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Multiple Current method applied to characterization of RADFETs

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Outline

- **Background and motivation**
- **Materials and methods**
  - Experimental set-up and read-out unit
  - Studied RADFETs from Tyndall
- **Experimental results**
  - Thermal characterisation
  - Calibration and linearity: Three current Method (3CM)
  - Thermal compensation: Two current Method (2CM)
- **Conclusions**
- **Acknowledgements**

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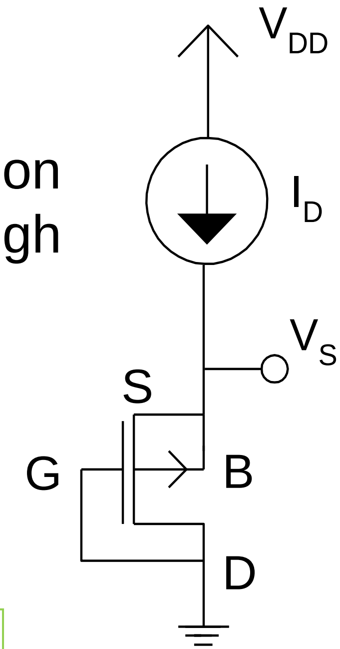
Background and motivation : pMOS as dosimeter

- Oxide charge build-up by ionizing radiation: V_t shift
- Main dosimetric parameter: V_t of pMOSFETs
- MOSFET used in dosimetry systems are the so-called RADiation sensitive Field –Effect Transistors (**RADFETs**): fabricated for high sensitivity to radiation.
- Readout of V_t at constant drain current in saturation regime

(V_{GD} = 0)



$$I_D = -\frac{\beta}{2}\left(|V_{GS}| - |V_t|\right)^2 \quad \beta \approx cte \quad \Rightarrow \quad \boxed{\Delta|V_t| \approx \Delta|V_S| = \Delta V_{out}}$$

Background and motivation : RADFETs challenges

- **High sensitivity to radiation**
  - Thick and post-processed gate oxide → Unstable oxide charges; High dose of pre-irradiation
  - Biasing during irradiation periods → Shortening of dose range
  - Stacking individual devices → Read-out complexity
- **Easy calibration: high linearity behaviour**
  - Depending on dose rate and dose range → Multiparameter calibration curve
  - Biasing during irradiation periods → Post-irradiation fading

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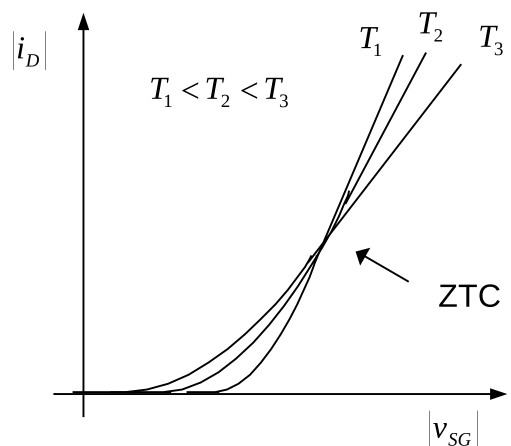
Background and motivation : RADFETs challenges

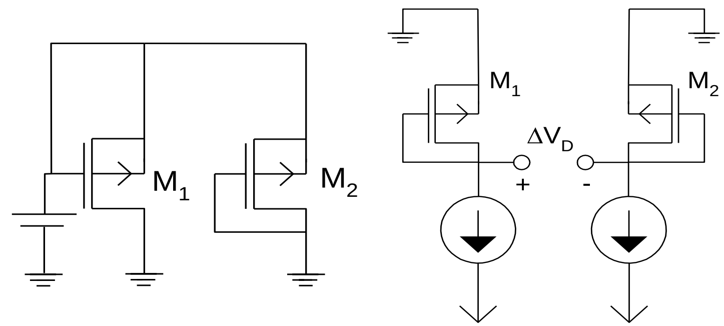
Main thermal compensation techniques

Biasing the pMOS at I_{ZTC}



- Shift of I_{ZTC} with accumulated dose
- Heating cycles effects (i.e. satellites)

Two identical pMOS with different sensibilities



During irradiation

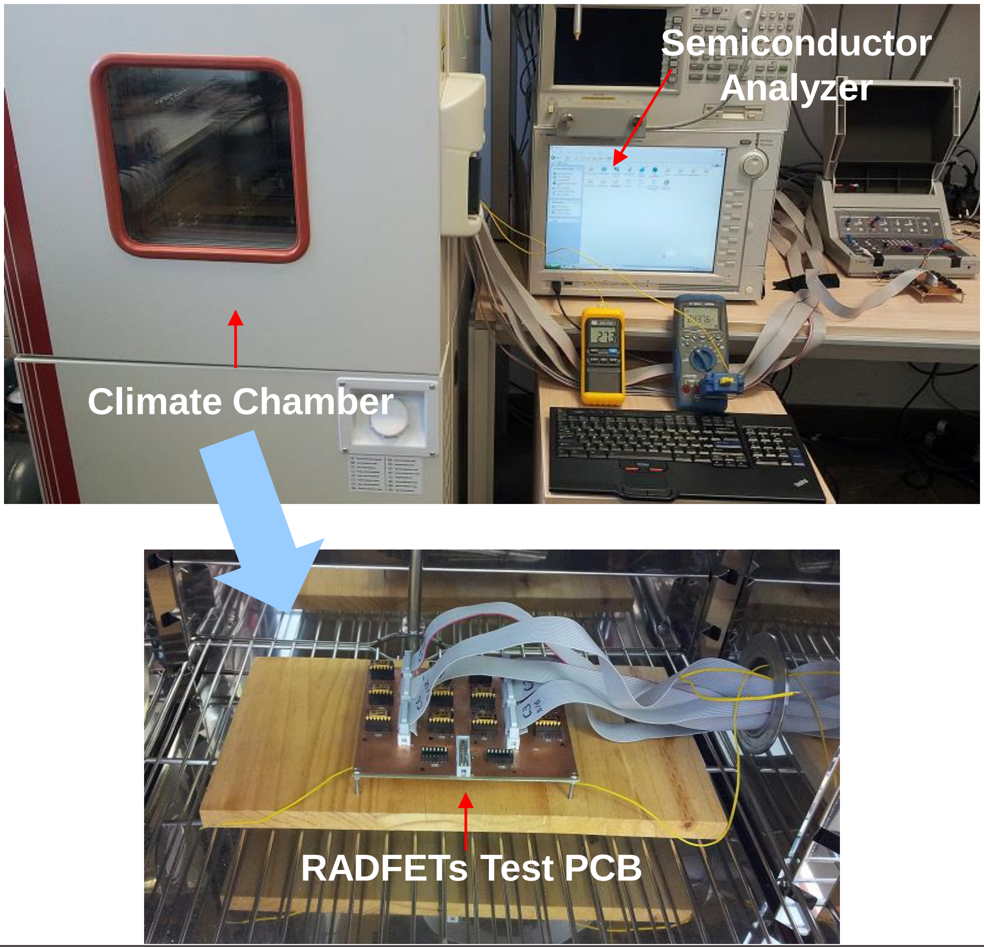
Read-out configuration

- Possible instability due to different biasing
- More complex read-out system

Background and motivation : Motivation and work plan

- Electrical and thermal characterisation of different **RADFETs** from Tyndall National Institute
- Response to radiation of unbiased single RADFETs
- Application of **multiple current algorithm** during read-out for:
  - Study of possible increase of linearity
  - Compensation of the temperature effects

