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# Radiation hardness of test structures fabricated by Canberra as X-ray Silicon Detectors

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- Irradiation and measurements of test structures produced by Canberra
- Structures under investigation: square GCD, MOS capacitor
- Current & Capacitance - Voltage (I-V & C-V) characteristics
- Method:
  - Irradiate the structure at one dose
  - measure C-V, G-V, I-V, TDRC
  - increase the dose
  - continue the procedure up to 100MGy
  - extract  $N_{it}$ ,  $N_{ox}$ ,  $J_{surf}$  and  $S_0$
- Plots of  $N_{it}$ ,  $N_{ox}$ ,  $J_{surf}$  and  $S_0$  vs. dose
- Comparison with the previous measurements
- Conclusion and outlook

Radiation damage induced by 12 keV X-rays (no bulk damage):

## **Fixed oxide charges ( $N_{ox}$ ):**

- positive charges in the oxide close to the Si-SiO<sub>2</sub> interface
- shift in gate voltage

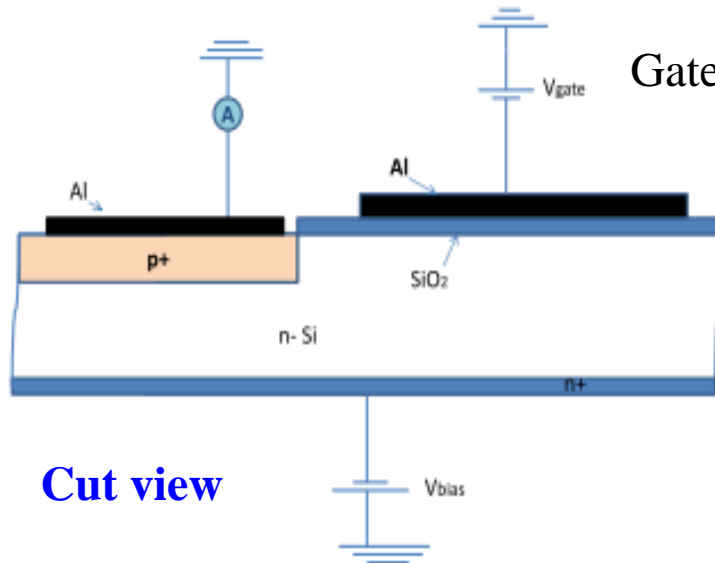
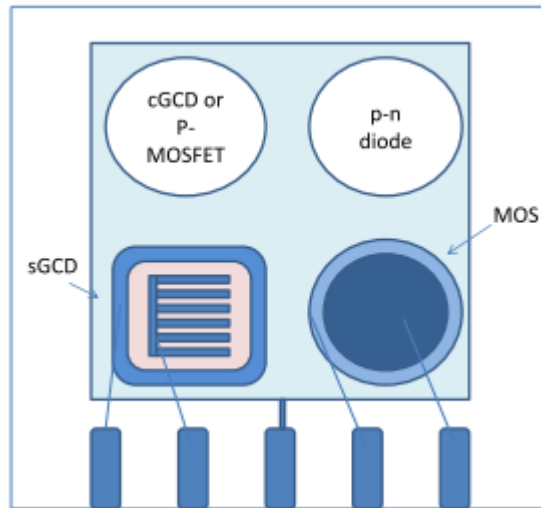
## **Interface traps ( $N_{it}$ ):**

- traps at the Si-SiO<sub>2</sub> interface
- with new levels in the silicon band gap
- can be charged or discharge (shift in gate voltage)
- contribute to the surface current

Influence of  $N_{ox}$  and  $N_{it}$  in silicon pixel sensors (relevance for AGIPD):

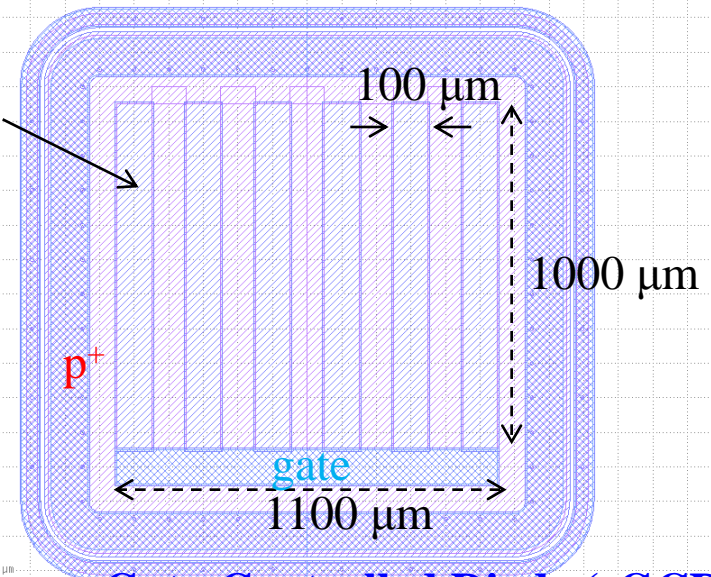
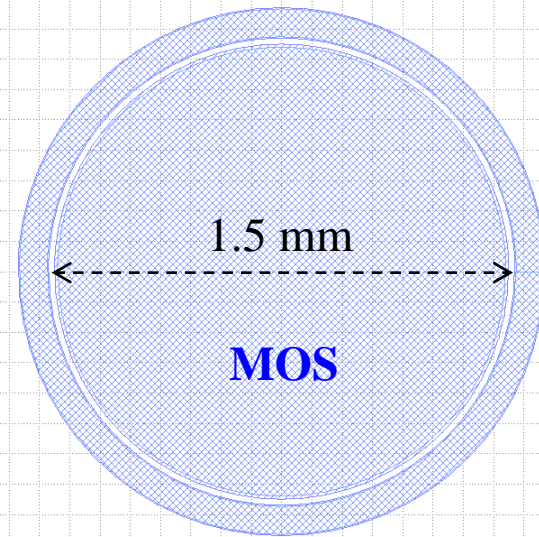
- electron accumulation layer
- increase of leakage current (power consumption) and inter-pixel capacitance (noise)
- reduction of breakdown voltage
- charge losses
- ...

