Radiation Effects Study of Components Operated at Cryogenic Temperature and Future Generations Semiconductor Devices

60 Mev Proton and Gamma Irradiation Effects on NO and RNO Deep Submicron MOSFETs Fabricated in IMEC's 0.13 μm CMOS Technology

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OUTLINE

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Goal of the project

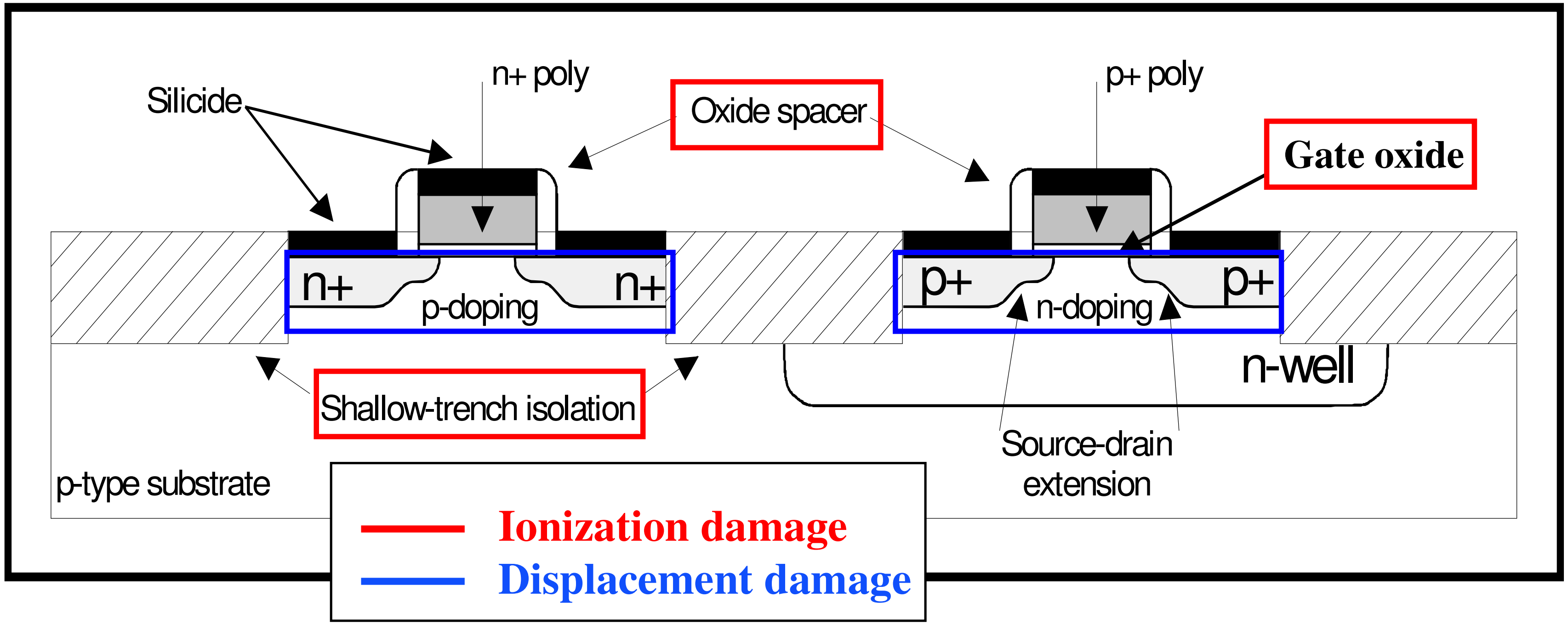
in line with the **Custom Off The Shelf (COTS) philosophy**, we investigate the impact of 60 MeV proton and gamma irradiations on the behavior of NO and RNO deep submicron MOSFETs currently fabricated at IMEC in a 0.13 μm CMOS technology with STI based isolation.

Study of the impact of irradiation **on :**

- Shallow trench isolation
- Gate oxide reliability
- Electrical device parameters

0.13 μm CMOS Technology

- Shallow trench isolation
- NO and RNO gate oxides
- n+ and p+-doped polysilicon gates (low threshold)
- source-drain extensions LDD (hot-electron effects)
- Self-aligned silicide (spacers)
- Non-uniform channel doping (short-channel effects)



Irradiation matrix

Devices

Two wafers namely **wafer 7 (NO)** and **wafer 9 (RNO)** from lot PLINE 9008. Fabricated in a 0.13 μm technology : **STI**, **2 nm gate oxide**, **150 nm polysilicon gate** and **80 nm nitride spacers.**

W =10 μm and L = 0.08 μm till 10 μm mounted in 24 pins dual-in-line packages for the irradiation under bias (V_G=1.5V)

+

Pieces of wafer with L-arrays and W-arrays for the irradiation without bias.

Electrical tests conditions

1/ $I_D(V_G)$ measurements for V_{DS}=25 mV (ohmic regime) and 1.5 V (saturation regime)
2/ $I_D(V_{DS})$ for different V_G
Measurement performed for V_{BS}=0 V;

+ Additionnal measurement with I V_{BS}I=0 to 1V
+ 1/f noise, gated diode, HF CV

Irradiation matrix

Irradiation conditions

Unbiased and biased (V_G=1.5V) 60 MeV proton and gamma irradiations were performed at the Cyclone cyclotron facility (Louvain-la-Neuve).

Proton : Two fluences typical for space applications, i.e., 10^{11} and 5.10^{11} p/cm^{-2}. The flux was 3.10^{8} p/cm^{-2}s.

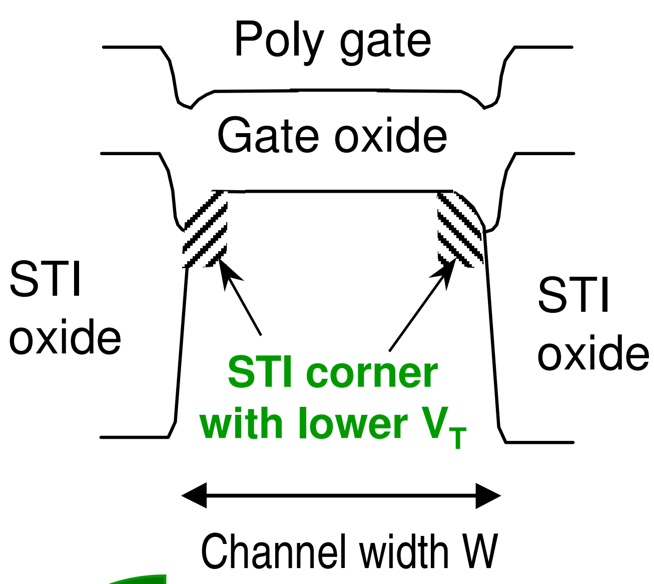
γ : Total dose of 100 krad(Si) and 13.5 krad(Si). The dose rate was 5 krad(Si)/hr.

