, is REM RFT300-CC10G1. This contains a gate oxide of thickness 300nm, has a sensitivity as high as 1.5 mV/cGy and a package nearly transparent to radiation. It is suitable for many radiation beams and for space.

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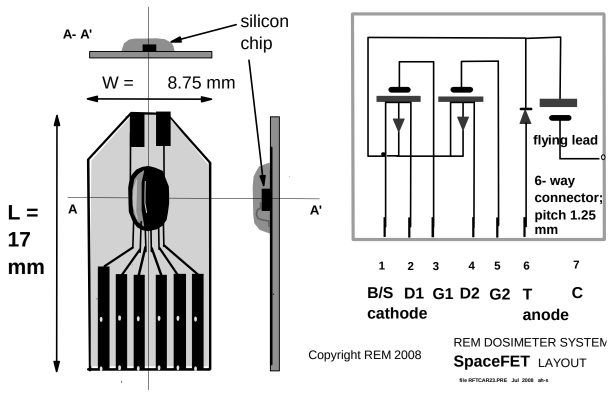
LOW-FADE SILICON MOSFET DOSIMETER

Two RADFETs, A Diode & Capacitor



TYPE RFT-300-CC10G1

PINOUT

1. Source/Body
2. D1
3. G1
4. D2
5. G2
6. T (diode)
7. C (capacitor)

D = drain, G = Gate

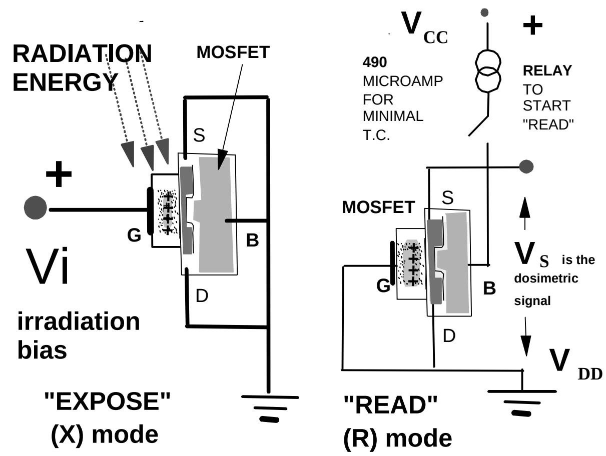
REM's latest medium-responsivity silicon sensor for ionizing radiation is the TOT600, consists of a dual MOSFET, a p+n diode and an MOS capacitor mounted on a dosimeter carrier (REM CC10) suitable for space and other automated vehicles. The sensor element is the smallest known solid state radiation dosimeter. Its development is part of REM's concept of a dosimeter system, known as DOT (for "Dosimetry by Oxide Trapping"). This is the product of over 30 years of experience within REM. The data sheet is for the sensor only. *References to an extensive literature are available, with a major bibliography given in REM's "Handbook of Radiation Effects" [1].*

RADFET CONSTRUCTION

Radiation-sensitive MOSFETs are enhancement pMOS transistors carrying a thick gate oxide.
DIE: Material: Si Wafer
Mask: REM TOT600 mask (FETs Q1 and Q2, diode T and MOS capacitor C)
Chip size: 0.635 x 1.25 x 0.5mm
Gate oxide thickness (micrometres):
0.20, 0.25 or 0.30 um (see "radiation response")
Diode T area : 0.05 mm^2
Capacitor C area : 0.05 mm^2
CHIP CARRIER (CC)
CC Material: FR4 CC thickness - 0.3mm.
CC Width - 8.75 mm, Length 17 mm
Die encapsulation: Black epoxy "glob" G1
Cable & connectors: commercial 6 way FFC .

OPERATION

Dosimetry involves tracking of the threshold voltage, V_T, at 10 to 500 uA (Fig 1)



V_T is kept low by channel implantation. The shift of V_T given by a fixed amount of charge trapping is dependent on the thickness of the gate oxide.