## Test field

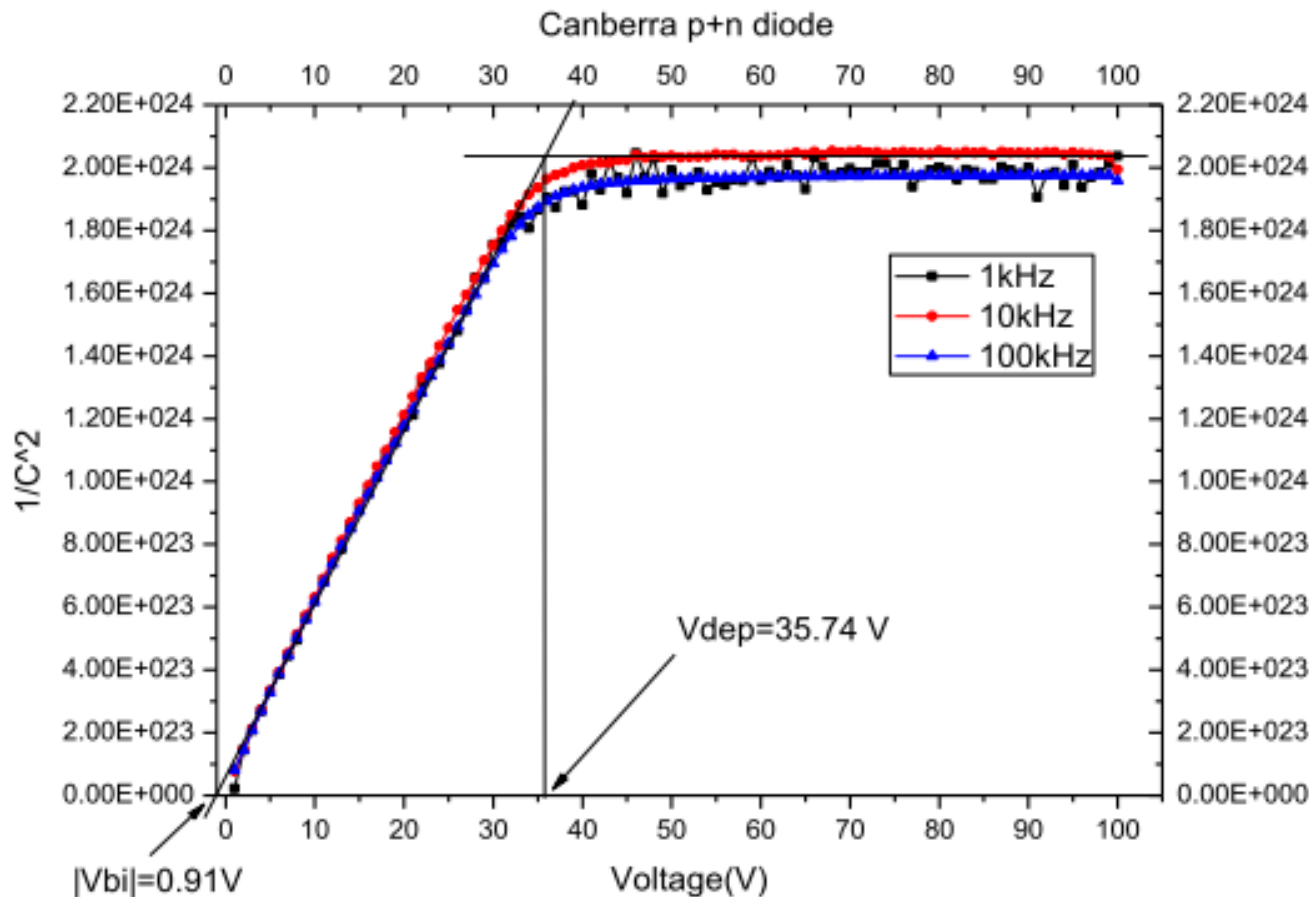


Cut view

Gate area ( $A_{\text{gate}}$ ):  
 $7.1 \cdot 10^{-3} \text{ cm}^2$



square Gate-Controlled Diode (sGCD)



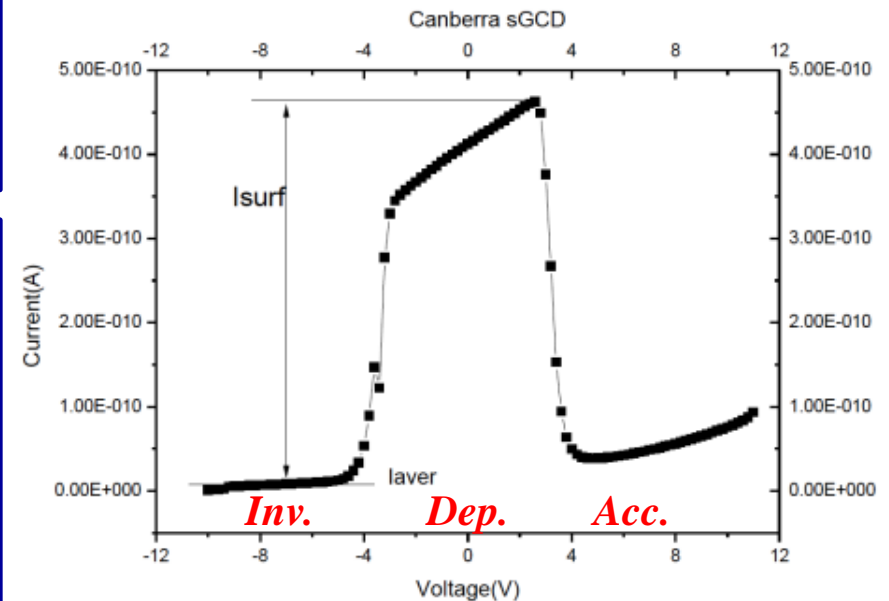
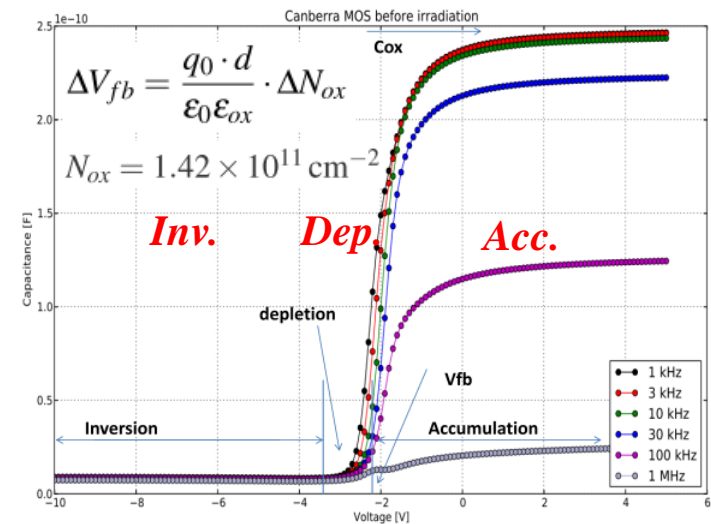
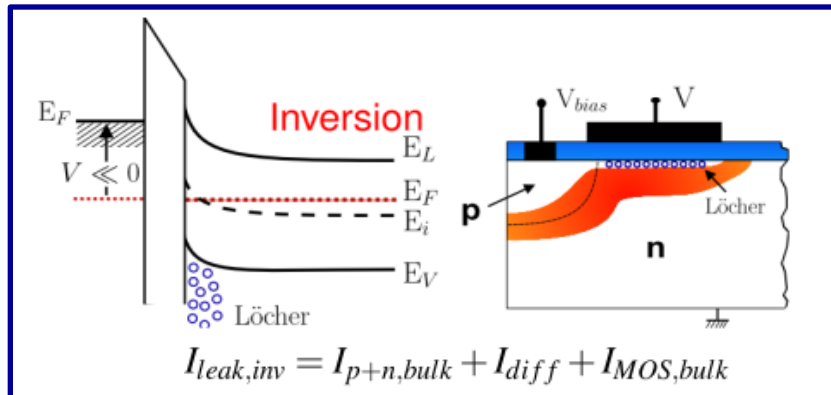
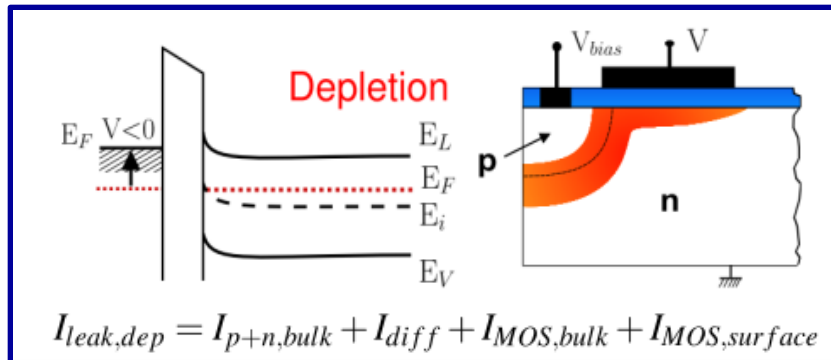
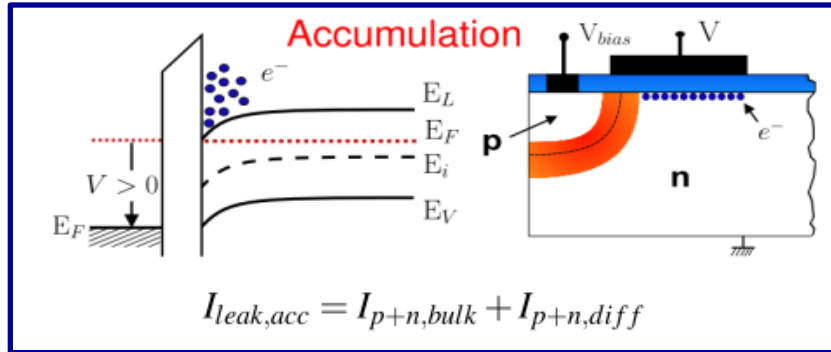
$$N_{eff} = \frac{(V_{dep} + V_{bi}) \cdot \epsilon_0 2 \epsilon_{Si}}{q_0 t_{Si}^2}$$