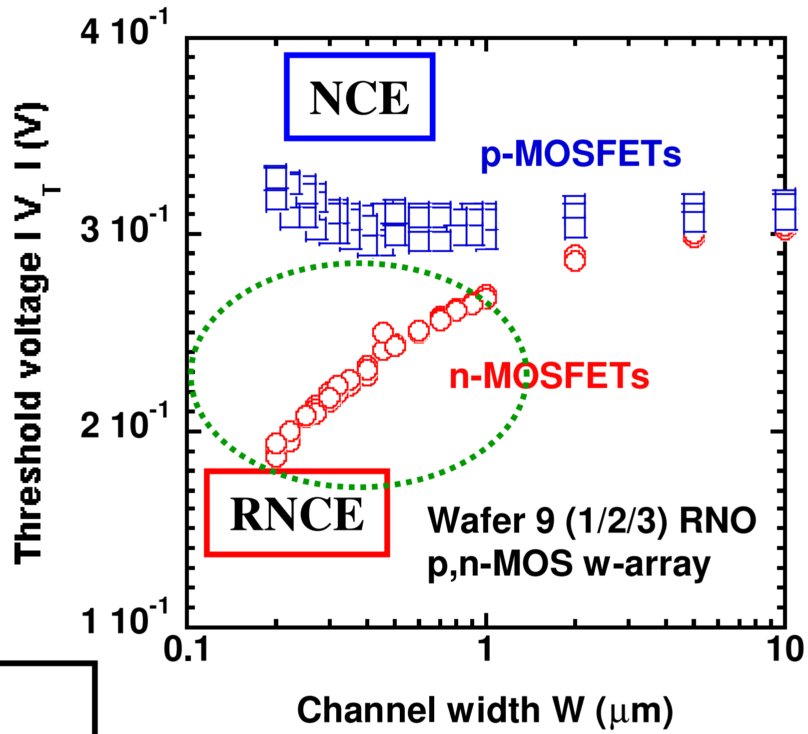
Conditions were chosen to be approximately equivalent in terms of total dose

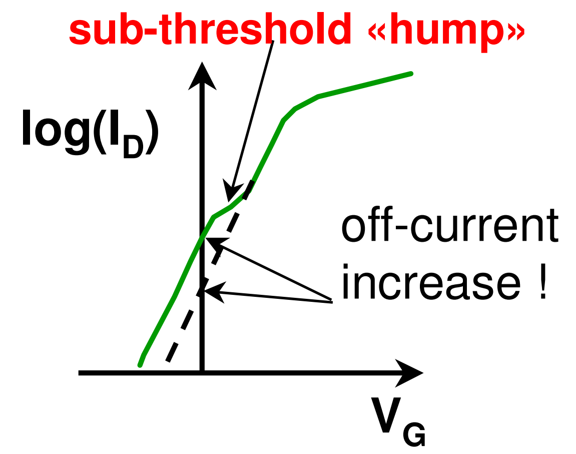
⇨ **separating the role of ionization damage from displacement damage.**

Shallow trench isolation
STI edge effects

Edge parasitic device in n-MOSFETs:

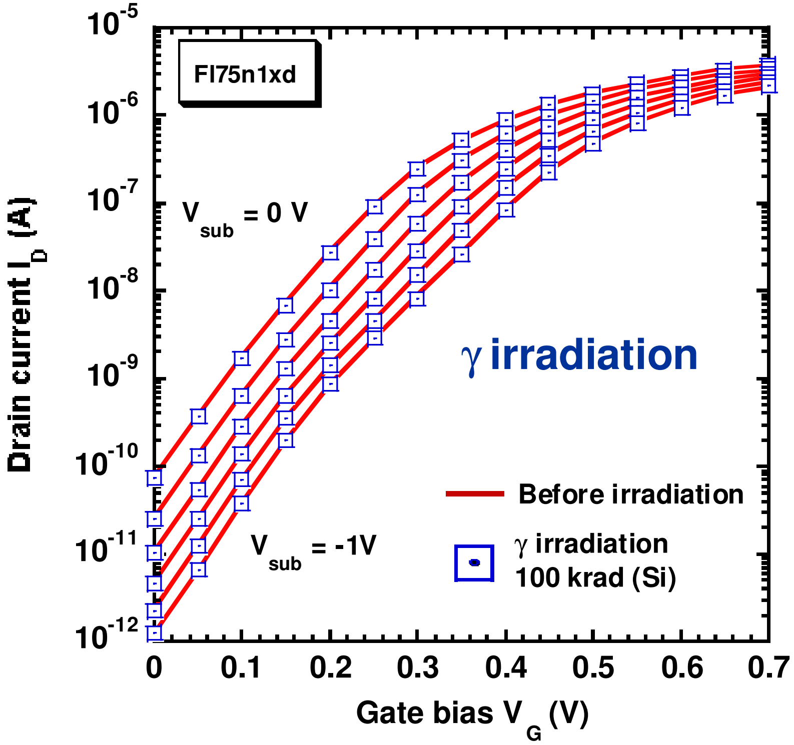


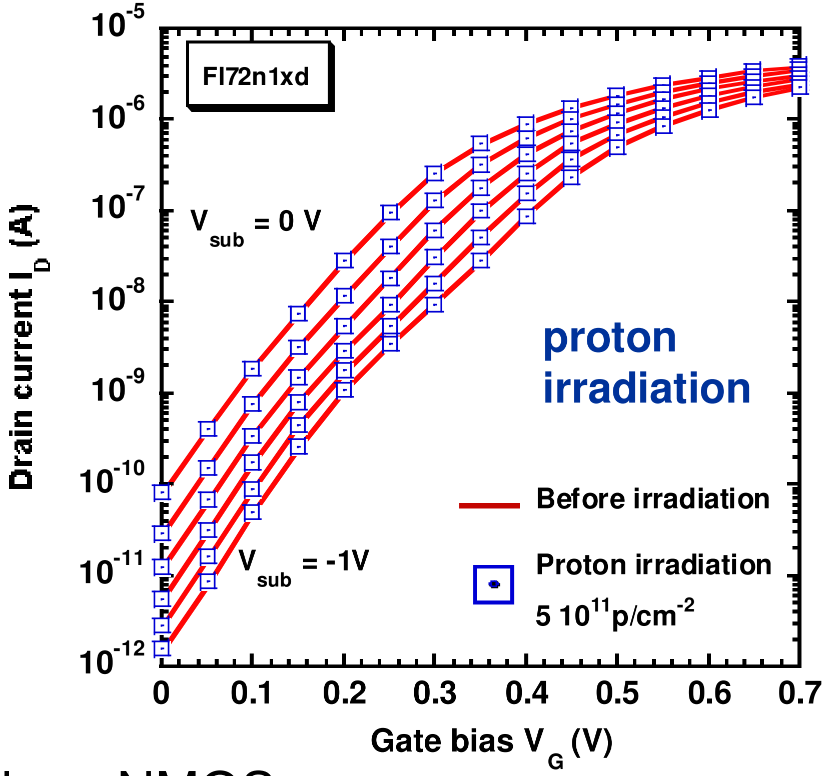




Wide and long NMOS devices can show this sub-threshold hump

No Subthreshold "hump" in IMEC STI module

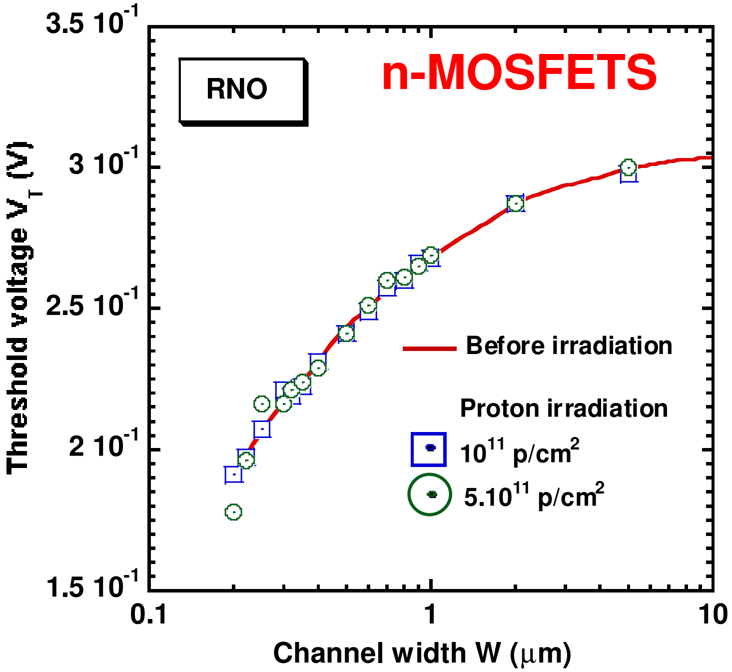


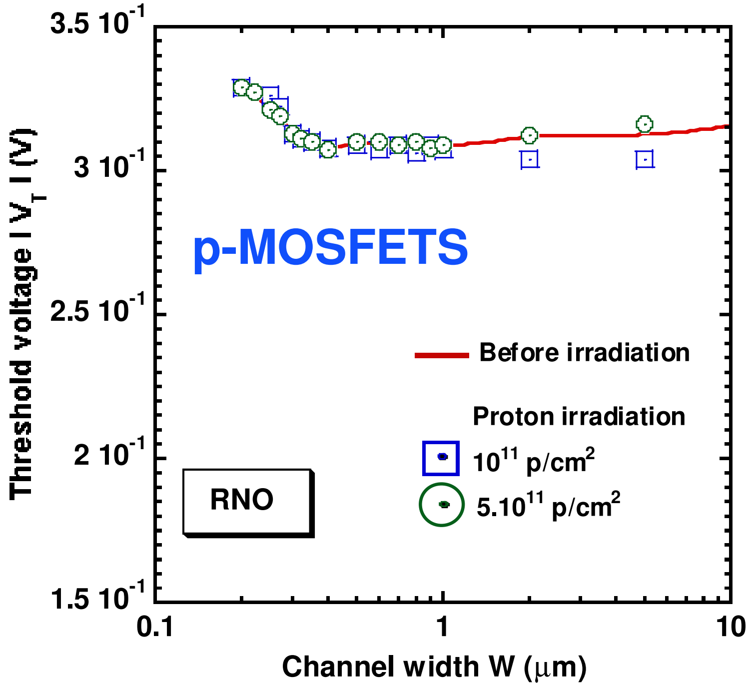


Wide and long NMOS device **(W/L=10μm/10μm)** is free of sub-threshold hump

No strong sub-threshold hump observed in IMEC STI module for n-MOS devices at high (negative) substrate bias after irradiation

Threshold voltage of W-arrays do not show evidence for radiation induced degradation