Method and Materials: Electrical and Thermal Set-up



Electrical and thermal Characterization:

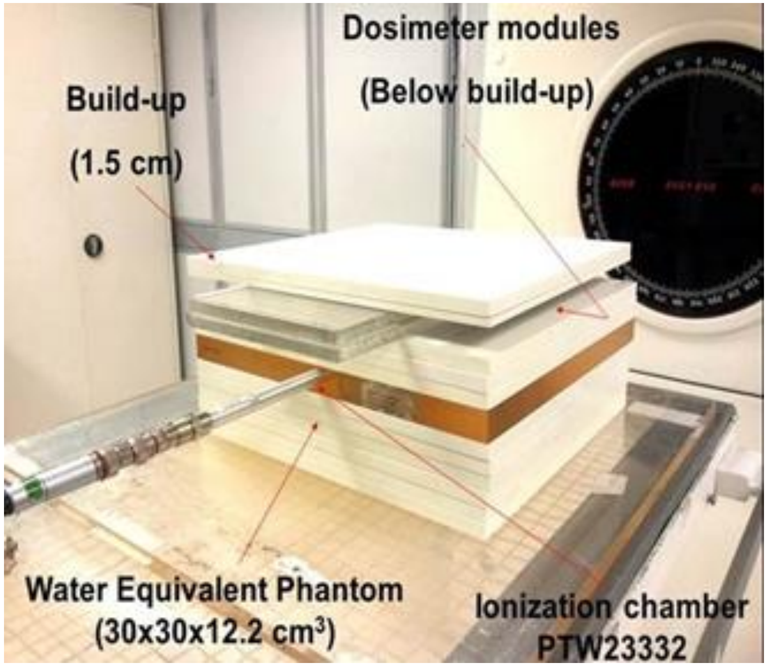
- I-V characteristics at different temperatures
- Extracted by a semiconductor analyser

  (B1500, Agilent Technologies)
- Temperature variations produced by a climate chamber (VCL4006 Vötosch Industryetedhnik, Germany)

Method and Materials: Irradiation Set-up

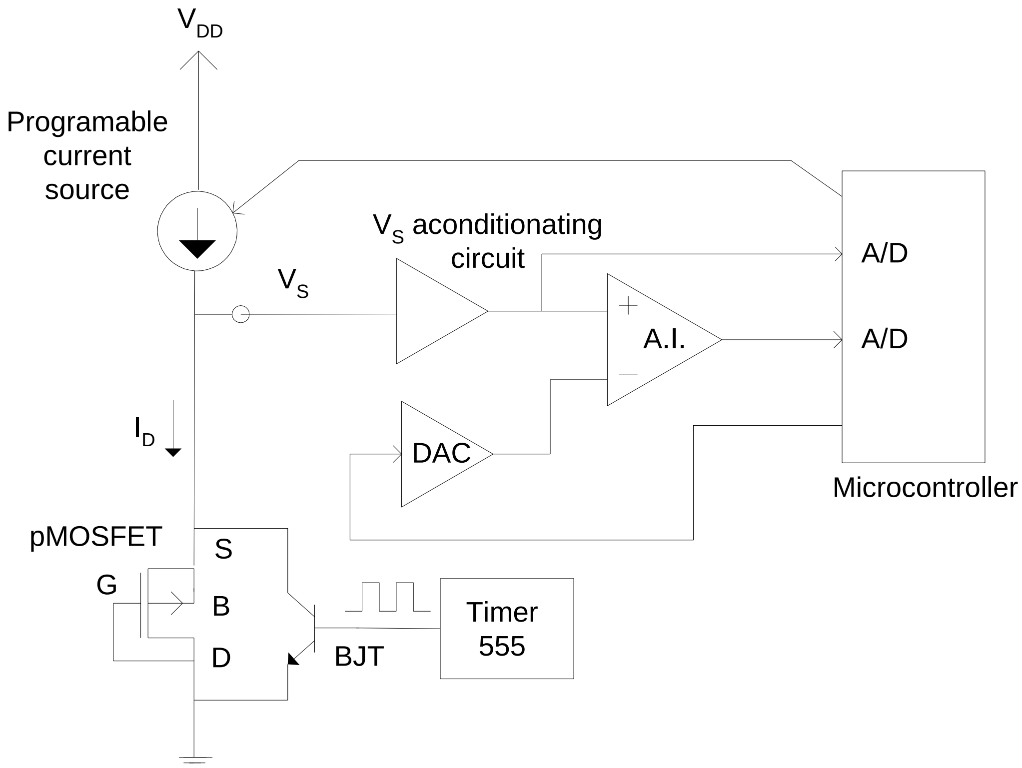
Irradiated by a Siemens Mevatron KDS:

- 6 MV photons
- Field 25x25 cm^2
- Dose Rate: 3.36 cGy/s
- At the iso-center, 100 cm
- Normal incidence
- University Hospital San Cecilio (Granada, Spain).