$$N_{eff} = 6.82 \times 10^{11} \text{ cm}^{-3}$$

Value calculated according to the inversion capacitance of MOS:

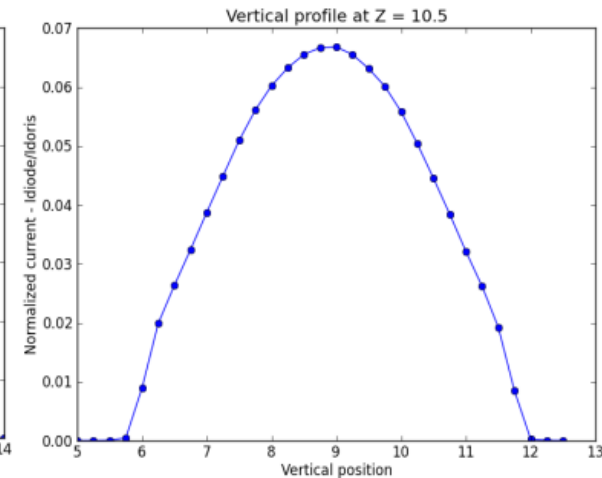
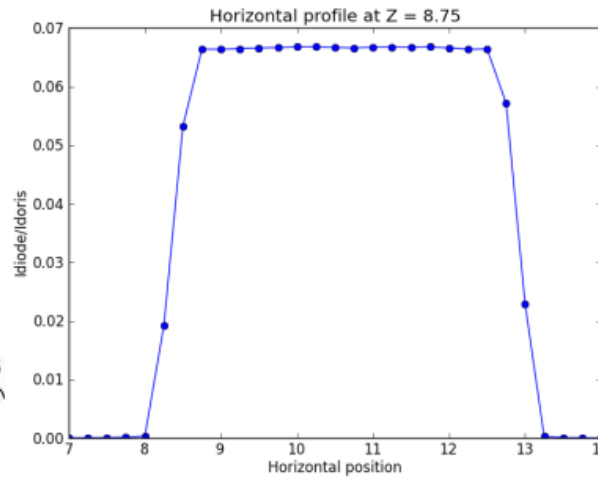
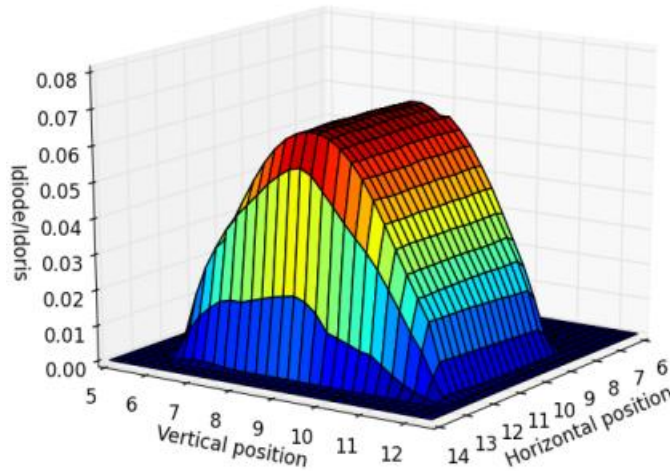
$$N_d = 6.7 \times 10^{11} \text{ cm}^{-3}$$

# Current & Capacitance Characteristics





# Irradiation setup: DORIS F4



## Beam profile:

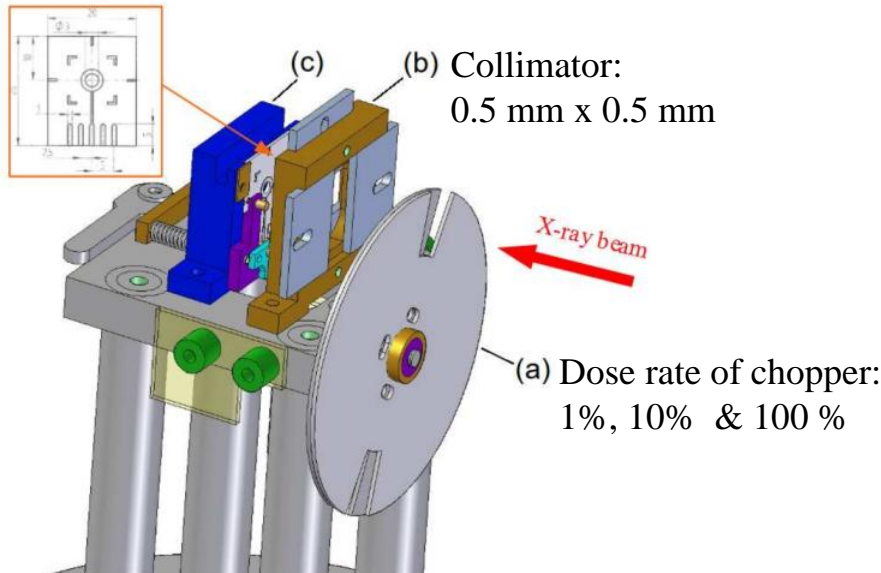
- Horizontal dis.: 4-5 mm (uniform)
- Vertical dis.: 4 mm (FWHM of Gaussian)

