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INVESTIGATION INTO THE DOSIMETRIC CHARACTERISTICS OF MOSFETs FOR USE FOR *IN VIVO* DOSIMETRY DURING EXTERNAL BEAM RADIOTHERAPY

by
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This thesis is dedicated to my parents,
both of whom passed away during this work.

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ABBREVIATIONS AND SYMBOLS

Symbol	Physical Constant / description	Value / unit
C_e	Concentration of electrons in conduction band	cm^{-2}
CF	Calibration factor	
C_h	Concentration of holes in valence band	cm^{-2}
CMRP	Centre for Medical Radiation Physics, University of Wollongong, New South Wales, Australia	
C_{ox}	Oxide capacitance per unit area	F/cm^2
D	Absorbed dose	$J\ kg^{-1}$
D_{max}	Depth of maximum dose	
D_{ref}	Reference absorbed dose	Gy
E	Energy level	J
$\bar{E}_{ab}$	Average energy absorbed per interaction	eV
E_c	Minimum energy of conduction band	eV
E_F	Fermi energy	eV
E_{gap}	Energy difference between conduction and valence bands in a semiconductor	eV
E_{tr}	Energy transferred by ionising radiation	eV
eV	Electron-Volt	
E_v	Maximum energy of valence band	eV
f	Frequency of radiation	s^{-1}
$f(E)$	Charge yield	coulomb
$F(E)$	Fermi-Dirac distribution function	
$F(E)_e$	Fermi-Dirac distribution function for electrons	
$F(E)_h$	Fermi-Dirac distribution function for holes	
F_{corr}	Correction factor	
g	Hole generation rate	$7.9 \times 10^{12}\ cm^3/cGy$
$G_{\square}$	Number of electron-hole pairs per second	s^{-1}
Gy	Absorbed dose	$1\ Gy = 1\ J\ kg^{-1}$
h	Planck’s constant	$6.62617 \times 10^{-34}\ J.s$
I	Current	ampere
IC	Ion chamber	
IVD	*In vivo* dosimetry	
k	Boltzmann’s constant	$8.617 \times 10^{-5}\ eV/K$
m_e^*	Density-of-states effective mass of electron	$1.08m_o^{-1}$
m_h^*	Density-of-states effective mass of hole	$0.811m_o^{-1}$
min	Minute	
m_o	Free electron mass	$9.1095 \times 10^{-31}\ kg$
MOS	Metal-oxide-semiconductor	
MOSFET	Metal Oxide Semiconductor Field Effect Transistor	
n	Density of electrons or holes	cm^{-3}
N	Number of electron-hole pairs	
$N(E)$	Density of quantum states per unit volume per unit energy	$cm^{-3}\ J^{-1}$
$N(E)_e$	Density of electron quantum states per unit volume per unit energy	$cm^{-3}\ J^{-1}$
$N(E)_h$	Density of hole quantum states per unit volume per unit energy	$cm^{-3}\ J^{-1}$
n_d	Density of donors	cm^{-3}
$n_e(t)$	Density of electrons at time *t* after irradiation	cm^{-3}
$n_h(t)$	Density of holes at time *t* after irradiation	cm^{-3}
N_{ss}	Density of interface states	cm^{-3}
$\Delta N_{ss}(t)$	Density of interface states with time after irradiation	cm^{-3}

N_T	Area density of available traps in trapping sheet	cm^{-2}
q	Electronic charge	1.60218 x 10^{-19} C
Q_i	Interface charge density per unit area	Cm^{-2}
s	Second	
SD	Standard deviation	
Si	Silicon	
SiO_2	Silicon dioxide	
SSD	Source-to-surface distance	cm
T	Temperature	kelvin
t	Time	s
T&N	Thomson Nielsen Electronics Ltd, Canada	
t_h	Time of travel for holes across SiO_2	s
t_o	Time of termination of irradiation	s
t_{ox}	Oxide thickness	cm
t_{sat}	Time of MOSFET saturation	s
v	Velocity	cm s^{-1}
V	Voltage	
V_{FB}	Flatband voltage	V
V_g	Gate voltage	V
V_{ss}	Voltage between source and substrate	V
V_{th}	Threshold voltage	V
$\Delta V_{th\ FB}$	Flatband threshold voltage shift	V or mV
ΔV_{th}	Threshold shift	V or mV
$\Delta V_{th\ i}$	Threshold shift for the first exposure of a new MOSFET	V or mV
$\Delta V_{th\ ox}$	Threshold shift due to oxide trapped charge	V or mV
$\Delta V_{th\ ref}$	Reference Threshold shift	V or mV
$\Delta V_{th\ sat}$	Threshold shift at saturation	V or mV
W	Energy to produce one electron-hole pair	> 17±1 eV in SiO_2
Wollongong MOSFETs	MOSFETs provided by University of Wollongong, New South Wales, Australia	
x	Distance travelled by holes or electrons in SiO_2	cm
x_h	Distance travelled by holes in SiO_2	cm
$\angle$	Angle	degree