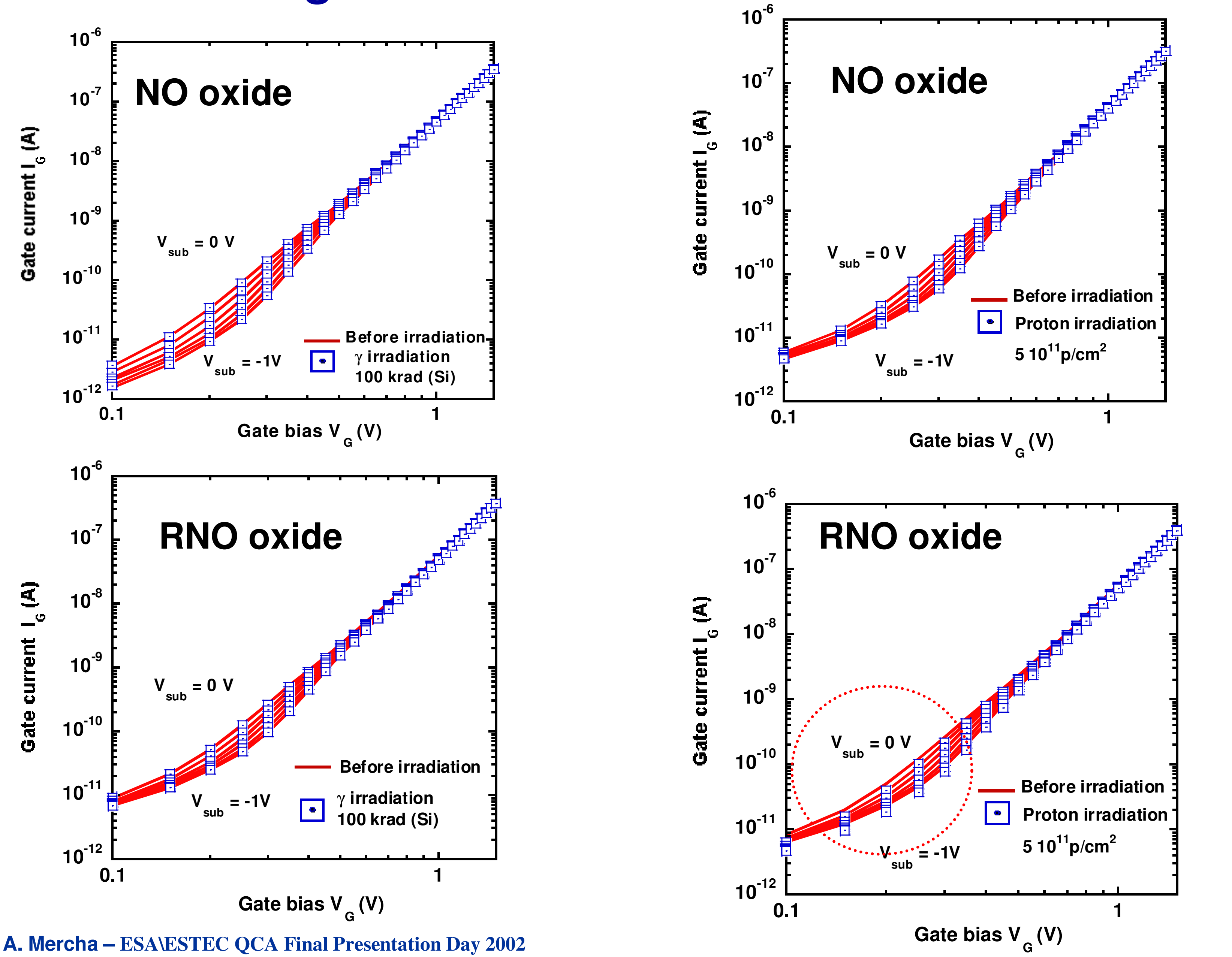




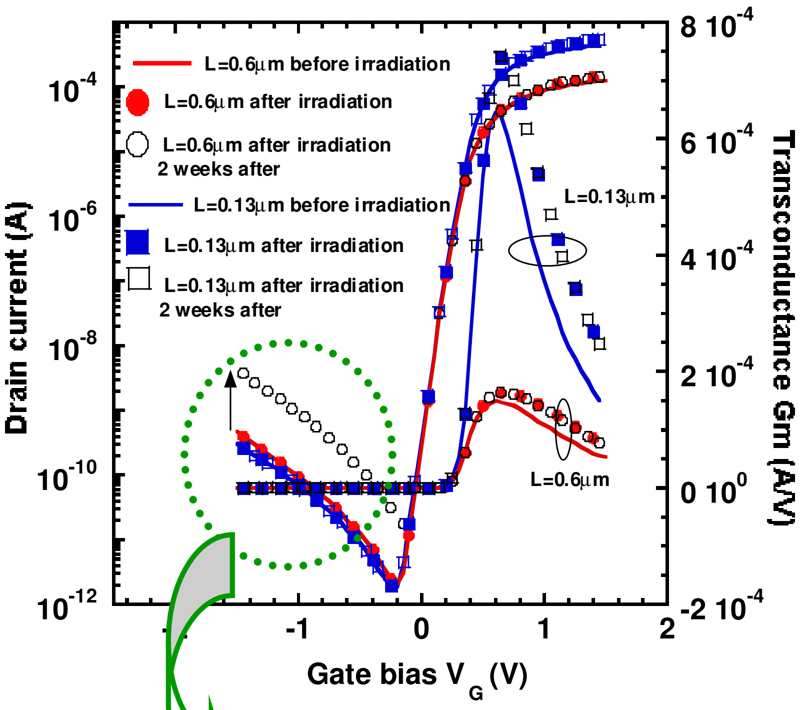
IMEC STI module is a good candidate for integration in hard technology