## Dose determination:

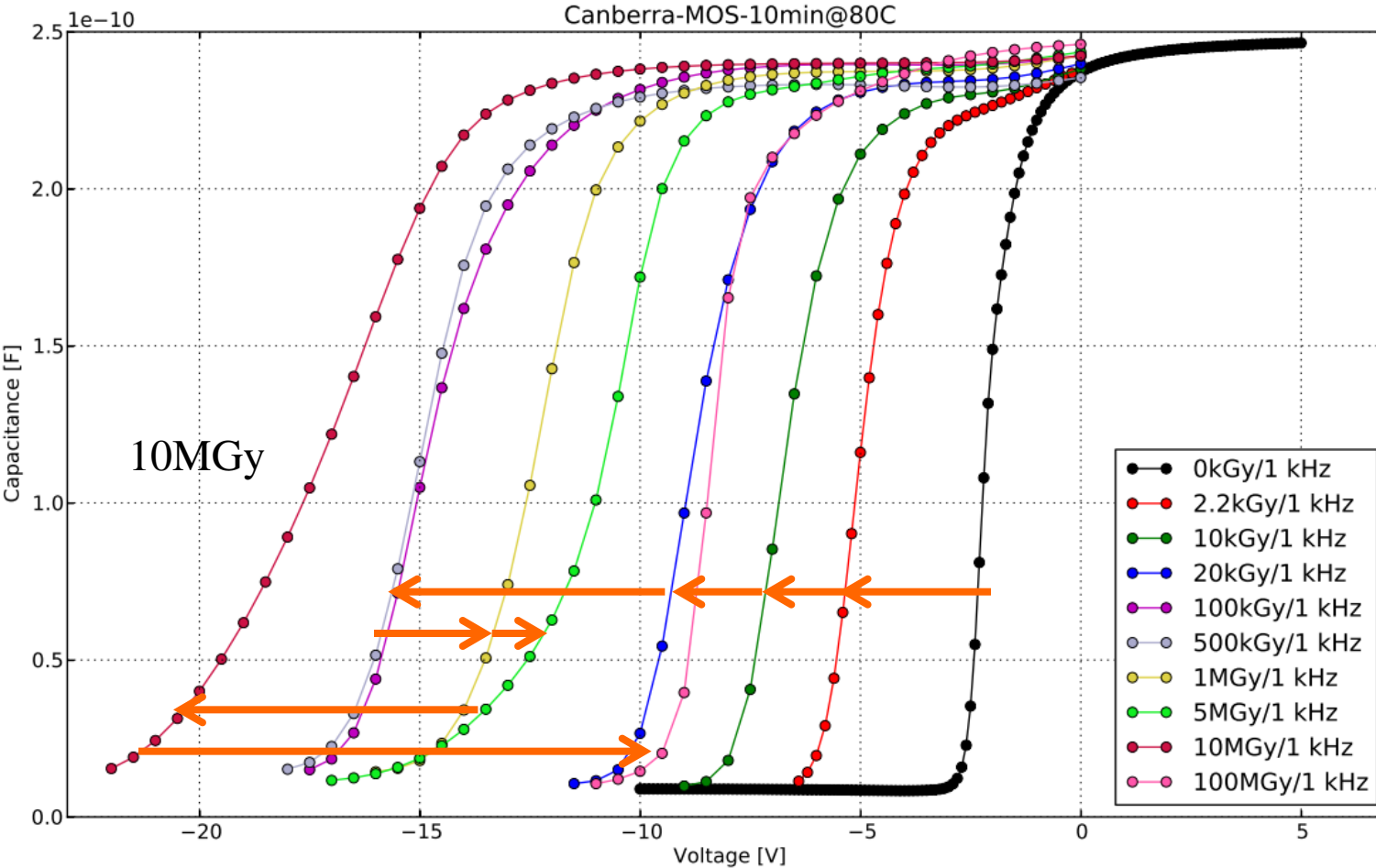
$$Dose = \frac{3.6eV \cdot R}{q_0 \rho_{Si} d_{Si} A} \iiint_{\Delta x, \Delta y, t_{irra}} J_{diode}(x, y) \cdot dx dy dt$$

$$R = \frac{\frac{E_{Insulator}}{\rho_{Insulator} \cdot d_{Insulator}}}{\frac{E_{Si}}{\rho_{Si} \cdot d_{Si}}} : \text{ratio of dose in Si and in SiO}_2$$