Method and Materials: Dosimetric System

- **Reader Unit:**



[Carvajal et al, 2012]

Method and Materials: Studied RADFETs from Tyndall

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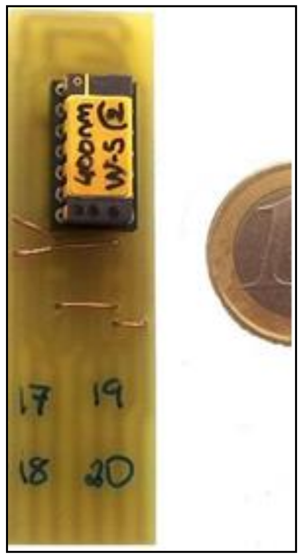
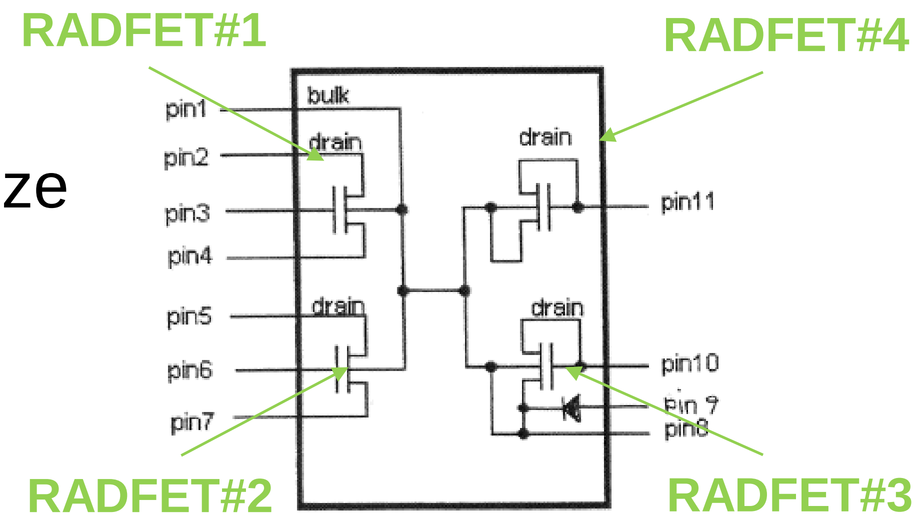
- Two sizes: 300/50 and 690/15
- 20 Chips→ **80 RADFETs**
- **8 RADFETs** for every model and size

MODEL
100nm_W8
400nm_IMPL_W5
400nmIMPL_W7
400nm_IMPL_W8
1µm_IMPL_W4





Sensor Module

Experimental results: Thermal Characterisation (II)

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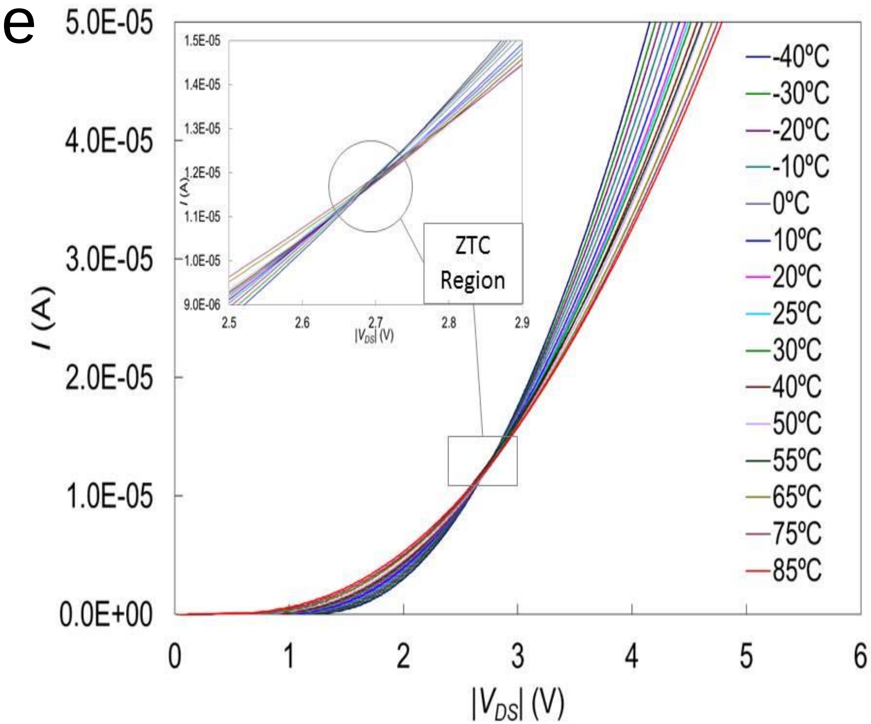
- **4 RADFETs** for every model and size (different to the radiation study)
- Total 10 chips → **40 RADFETs**

$$I_D = -\frac{\beta}{2}\left(|V_{GS}| - |V_t|\right)^2$$

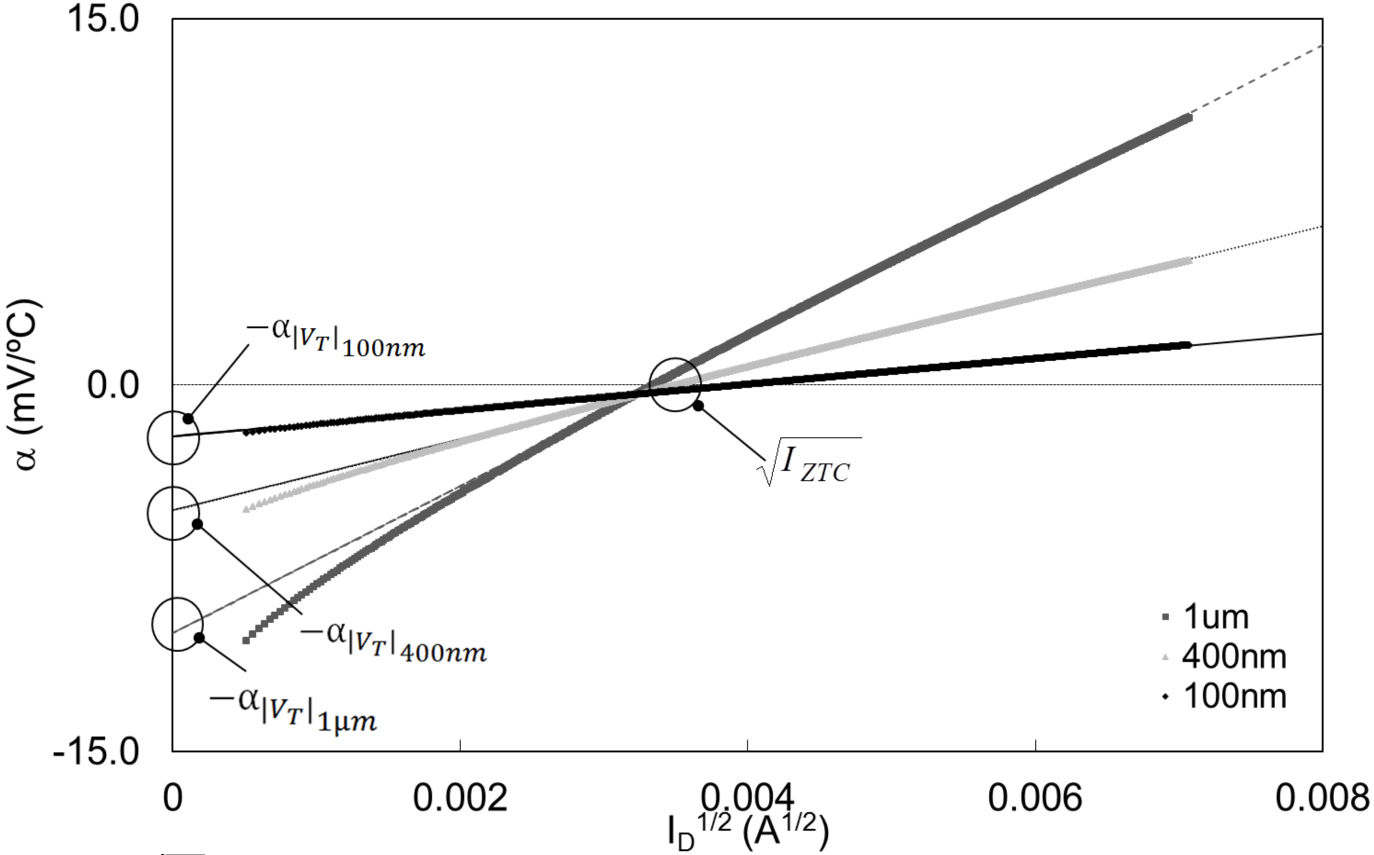
$$\Delta |V_T|(T) = \Delta |V_T^0| + \alpha_{|V_T|}\Delta T$$