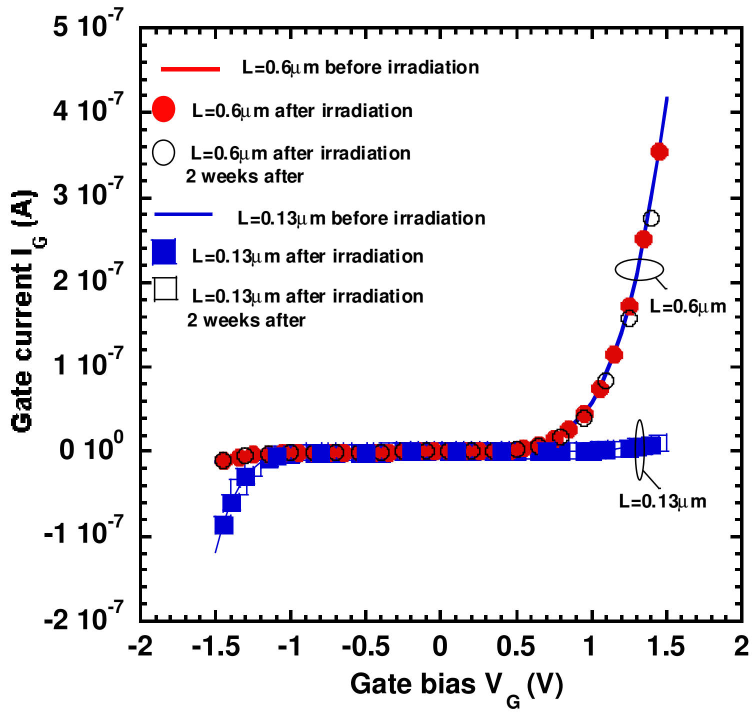
until a total dose of 100 krads

Gate current do not show evidence for radiation induced degradation



The subthreshold slope do not show evidence for interface or oxide degradation



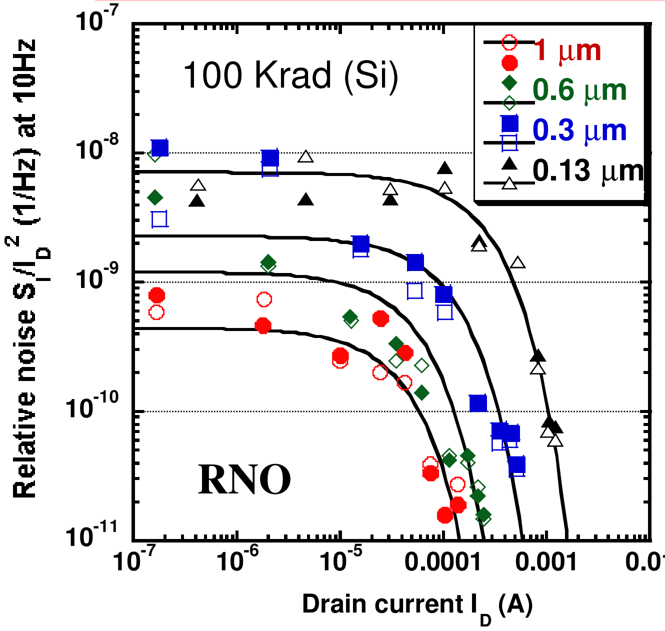


After some time gate induced drain leakage can appear

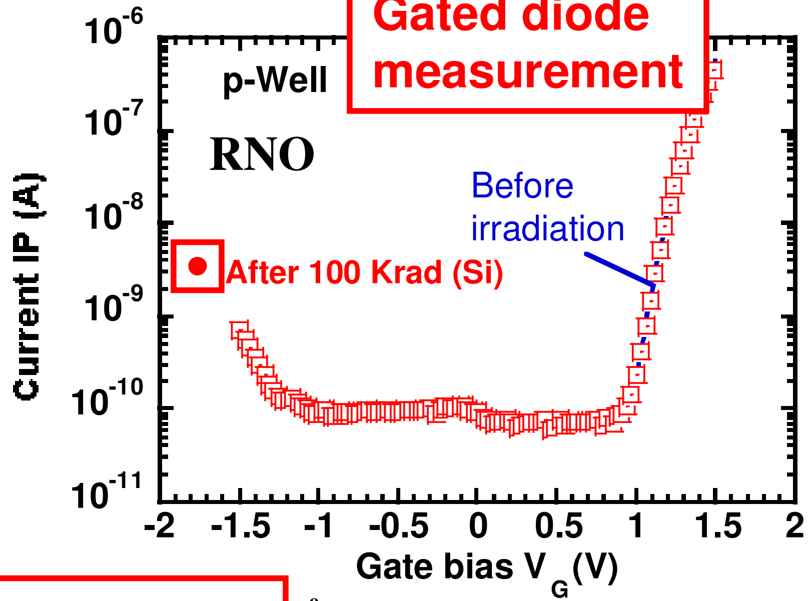
But the rest of the characteristic remains unchanged

Other techniques to assess the oxide and interface degradation

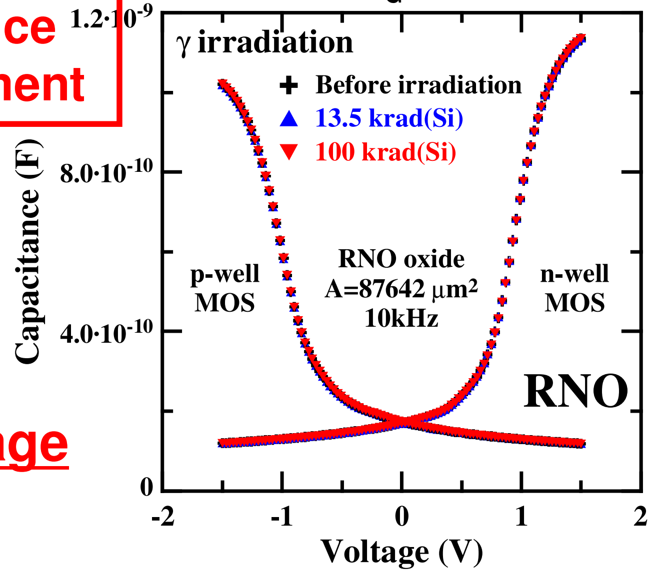
1/f noise measurement



Gated diode measurement



Capacitance measurement



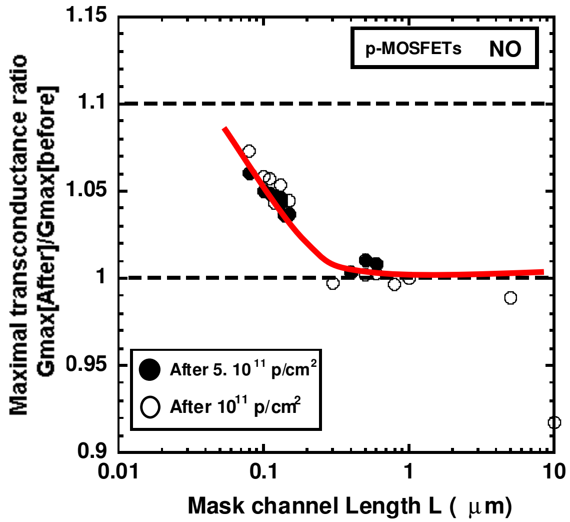
γ Irradiation
Total dose of 100krad (si)