$$Dose \sim \frac{1}{Vx * Step} \quad \text{for irradiating entire test field}$$



# C-V curves after 10min@80 °C



**Fixed oxide charges:**

-> shift of flatband voltage

**Interface traps:**

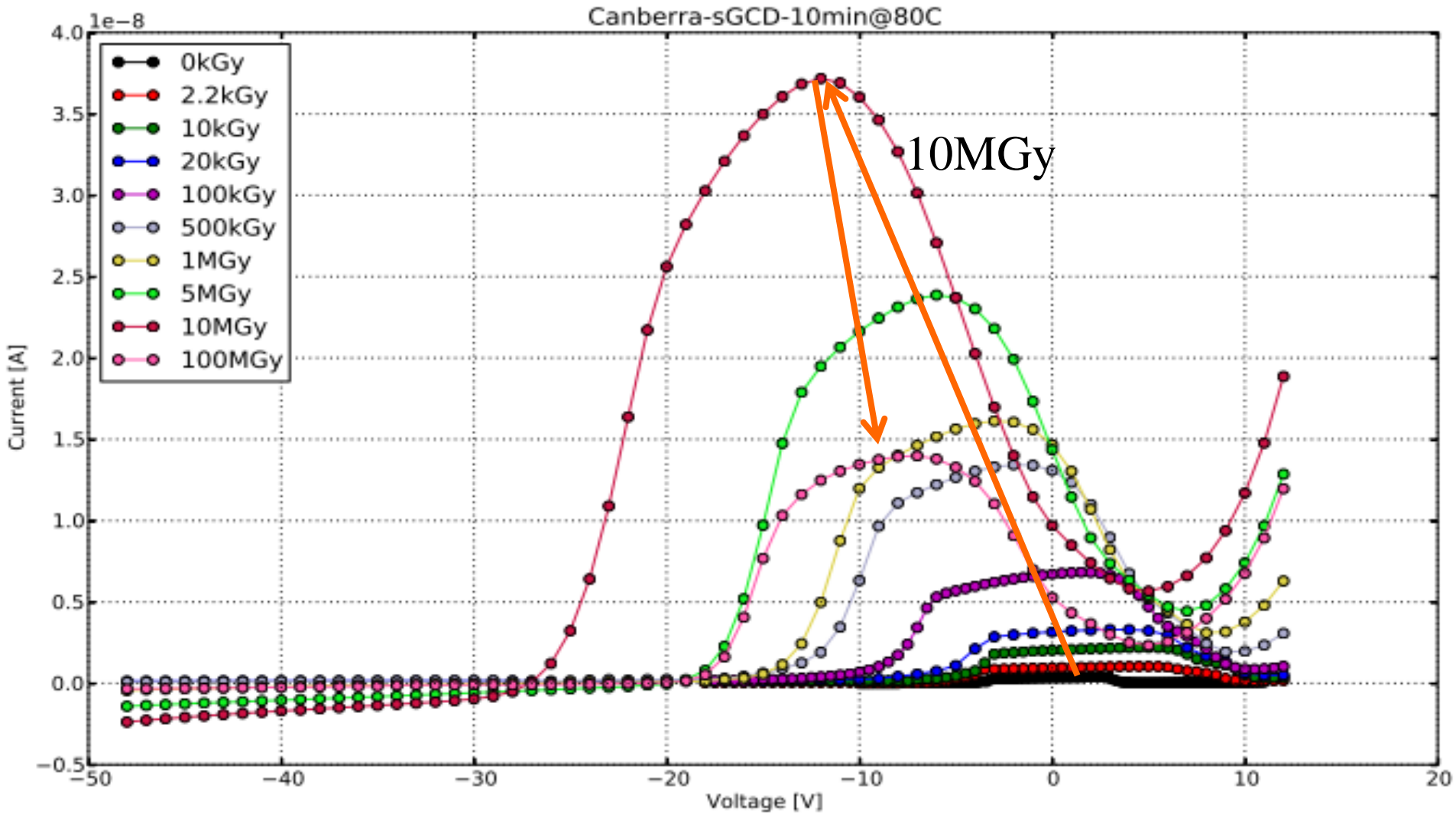
-> shift of C/G-V curves

-> change of the slope

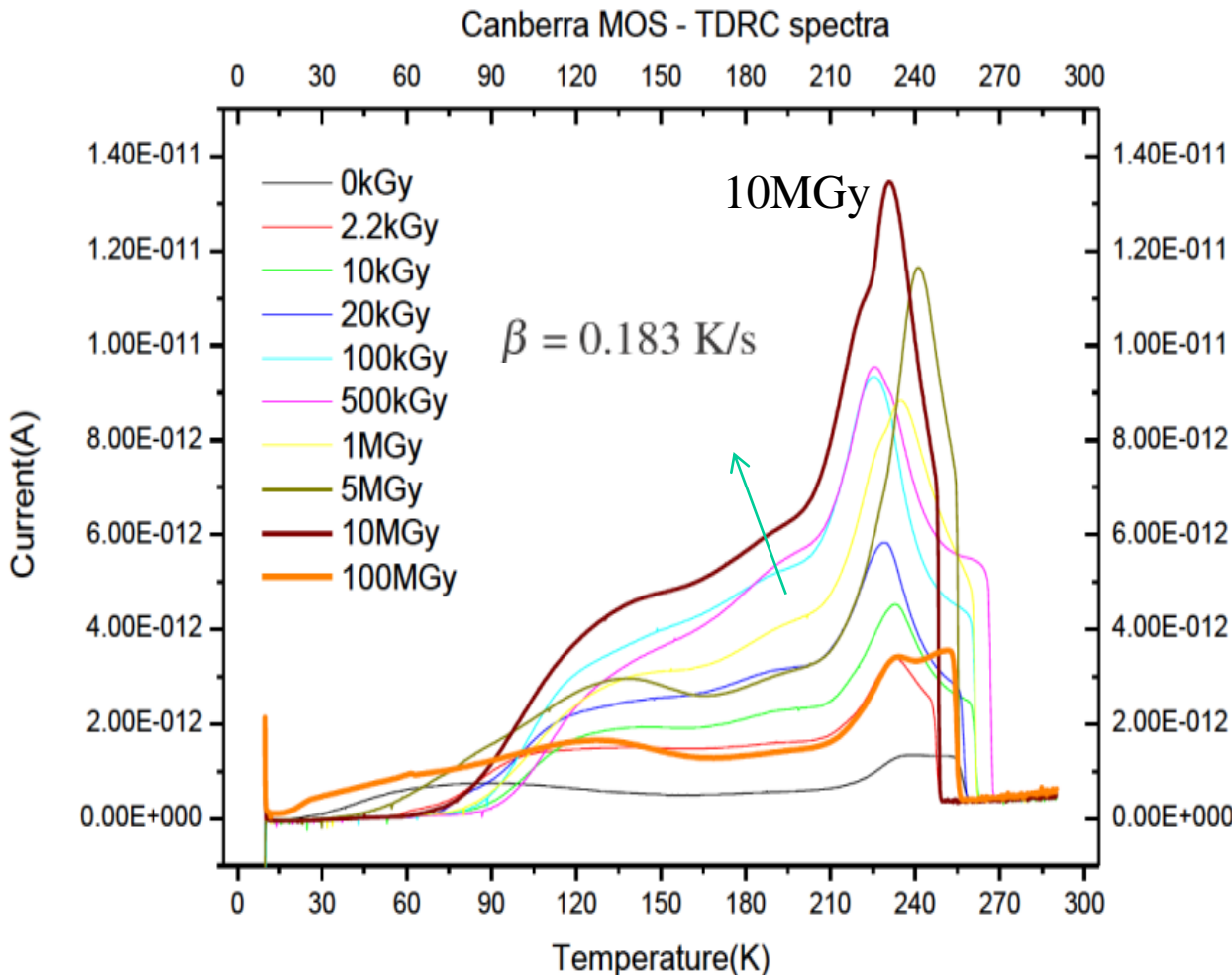
$$\Delta V_{fb} = \frac{q_0 \cdot d}{\epsilon_0 \epsilon_{ox}} \cdot \Delta N_{ox}$$



# I-V curves after 10min@80 °C



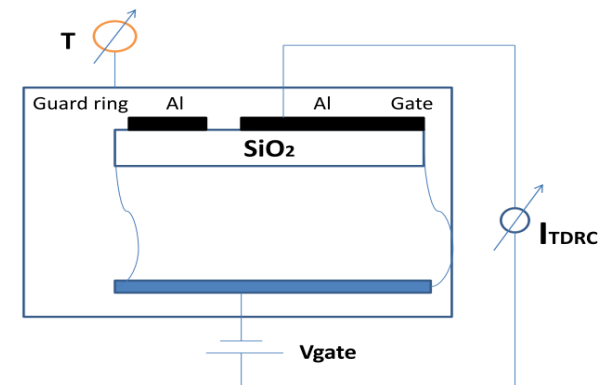
-Increase of  $I_{leak}$  after irradiations caused by Nit.



(reason for deep trap shifts not clear)

## Procedure:

- (1) Bias the MOS capacitor to accumulation-> fill interface traps with electrons;
- (2) Cool down the device to 10K-> freeze traps;
- (3) Reverse the bias and heat up the device till 290K->trapped charges at Si-SiO<sub>2</sub> interface get released.

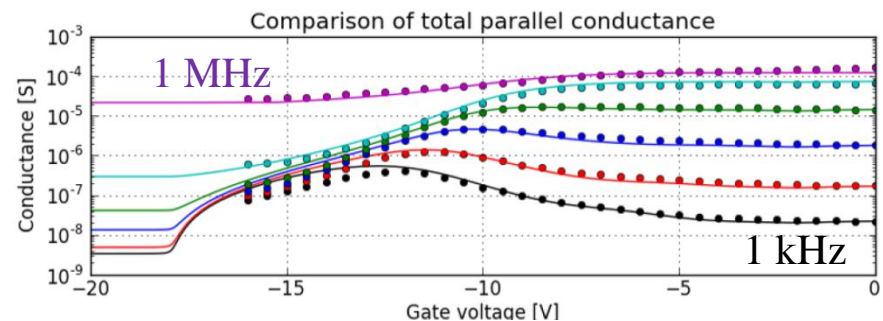
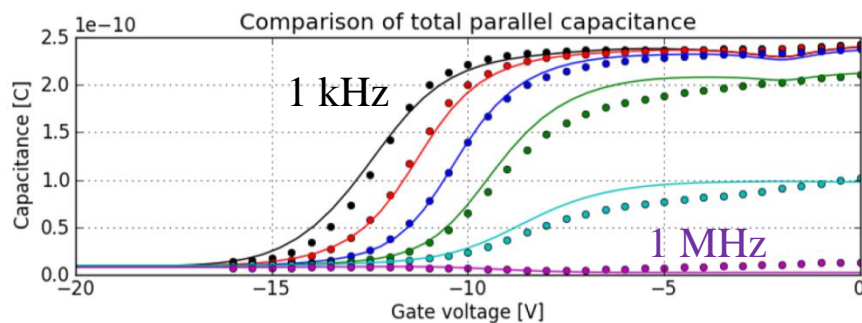
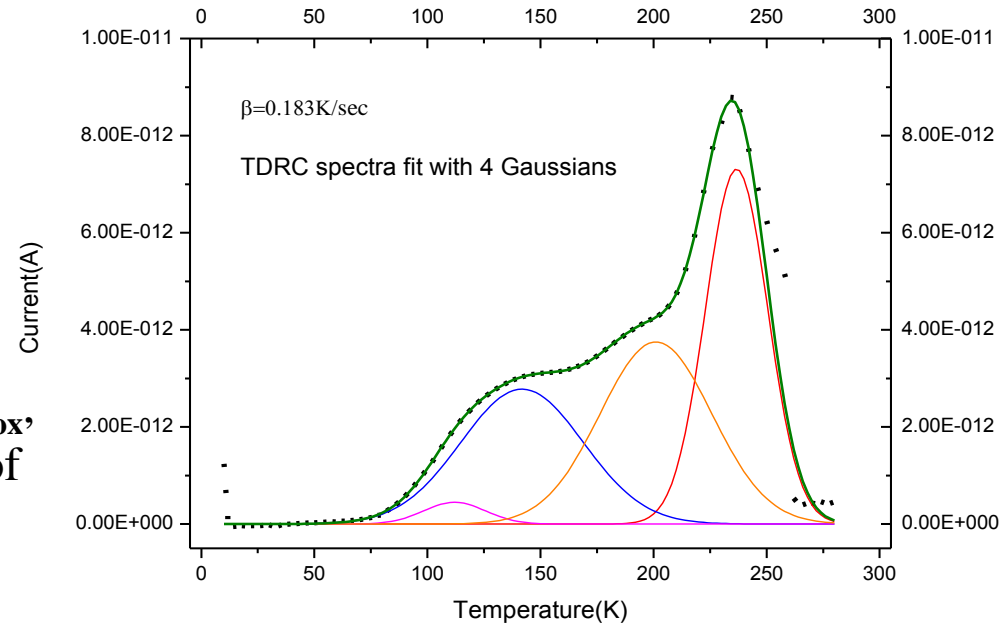