RESPONSE TO RADIATION

The V_T shift of the TOT601 series is given in Fig. 1 and Tables 1 and 2

The present standard REM RADFET process, Type TOT601B, is suitable for radiation environments which exisit in Earth orbits which intersect the trapped radiation belt and hot cells, radiotherapy, particle and X-ray beams.
An electrical measurement [shift of threshold voltage] gives a relative value of the dose accumulated in a silicon environment (rad or cGy(Si)). The oxide dielectric responds to all forms of particle and photon radiation in proportion to the linear energy transfer (LET) and the radiation induced charge stays there for many years. Dose range varies with the gate oxide thickness and the exposure bias. REM Bias Board Type BB2 is

designed to fit in line with the FCC sensor cable, applies the needed bias and switches the sensors individually to the reader input.

TABLE 1
PRACTICAL DOSE RANGES FOR TOT601B

A. Positive bias (PB) 10 to 100,000 cGy
B. Zero-bias (ZB) mode (V_I = 0V) 20 to 2 million cGy

The response for ZB mode operation is about 6 times lower than for PB mode but this means that the practical dose range for ZB is higher (see Fig.1).

TABLE 2
RESPONSIVITY FOR THREE EXPOSURE MODES

t_{ox} μm	PB Lo Mode mV/cGy	PB Hi Mode mV/cGy	ZB Mode mV/cGy
0.20	0.65	0.85	0.12
0.25	0.95	1.20	0.16
0.30	1.25	1.75	0.20

The highest responsivity value shown here is 1.250 mV/cGy [Vi+9 for 0.30 micrometre oxide]. With thicker oxides, up to ten times this response is possible.

ELECTRICAL CHARACTERISTICS

Threshold voltages, I-V slope and drift

TABLE 3
REM RADFET TOT601B: RANGES FOR THE SOURCE-DRAIN VOLTAGE DROP AT 490 microA ["-V_t"]

The values measured were in the following range:
t_{ox} = 0.20 micrometres 4.00 to 4.50 V
t_{ox} = 0.25 micrometres 4.50 to 5.10 V
t_{ox} = 0.30 micrometres 5.00 to 6.00 V

Target voltages for lot 601C will be centred around 1.5V.

TABLE 4
REM RADFET TOT601B: DIFFERENCES ("diff") BETWEEN V_t values various drain currents

(I_d values routinely used are I_{d1} = 4 90 uA; I_{d2} = 160 uA; I_{d3} = 90 uA) Values are within ten percent of the following

	$V_t(I_{d1})$ - $V_t(I_{d2})$	$V_t(I_{d2})$ - $V_t(I_{d3})$	
Wafer 9	183	565	mV
Wafer 4	160	500	mV
Wafer 2	150	450	mV

STABILITY - LOW FADE or room-temperature annealing (RTA)

Charge is retained by REM's oxide layer, so that there is only a slight loss of the charge with time, called "fade" or "room-temperature anneal (RTA)". Fade is usually measured as a percentage of the original V_t shift per decade of time. Discharge may take months or many years depending on the quality of the oxide. TOT601B has a slow rate of RTA. Fig. 2 and Table 5 present a fade model based on measurements on devices tested in PB mode over more than 100 days. *Raising the temperature increases fading. The rate is about doubled at 50°C while high-temperatures (say 250°C) cause emptying of nearly all charge traps (Refs 1 and 2).*

BORDER-STATE DRIFT

In unirradiated devices, there is a small transient "drift up" (du) in the tracker voltage with time (see "Technical Terms). This tendency to drift increases more than tenfold after irradiation.