$$\alpha_i = \alpha_{|Vt|}\left(1 - \sqrt{\frac{I_i}{I_{ZTC}}}\right)$$



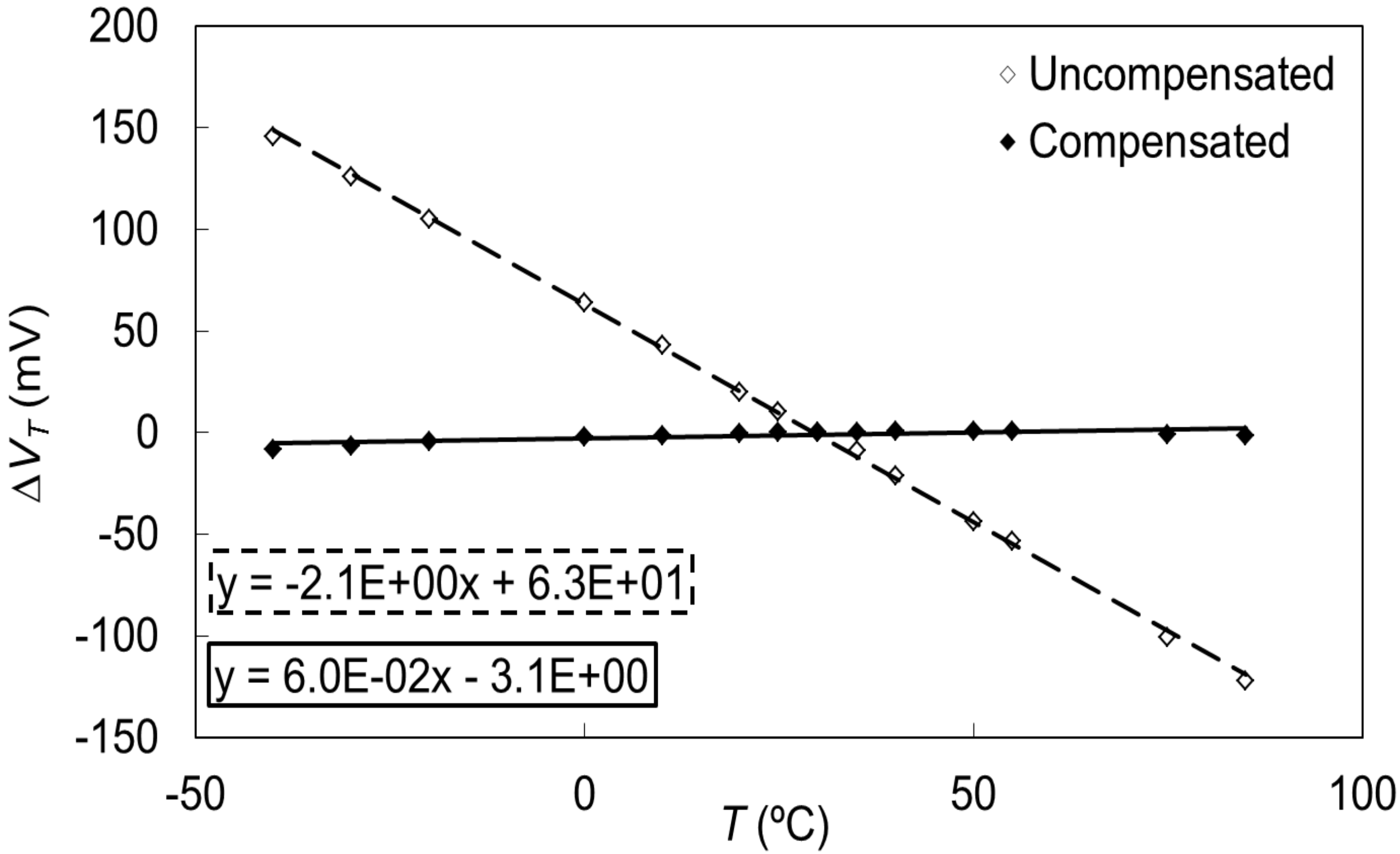
R#1 → 400nm and 300/50 type

Experimental results: Thermal Characterisation (III)



$\alpha(I_D)$ as a function of $\sqrt{I_D}$ of RADFET with t_{OX}100nm, 400nm_IMPL_W8 and 1µm (300/50size). Dots represents experimental data and line theoretical model.

Experimental results: Thermal Characterisation (III)



Thermal drift of the threshold voltage of a RADFET with t_{OX} 100nm and size 690/15 dosimeter before (open circles) and after (filled circles) applying the thermal compensation method.