# Extract $N_{ox}$ , $N_{it}$ and $I_{surf}$

$$N_{it} = \frac{1}{A_{gate} q_0} \int_0^{250} \frac{I_{TDRC}(T)}{\beta} dT$$

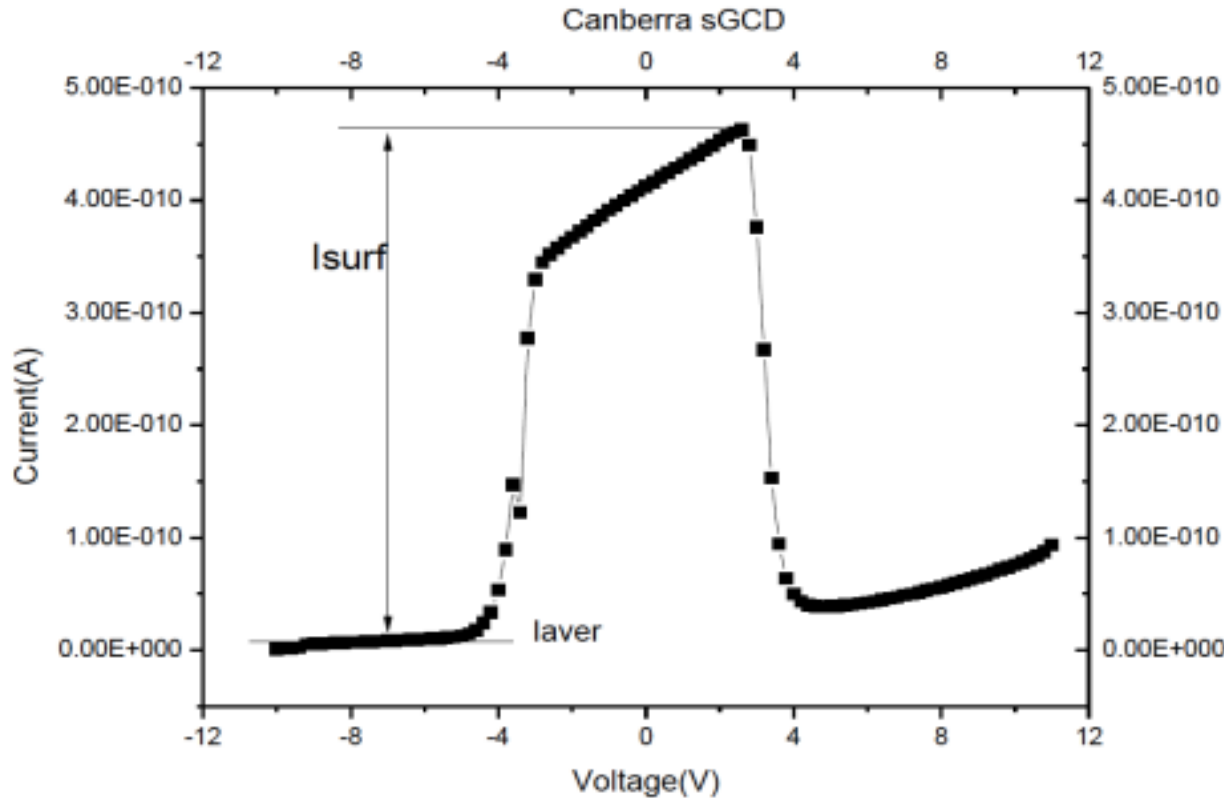
$$N_{ox} = \frac{Q_{ox} q_0^{-1}}{A_{gate}}$$

- Mathcad program for dose 1MGy after annealing for 10min@80°C.
- Input the TDRC signal of each trap and  $N_{ox}$ , change the effective capture cross section of electrons and try to find the best fit.
- The program calculates the total  $N_{it}$ .



1 MGy after 10min@80°C, 6 frequencies (1, 3, 10, 30, 100, 1000 kHz) shown in the plot

# Extract $N_{ox}$ , $N_{it}$ and $I_{surf}$



$-I_{surf}$  caused by generation of charge carriers at the Si-SiO<sub>2</sub> interface.