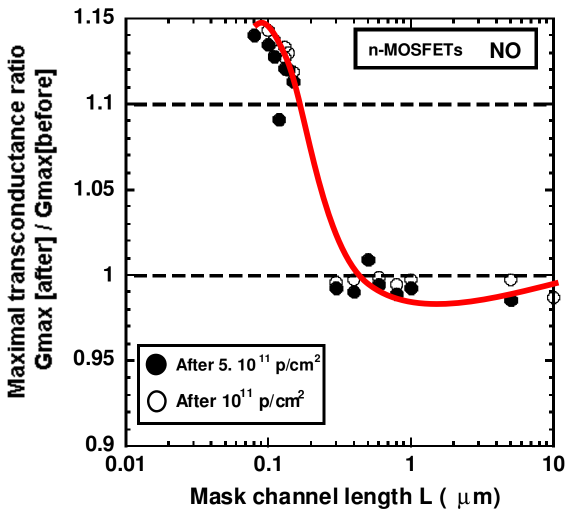
No clear evidence for ionization damage

Irradiation impact on electrical parameters

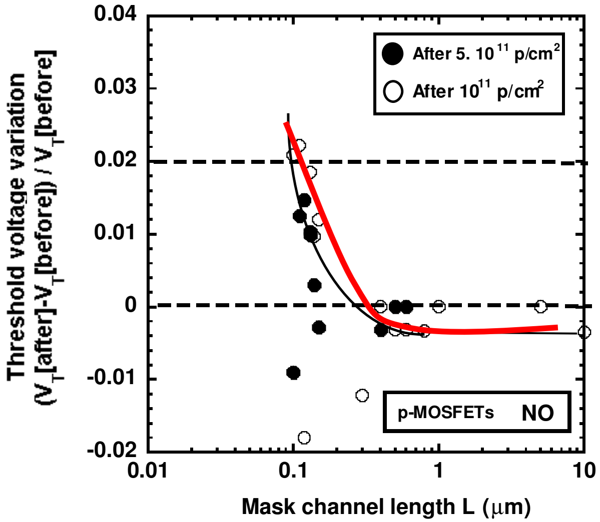
Devices irradiated under bias I V_G I=1.5V

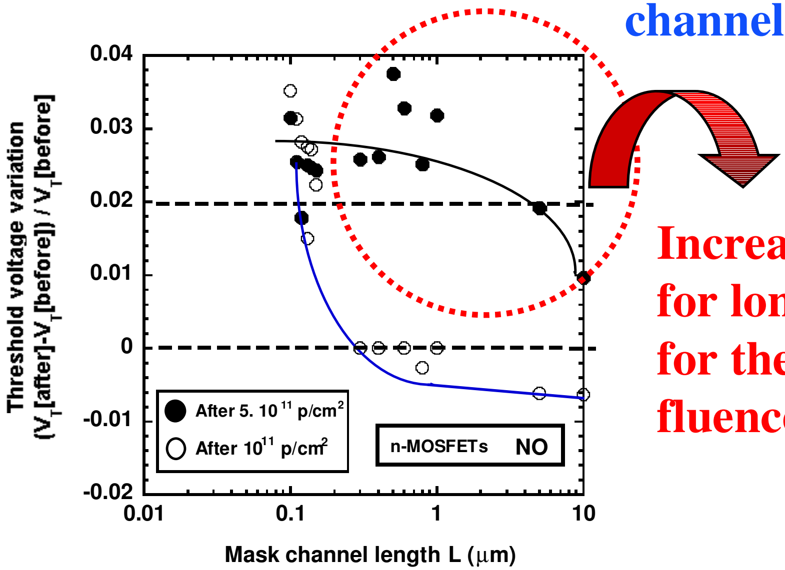
RNO





- **Smaller variation for p-MOSFETS**
- **Increase of the G_m and V_T for small channel length**



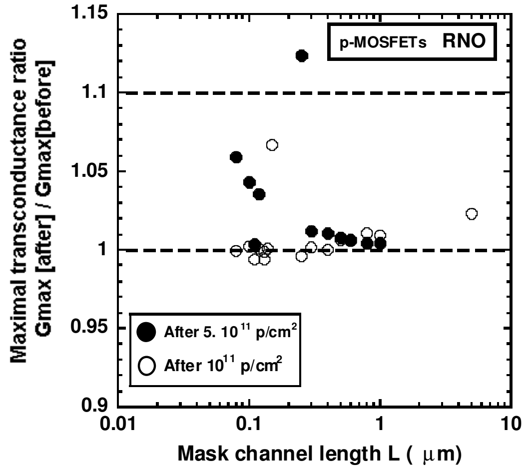


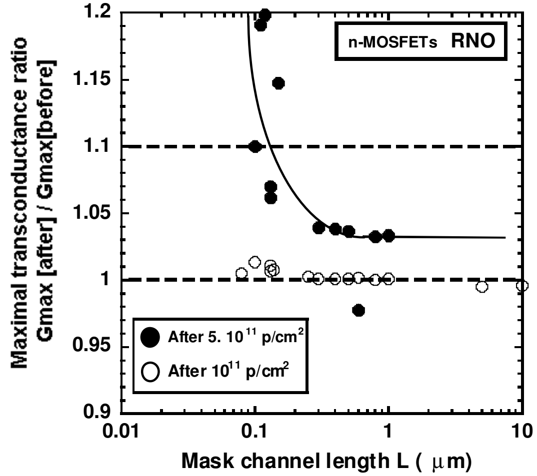
Increase of V_T for long device for the highest fluence

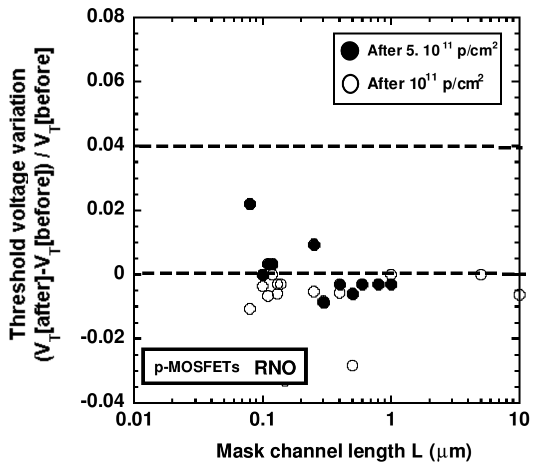
Irradiation impact on electrical parameters

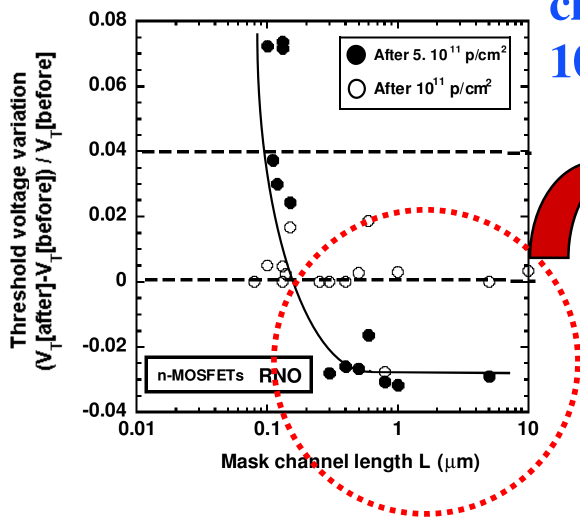
Devices irradiated under bias I V_G I=1.5V