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Experimental results: Thermal Characterisation (III)

Model	Size (W/L)	I_{ZTC} (µA)	α_{V_T} (mV/°C)
100nm_W8	300/50	19.89 ± 0.01	-2.2427 ± 0.0004
	690/15	179.29 ± 0.04	-2.1394 ± 0.0002
400nm_IMPL_W5	300/50	12.20 ± 0.03	-5.0515 ± 0.005
	690/15	131.9 ± 0.4	-4.903 ± 0.006
400nm_IMPL_W7	300/50	10.63 ± 0.03	-4.809 ± 0.005
	690/15	115.7 ± 0.4	-4.6408 ± 0.006
400nm_IMPL_W8	300/50	11.61 ± 0.03	-4.957 ± 0.006
	690/15	122.5 ± 0.4	-4.783 ± 0.006
1um_IMPL_W4	300/50	11.37 ± 0.04	-10.19 ± 0.01
	690/15	134.1 ± 0.7	-9.82 ± 0.02

Calibration and linearity: Three current Method (3CM)

- **Thermal compensation and linear range improvement.**
  - Biasing with three drain currents during read-out phase: I_{ZTC}, I_2 and I_C

$$\Delta V_{S2}^{0} = \Delta V_{S2} + \left(\Delta V_{SC} - \Delta V_{S2}\right)\frac{\sqrt{I_2} - \sqrt{I_{ZTC}}}{\sqrt{I_2} - \sqrt{I_C}}$$

$$\Delta\left|V_t\right| = \Delta V_{S,ZTC} + \frac{\Delta V_{S2}^{0} - \Delta V_{S,ZTC}}{1 - \sqrt{\dfrac{I_2}{I_{ZTC}}}}$$

  - For **3N163**, reduction in a factor of 50 in the thermal drift and 2.5 times linear range.

[Carvajal et al, 2010,Carvajal et al, 2011]

Experimental results: Three current Method (3CM)

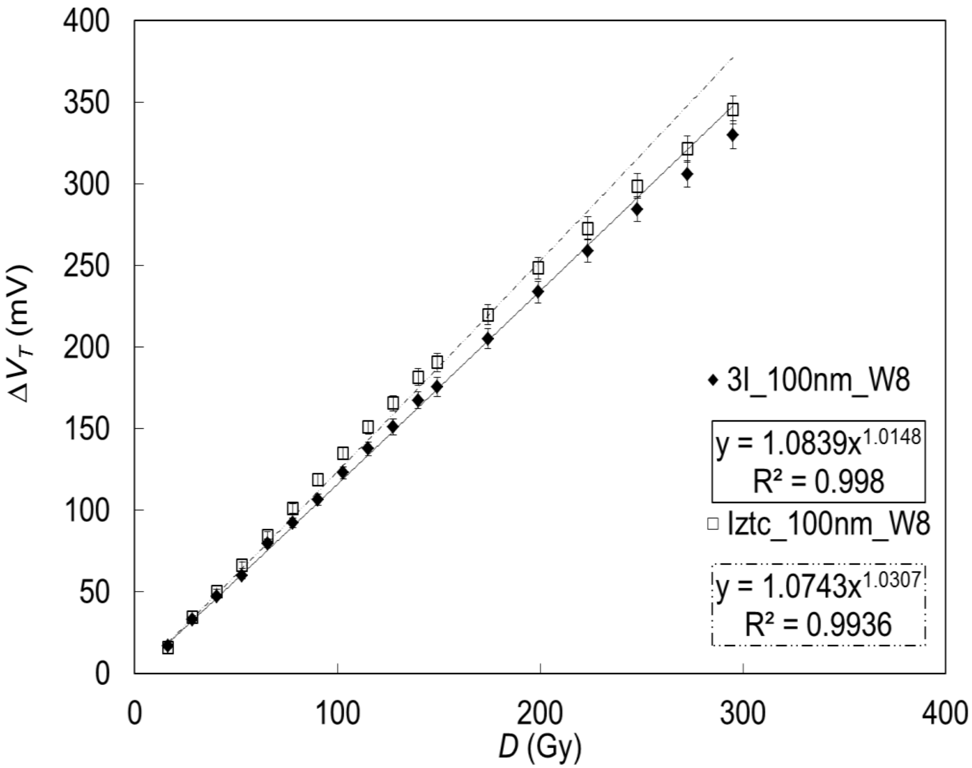
- Two different algorithms have been compared:
  - **3CM**
  - ***I_{ZTC}***

- The expected response of the voltage shift, ΔV_T will be modelled by:

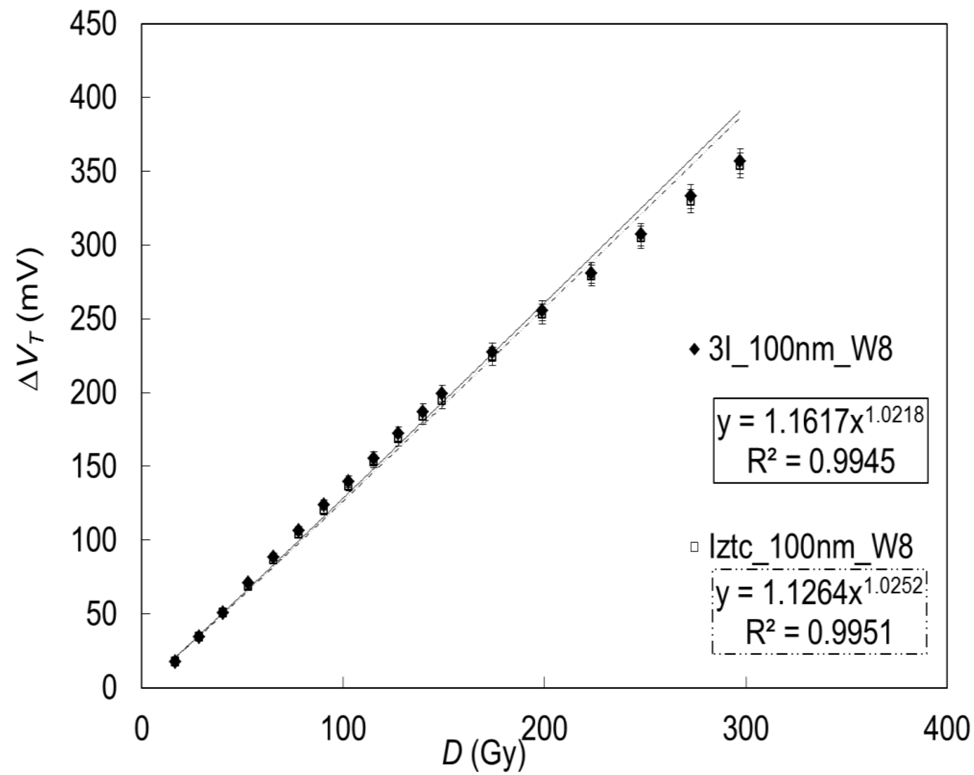
$$\Delta V_T = A \cdot D^n$$

Experimental results: Three current Method (3CM)(II)