$$I_{surf} = I_{max} - I_{aver}$$

$$I_{surf} = q_0 n_i S_0 A_{gate} \quad (n_i = 10^{10} \text{ cm}^{-3})$$

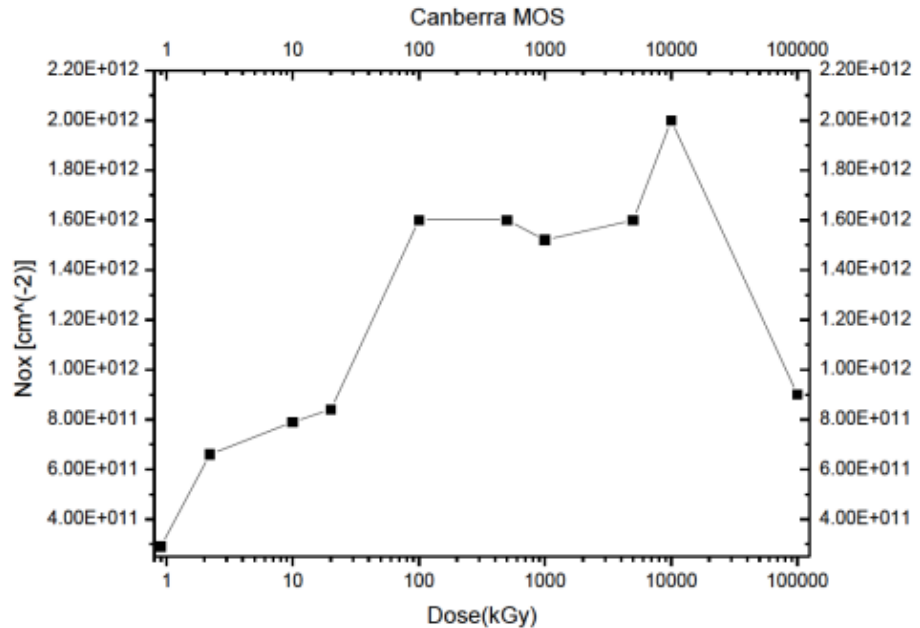
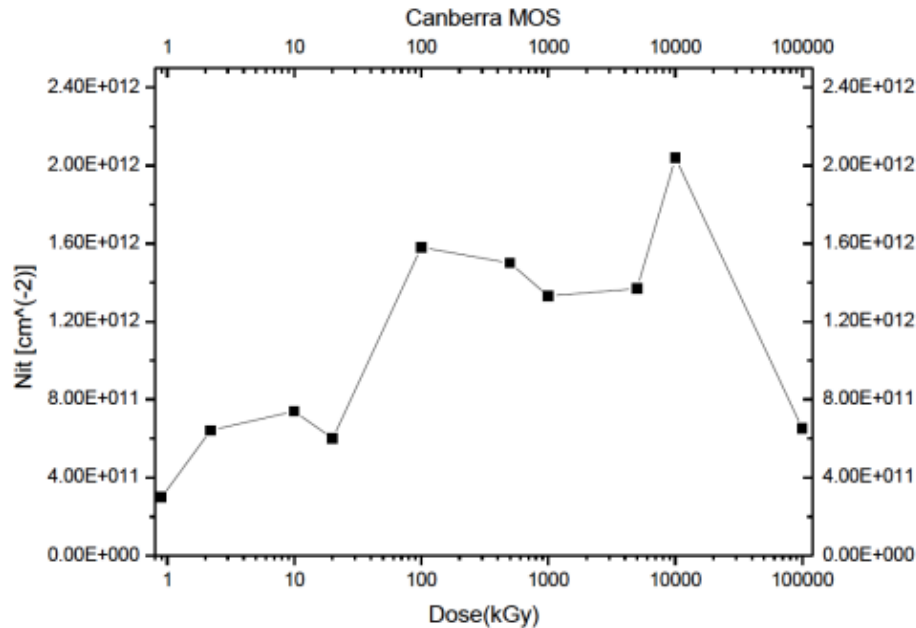
$$J_{surf} = \frac{I_{surf}}{A_{gate}}$$

$$S_0 = \sigma v_{th} \pi k_B T D_{it}$$



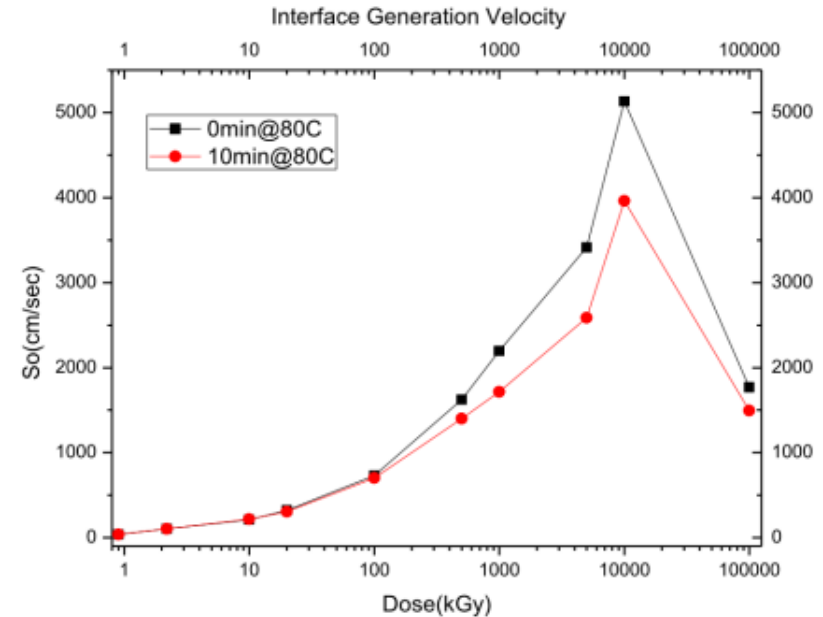
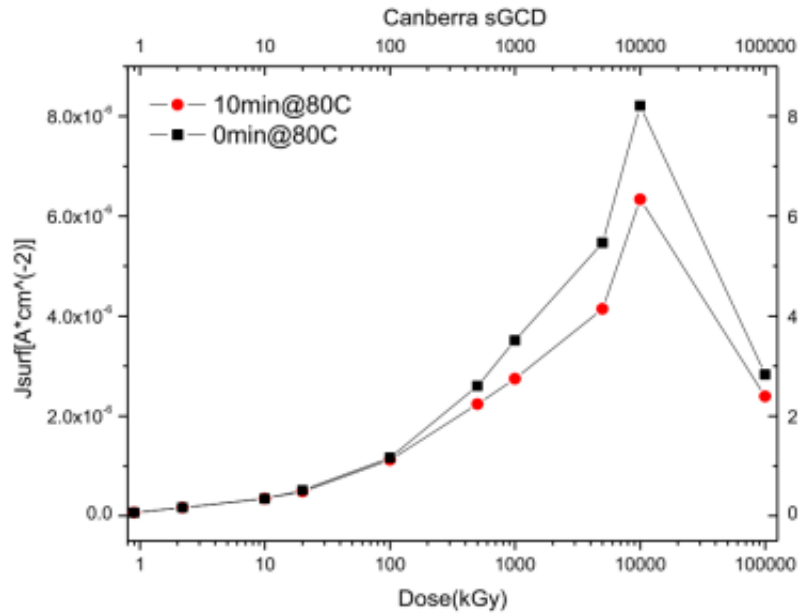
Interface state density at the midgap