NO







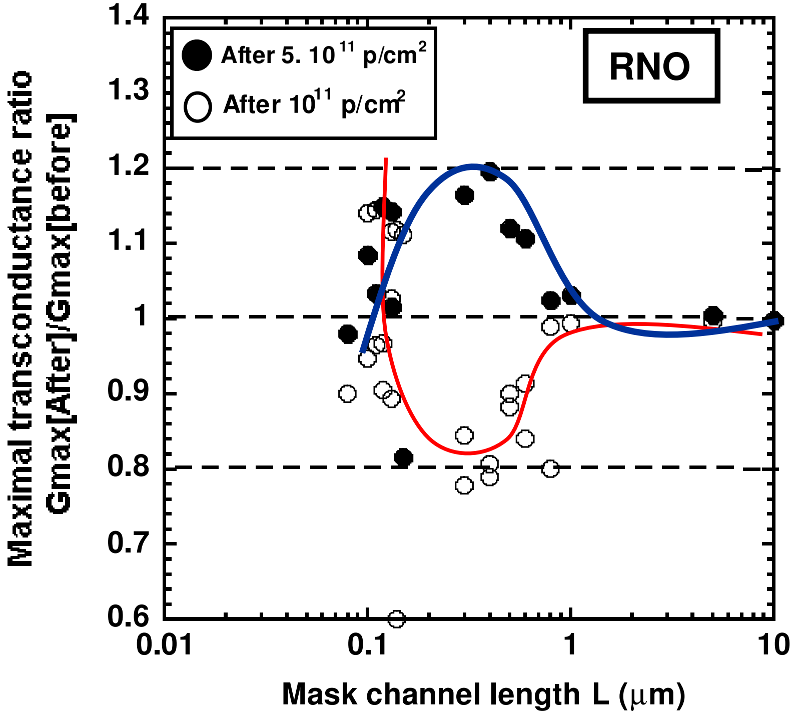


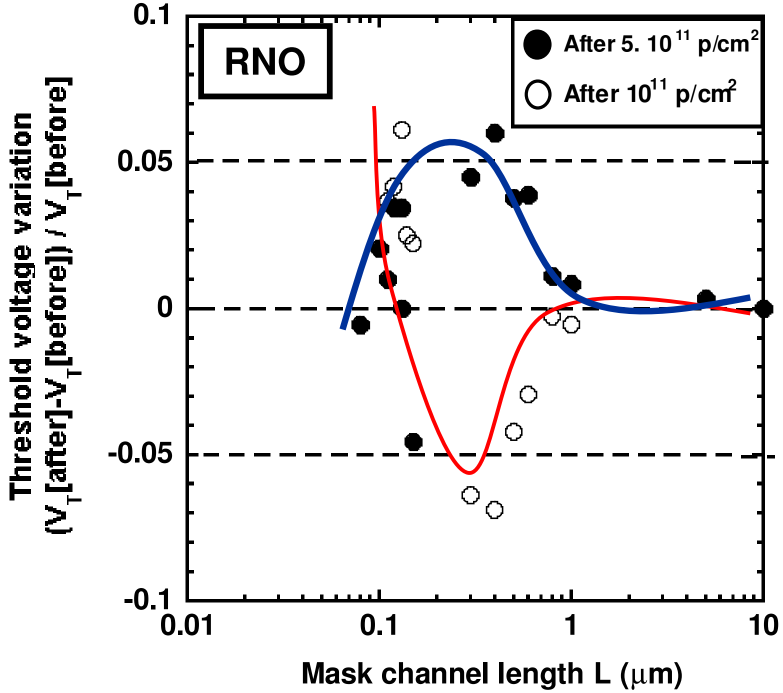
- No variation for p- and n- MOSFETs at 10^{11}p/cm^2
- Increase of the G_m and V_T for small channel length at 5 10^{11}p/cm^2