TABLE 5. REM RADFET TOT601B: FADE MODEL (irrad. to 1E4 cGy in 1 hr under positive bias mode) *(see Fig. 2)*

Anneal time	**Fade (%)**	**Remarks**
1 day	+1*	charge gain
10 day	-1	charge loss
100 day	-3	" "
1000 day	-5	" "

**This "reverse annealing" is a well-understood effect*

Figures

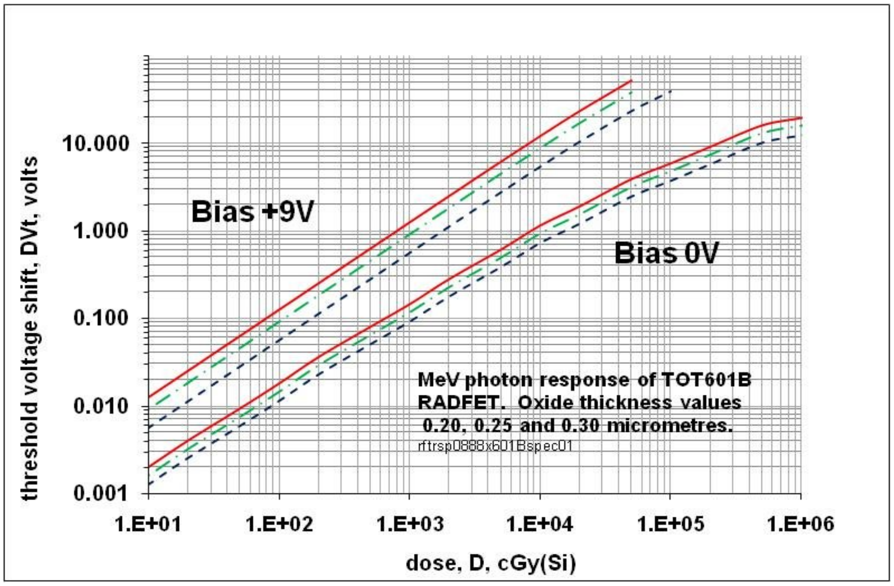


Fig 1. Specification for shift in threshold voltage with dose of MeV photons for REM Model TOT601B RADFETs at 0V or +9V bias during exposure. Solid line : 0.30 micrometre oxide ; chain dots 0.25 ; dashes 0.20. Devices with this range of response are suitable for Earth orbits and nuclear hot cells.

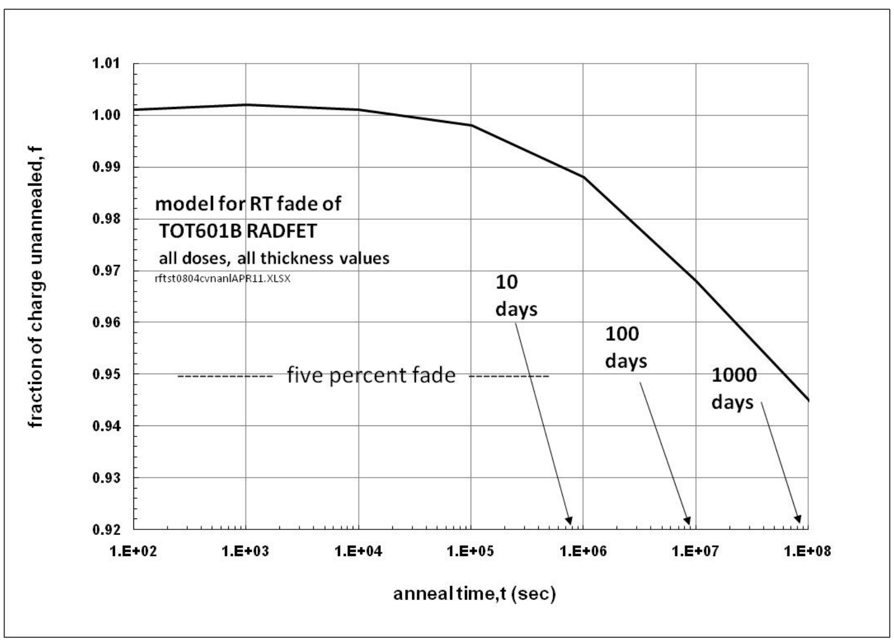


Fig. 2. Room-temperature fade or annealing curve. Typical values for all TOT601B devices (0.2 to 0.3 micrometre thickness). Irradiation in positive bias mode. A nominal figure for 100 days' anneal is 3 percent of the original V_t shift. The data is for PB mode only. Recent research shows more variable anneals in the ZB mode.