# $N_{ox}$ , $N_{it}$ vs dose



## Conclusions:

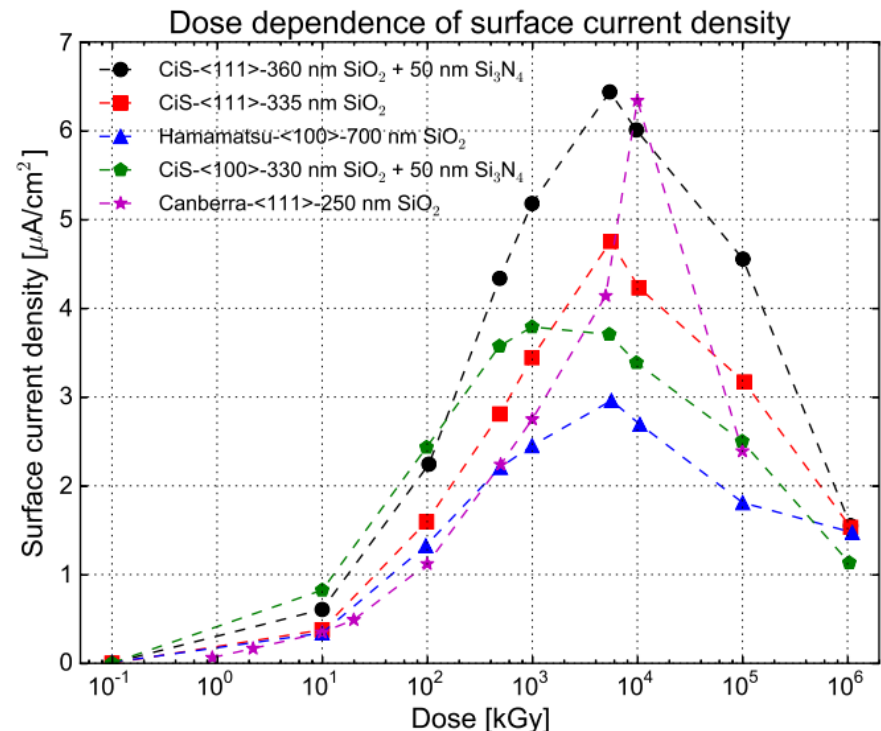
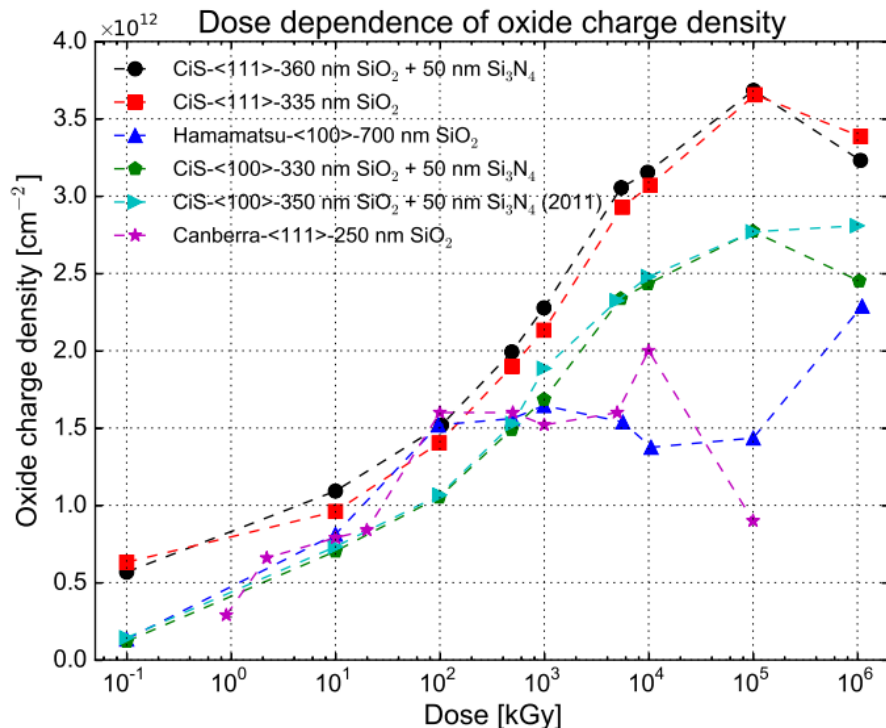
1.  $N_{it}$  and  $N_{ox}$  shows similar dose dependence
2.  $N_{it}$  and  $N_{ox}$  seem to be saturate around 100 kGy (but maximum @ 10 MGy)
3. Saturation values of  $N_{it}$  and  $N_{ox}$ :  $\sim (1.5-2.0) \times 10^{12} \text{ cm}^{-2}$



## Conclusions:

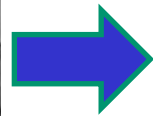
1.  $J_{\text{surf}}$  and  $S_0$  reach maximum @ 10 MGy, then decrease
2. Saturation values of  $J_{\text{surf}}$  and  $S_0$ :  $\sim 8 \mu\text{A}/\text{cm}^2$  & 5000 cm/s  
(compatible with previous results from CiS)

- In all the cases an increase of the density is observed till 10 MGy with subsequent decrease at 100 MGy for test structures from Canberra
- Strange dose dependence at high dose to be understood
- Results within similar magnitude of previous ones





*Thank you very much  
for your attention!*

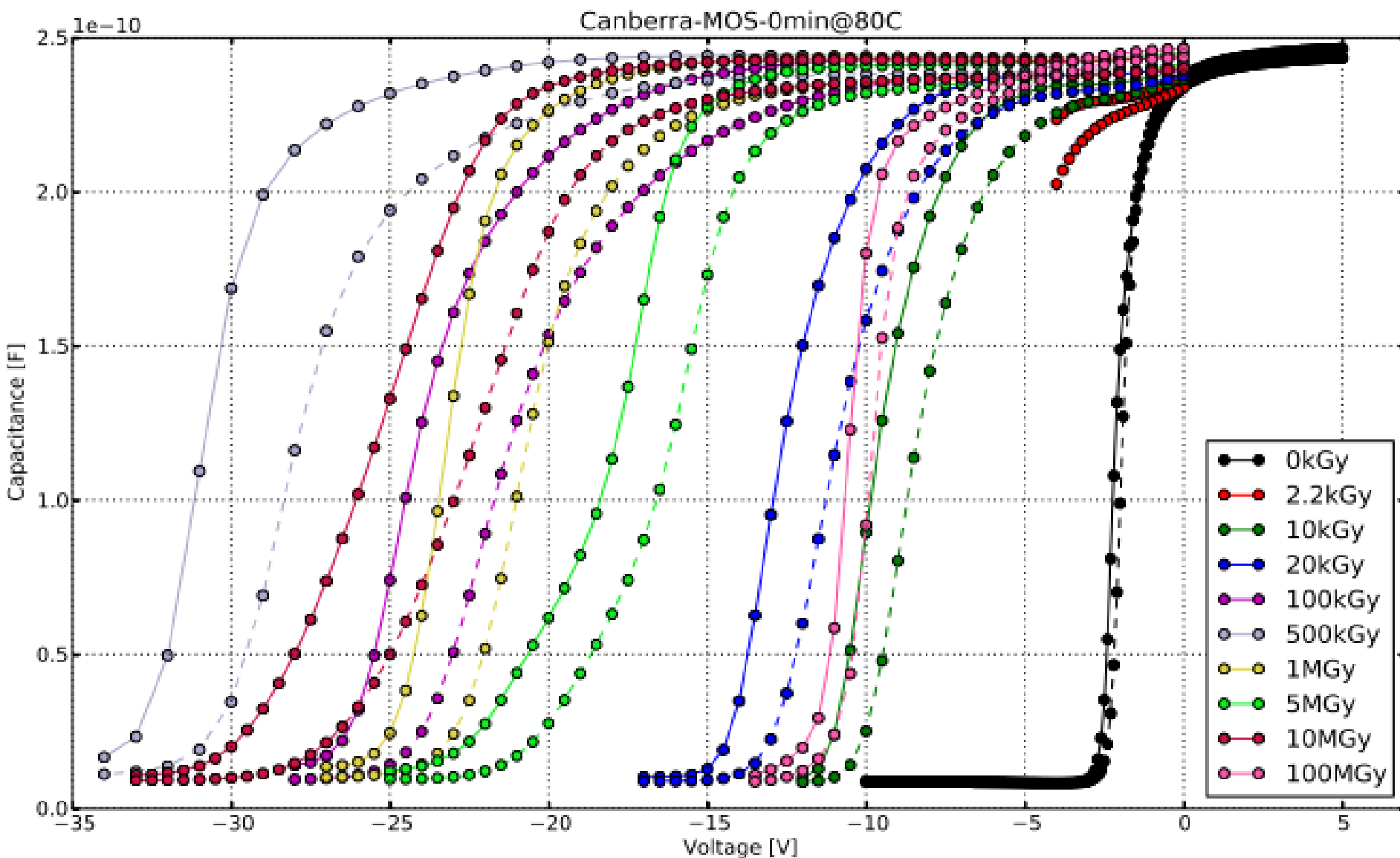


**Science emerges in Dialogue.**

**(Natural) Science = experiment + dialogue**

**Werner Heisenberg**

5 Dec1901 – 1 Feb1976



# Irradiation History

Dose (kGy)	2.2	10	20	100	500	1000	5000	$10^4$	$10^5$
Structure	145-3	147-3	147-3	145-3	145-4	145-4	145-4	146-3	145-4