- **100nm_W8**



W/L=300/50



W/L=690/15

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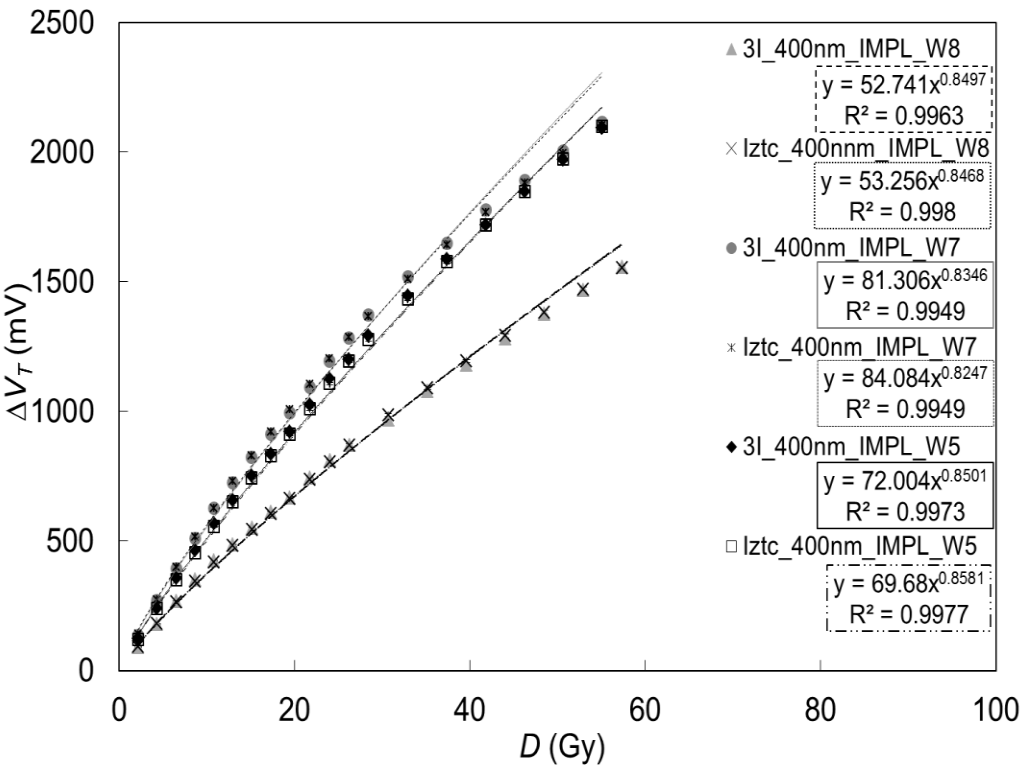
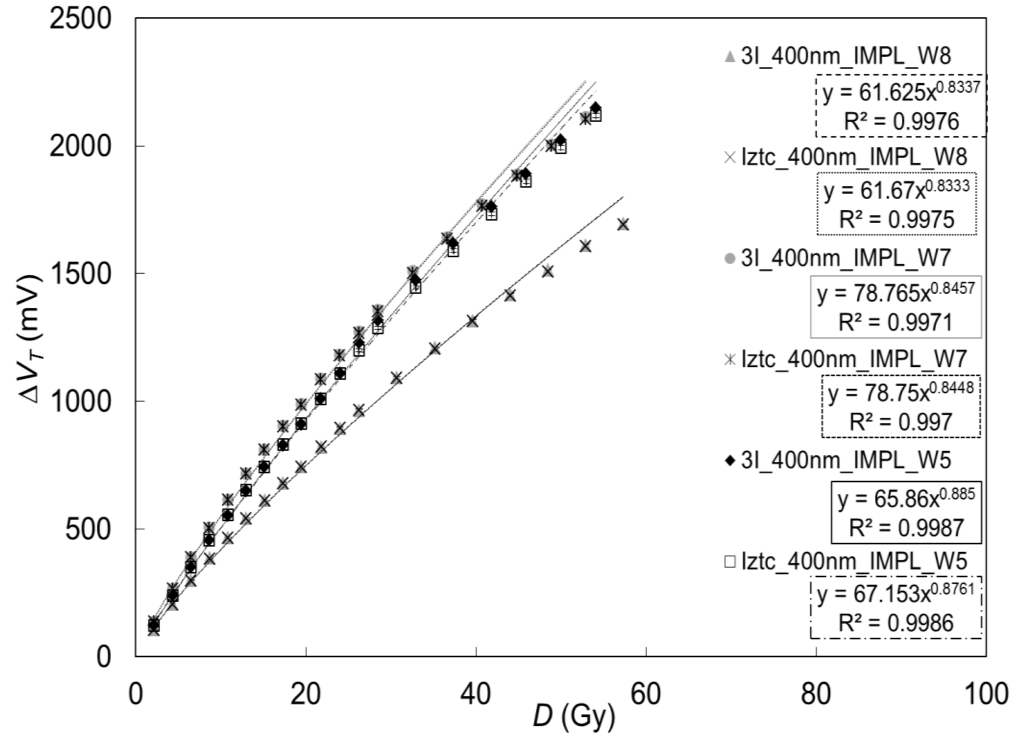
Experimental results: Three current Method (3CM)(III)