TECHNICAL TERMS

RADFET

Radiation-Sensing Field-Effect Transistor microminitaure silicon pMOSFET transistor which acts as an integrating dosimeter, measuring dose in rad or Gy(Si) by virtue of the field effect caused by space charge trapped in an inorganic insulator (SiO_2). Radiation-induced charge remains stored for many years. The RADFET was invented in 1970 by Andrew Holmes-Siedle (now sole owner of REM) and his co-worker, the late Waldemar Poch. Details were published in 1974. The acronym "RADFET" was coined by Robert Hughes in 1986 and is used with permission. The RADFET has been used for the last 30 years in aerospace industry, and is being used increasingly in medicine, nuclear industry and science.

Threshold voltage shift, deltaV_t

The electrical parameter used to detect the field produced when charge is trapped in the gate oxide of a MOSFET. Measurement of deltaV_t by a reader gives a relative value of dose in a silicon environment (rad or cGy(Si). The V_T tracker measures source to drain signal at a constant I(D), at a set time after switching the bias to the MOSFET.

I-V characteristic, "diff"

REM's automatic DOT tracker measures two points on the drain-current / gate voltage characteristic of the MOSFET. The difference between the values of V(T) at two currents, being the inverse of the I-V slope, is a measure of device functionality and a useful "health check".

Minimum Temperature Coefficient (MTC)

At a certain point in the I-V curve, the temperature coefficient (TC) is at a minimum. The value for TOT601B is near 490 mA.

"Drift up", du

A "border-state instability" which can interfere with accurate measurement of delta V_t. Caused by transien, bias-induced charging of traps in the oxide-silicon interface. The value of du increases over 10x on irradiation and this can have an impact on accuracy. However, good tracker design can greatly minimise that impact.

"DOT" Reader System

The DOT "Dosimetry by Oxide Trapping" system designed by REM detects the field produced when space-charge is trapped in the gate oxide region of the RADFET chip. The electronics measure the shift of threshold voltage. Software then converts this to a value of dose in rad or cGy(Si). The components of the DOT system, invented by REM in 1970, include the silicon sensor die or "chip" mounted on application-specific forms of "chip carrier" and probe, using lightweight cables, battery bias on the MOSFET and electronics to apply bias, digitize voltages, process and transmit the readings by RF link or thin cable. The DOT electronics is not at present in commercial production but working prototypes exist at REM Oxford, operation of one is described in Reference 4.

REM is a specialist in developing new RADFET sensor designs and meeting new applications such as very small probes, large arrays of sensors, medical applications, megarad measurement.

For information on sensor prices, on the DOT reader system and developing areas of RADFET dosimetry see the REM website.

www.radfet.com

Or Phoenix Semiconductor

www.phoenixsemi.com

REFERENCES

1. A. Holmes-Siedle and L. Adams, "Handbook of Radiation Effects" (Oxford University Press, 2nd Edition 2002). *Effects explained; Appendix D is a bibliography of research on RADFETs.*
2. A.G. Holmes-Siedle, "The Space Charge Dosimeter - General Principles of a New Method of Radiation Dosimetry", Nucl. Instrum. Methods 121,169 (1974). *The original archival literature reference. Puts the MOSFET dosimeter in the public domain, and gives priority of invention to REM.*
3. Andrew Holmes-Siedle, Federico Ravotti and Maurice Glaser (2007). "The dosimetric performance of RADFETs in radiation test beams". NSREC07 Data Workshop, Jul. 24, 2007, Proc.Workshop Record, IEEE Cat.No. 07TH0000 (2007). Available as REM Reprint iens0701.
4. A. Holmes-Siedle, P. Menary, P. Sharpe and J. Mills "MOSFET radiation dose monitors (RADFETs) in medicine: are they coming of age? " SCOPE, Volume 19. Issue 2, 21-27 (June 2010, a journal of the IPEM, London) and http://www.scopeonline.co.uk/pages/articles/radfet/radfet.shtml

This is a comprehensive data compilation