Greek symbols

ε	Electric field strength of oxide	V cm^{-1}
ε_o	Permittivity in free space	8.854 x 10^{-14} F/cm
ε_S	Permittivity in silicon	11.9 F/cm
ε_{ox}	Permittivity in silicon dioxide	3.9 F/cm
□	Activation energy for annealing process	eV
μ	Coefficient of mobility	cm^2 / V.s
μ_{en}/ρ	Mass energy absorption coefficient	cm^2/g
ρ	Density of material	cm^{-3}
ρ_{ox}	Density of oxide charge	Cm^{-3}
τ	Timescale of charge build-up, or time constant	s
τ_e	Lifetime of electrons	s
τ_h	Lifetime of holes	s
$\square_F$	Bulk potential of silicon	V
$\square_M$	Work function of metal	V
$\square_S$	Work function of semiconductor	V
□	Electron affinity for semiconductor	4.05 V

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THESIS ABSTRACT

This thesis investigates the response to ionising radiation, of p-type Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) (REM Oxford (UK)) and a reader system developed by the Centre for Medical Radiation Physics, The University of Wollongong, to determine their feasibility for measurements of dose during radiotherapy treatment (in vivo dosimetry (IVD)). Two types of MOSFET probes were used – "single sensitivity", for measuring low doses, and "dual sensitivity", to measure both high and lose doses. Sensitivity, linearity of response with dose, and response changes with accumulated dose and direction of incident radiation (angular dependence) were investigated.

The average sensitivity reduction over the lifetime of the probes was 22.37% with a standard deviation of 0.63%. This reduction in sensitivity can be corrected for by the use of "drift equations". MOSFETs have a limited "lifetime" due to saturation effects with increasing accumulated dose. Saturation occurred at an average of 40 Gray (Gy) accumulated dose, for the high sensitivity probes investigated.

The high sensitivity probes were linear within 1.6% for doses between 5 and 140 cGy, and 3.8% for the high sensitivity probes for doses between 50 and 500 cGy.

Drift (changes in readings with time since irradiation due to electronic processes) over the long-term (from hours to weeks following irradiation) has been previously well characterised in the literature. This work focuses on short-term drift, within the first few seconds or minutes following irradiation, being the most clinically relevant for in vivo measurements. Drift is investigated for various reading methods, such as reading frequency, and delays between irradiation and readings. It is shown that sensitivity, and consequently dose determination, is significantly influenced by the reading methodology.

During the first five minutes following an irradiation, drift increased inversely with delivered dose, and was greater for probes having accumulated dose of > 20 Gy (2.0 – 16.2% compared with 1.2 – 7.4% for < 20 Gy probes).

When two post-irradiation readings were taken following an irradiation, the difference between them generally increased as the time interval between the two readings increased, by up to 8.8%.

Delays in taking pre- and post-irradiation readings resulted in drift of up to 5.7% or 9.3% respectively, compared with readings without a delay.

These results emphasise the necessity for consistent methodologies between calibration and measurement in the clinical situation.

Greater sensitivity was measured with the epoxy bubble, rather than the substrate side, facing the beam. The greatest variation, for orientations other than the bubble side facing directly towards the beam, was 10%, or 5% uncertainty in dose. The variations with angle were found to be reproducible, so that appropriate correction factors could be applied to correct measurements at angles other than with the sensitive area of the probes facing directly towards the radiation beam.

AUTHOR'S STATEMENT

I hereby certify that this thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Raelene Nelligan 9 October 2008

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