- **400nm _IMPL**



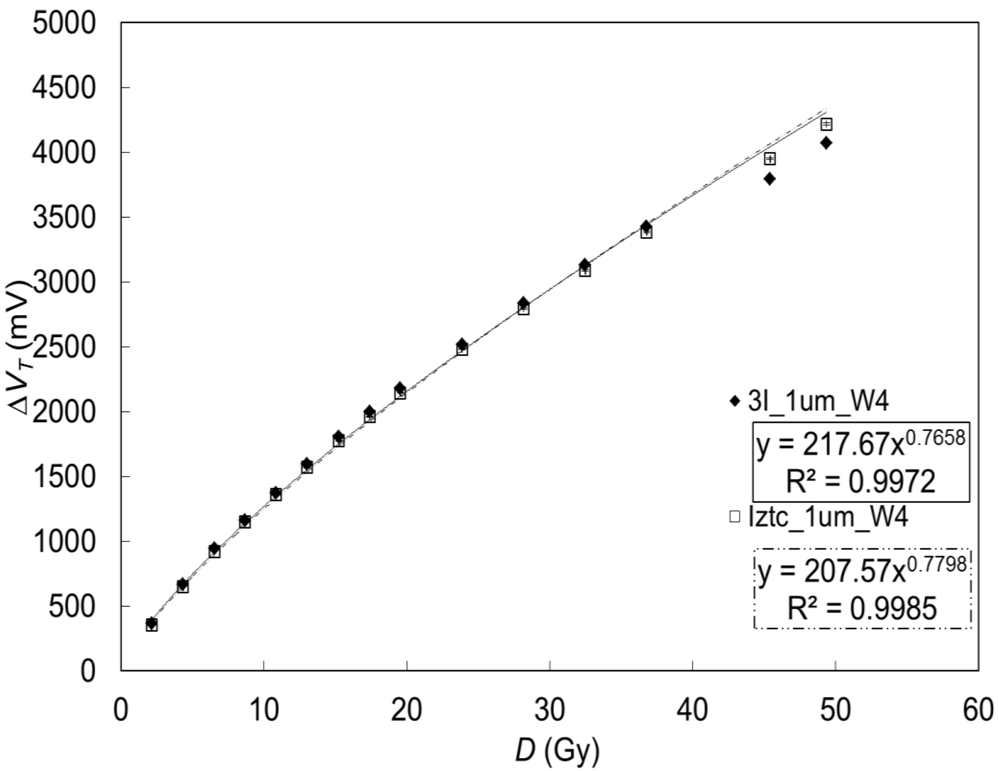
W/L=300/50



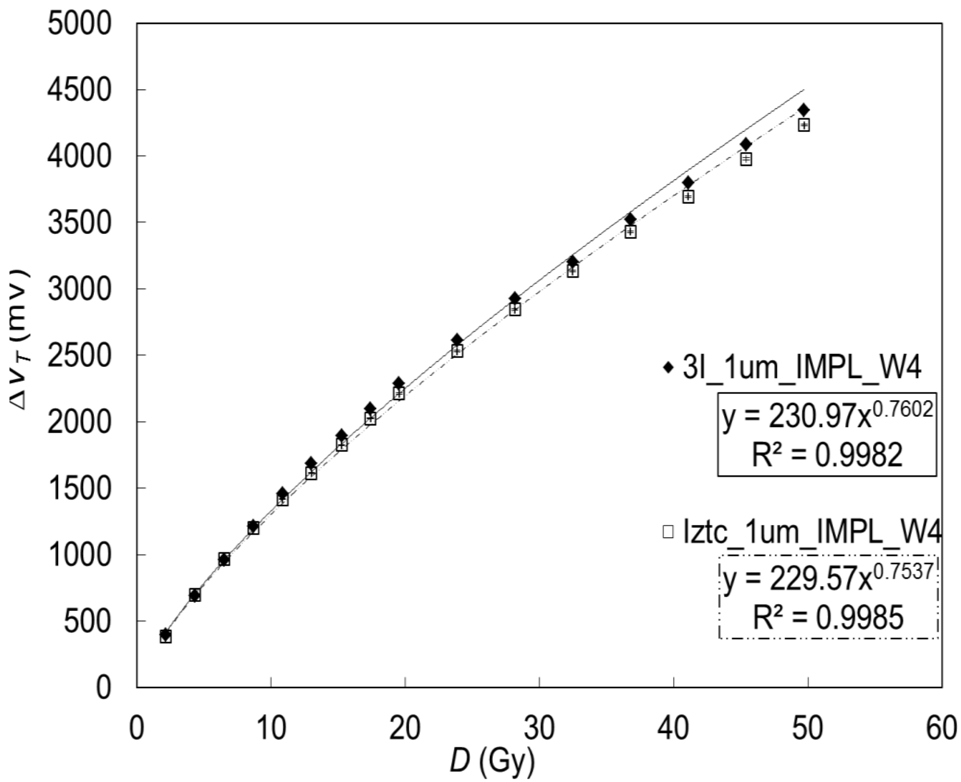
W/L=690/15

Experimental results: Three current Method (3CM)(IV)

- **1µm_IMPL_W4**



W/L=300/50



W/L=690/15

Experimental results: Three current Method (3CM)(V)

- **Size W/L=300/50**

Model	3CM		I_{ZTC}		Accumulated Dose (Gy)
	A (mV/Gy)	n	A (mV/Gy)	n	
100nm_W8	1.167	1	1.211	1	295.11
400nm_IMPL_W5	74.832	0.84465	72.320	0.8531	55.05
400nm_IMPL_W7	79.299	0.832	82.660	0.825	55.06
400nm_IMPL_W8	55.840	0.870	58.733	0.858	57.34
1µm_IMPL_W4	205.0	0.783	200.875	0.786	49.36

- 3CM does not improve the results $N_{ot} >> N_{it}$

Experimental results: Three current Method (3CM)(VI)

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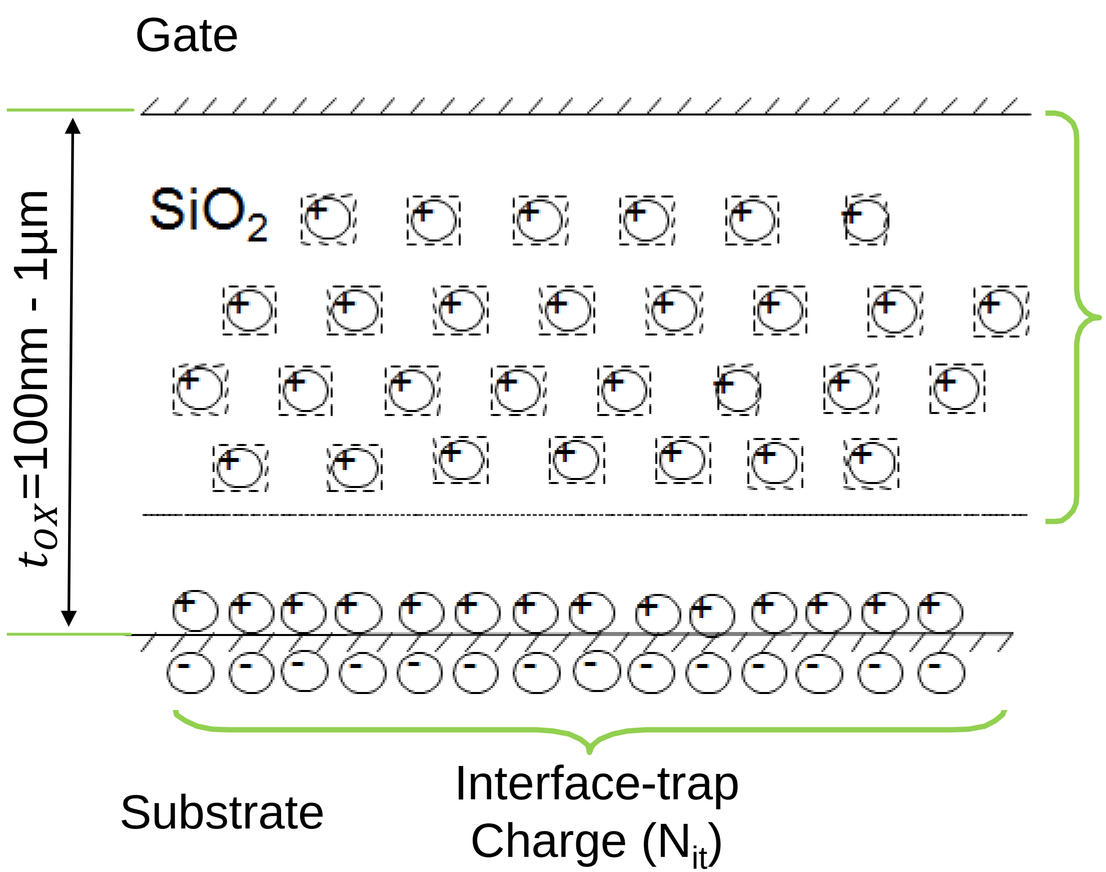
- **Size W/L= 690/15**

Model	3CM		I_{ZTC}		Accumulated Dose (Gy)
	A (mV/Gy)	n	A (mV/Gy)	n	
100nm_W8	1.244	1	1.23	1.17	295.11
400nm_IMPL_W5	65.378	0.8840	65.507	0.8847	55.05
400nm_IMPL_W7	77.098	0.8451	77.149	0.8446	55.06
400nm_IMPL_W8	65.876	0.834	65.984	0.835	57.34
1µm_IMPL_W4	202.867	0.789	203.220	0.780	49.36

- 3 CM does not improve the results $N_{ot} >> N_{it}$

Experimental results: Three current Method (3CM)(VII)



$N_{ot} >> N_{it}$

Thermal compensation: Two current Method (2CM)

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- **Thermal compensation**

$$\Delta|V_T|(T)=\Delta|V_T^0|+\alpha_{|V_T|}\Delta T$$

For I_1 and I_C

$$\Delta V_{S1}(T)=\Delta V_{S1}^0+\alpha_1\Delta T$$

$$\Delta V_{SC}(T)=\Delta V_{SC}^0+\alpha_C\Delta T$$

$$\Delta T=\frac{(\Delta V_{SC}-\Delta V_{S1})-(\Delta V_{SC}^0-\Delta V_{S1}^0)}{\alpha_C-\alpha_1}$$

$$\Delta\left|V_T^0\right| \sim \Delta\left|V_{S1}^0\right| \sim \Delta\left|V_{SC}^0\right|$$

$$\Delta T=\frac{(\Delta V_{SC}-\Delta V_{S1})}{\alpha_C-\alpha_1}$$

From the equation for $\Delta V_{S1}(T)$ and ΔT

$$\Delta V_{S1}^0=\Delta V_{S1}-\frac{\Delta V_{SC}-\Delta V_{S1}}{1-\dfrac{\alpha_C}{\alpha_1}}$$

[Carvajal et al, 2011]

Experimental results: Two current Method (2CM)

- Size 300/50 → small I_{ZTC}
- If I_{ZTC} does not change α^0_{S1} → zero.
- If I_{ZTC} changes α^0_{S1} → influence ΔI_{ZTC}
- 5 different temperatures : 10ºC, 20ºC, 30ºC, 40ºC and 50ºC
  - **10 μA**
  - ***I_{ZTC}***
  - ***2CM*** *(I_C~4* I_{ZTC} and I_1~20* I_{ZTC})*, with I I_{ZTC} previously known.

$$\Delta V^0_{S1} = \Delta V_{S1} \frac{\Delta V_{SC} - \Delta V_{S1}}{1 - \frac{\alpha_C}{\alpha_1}}$$

ΔI_{ZTC} → $\frac{\partial V^0_{S1}}{\partial T}$

$$\alpha^0_{S1} = \alpha'_1 \frac{\alpha'_C - \alpha'_1}{1 - \frac{\alpha_C}{\alpha_1}}$$

→

- Δ I_{ZTC} *OF:*
  - 0 %
  - 10 %
  - 50 %

Experimental results: Two current Method (2CM)(II)

- **100nm_W8 model**

Method	ΔI_{ZTC}		
	$0\%I_{ZTC}$	$10\%I_{ZTC}$	$50\%I_{ZTC}$
	α (mV/ºC)	α (mV/ºC)	α (mV/ºC)
10uA	-0.49±0.11	-0.6±0.1	-1.53±0.09
I_{ZTC}	0.001±0.117	-0.11±0.12	-0.6±0.1
2CM	0.00±0.00	-0.07±0.10	-0.3±0.1

Results: Thermal Dependence (2CM) (III)

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- **400nm_IMPL_W5 model**

Method	ΔI_{ZTC}		
	$0\% I_{ZTC}$	$10\% I_{ZTC}$	$50\% I_{ZTC}$
	α (mV/ºC)	α (mV/ºC)	α (mV/ºC)
10uA	-0.47±0.05	-0.76±0.05	-2.33±0.06
I_{ZTC}	0.02±0.04	-0.24±0.04	-1.53±0.06
2CM	0.00±0.00	-0.16±0.14	-0.78 ±0.16

- **400nm_IMPL_W7 model**

Method	ΔI_{ZTC}		
	$0\% I_{ZTC}$	$10\% I_{ZTC}$	$50\% I_{ZTC}$
	α (mV/ºC)	α (mV/ºC)	α (mV/ºC)
10uA	-0.19±0.03	-0.45±0.03	-1.80±0.03
I_{ZTC}	0.02±0.03	-0.23±0.03	-1.49±0.03
2CM	0.00±0.00	-0.12±0.12	-0.74 ± 0.18

- **400nm_IMPL_W8 model**

Method	ΔI_{ZTC}		
	$0\% I_{ZTC}$	$10\% I_{ZTC}$	$50\% I_{ZTC}$
	α (mV/ºC)	α (mV/ºC)	α (mV/ºC)
10uA	-0.29±0.07	-0.56±0.07	-1.98±0.07
I_{ZTC}	0.01±0.08	-0.24±0.07	-1.49±0.07
2CM	0.00±0.00	-0.14±0.15	-0.77±0.16

Results: Thermal Dependence (2CM) (IV)

- **1µm_IMPL_W4 model**

Method	ΔI_{ZTC}		
	$0\%I_{ZTC}$ α (mV/ºC)	$10\%I_{ZTC}$ α (mV/ºC)	$50\%I_{ZTC}$ α (mV/ºC)
10uA	-0.63±0.05	-1.22±0.05	-4.24±0.07
I_{ZTC}	0.04±0.05	-0.48±0.04	-3.16±0.06
2CM	0.00±0.00	-0.32±0.21	-1.55±0.22

Conclusion

- 3CM does not improve the linearity in RADFETs. This is could be caused because $N_{ot} >> N_{it.}$
- 3CM seems fit slightly better with transistors with t_{OX}100nm and size 690/15.
- 2CM solves the thermal dependence better than the I_{ZTC} procedure with shift of the zero thermal current, for the five studied model of RADFET, for both sizes.

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Thank you very munch for your attention

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