Reduction of V_T for long device for the highest fluence

Irradiation impact on electrical parameters

Devices irradiated without bias

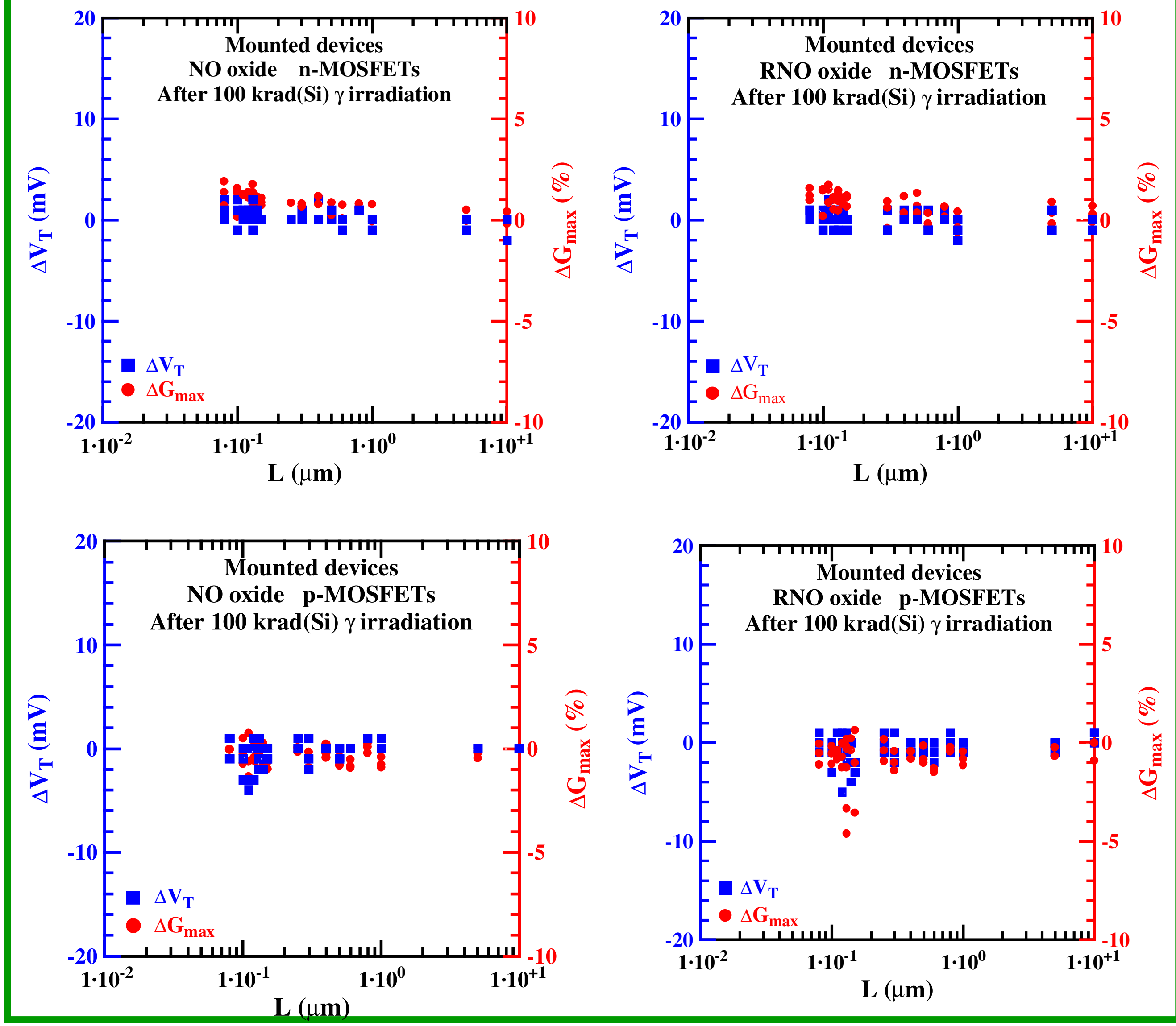




A rebound behavior for both V_T and G_m

<u>**The rebound sign seems to depend on the fluence ?**</u>

100Krads γ irradiated under bias devices do not show significant variations

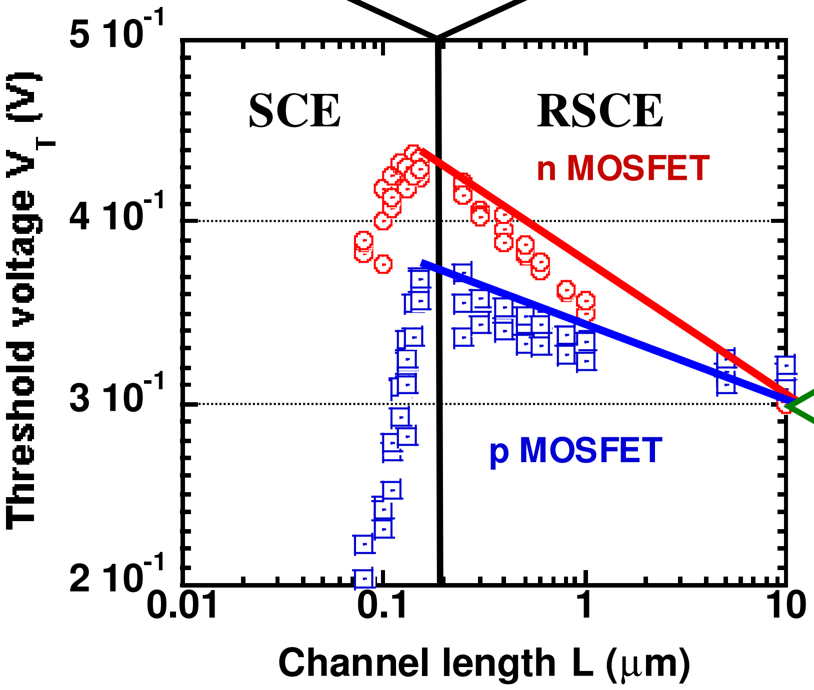


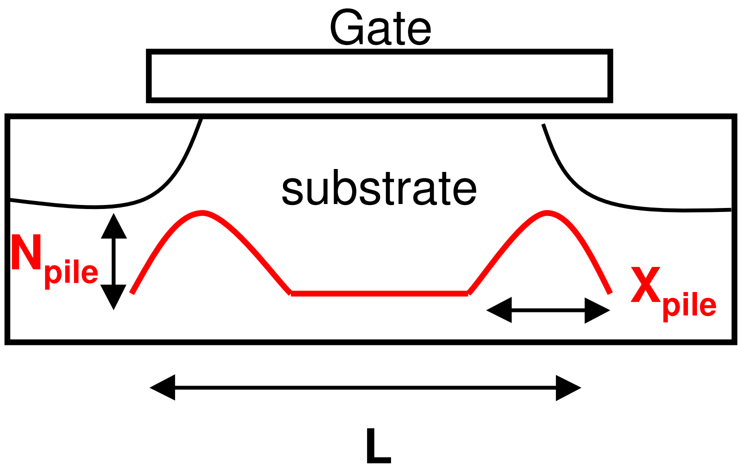
No ionization damage

Variations after Proton irradiation are probably due to damage in the <u>substrate</u>

Doping profile and Reverse Short Channel Effect

Onset of V_T roll up controlled
by lateral pile up length
X_{pile}

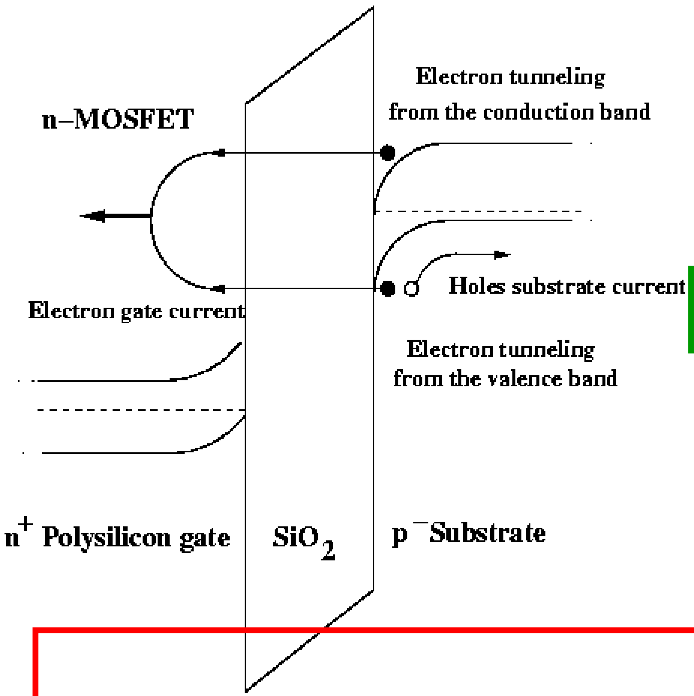


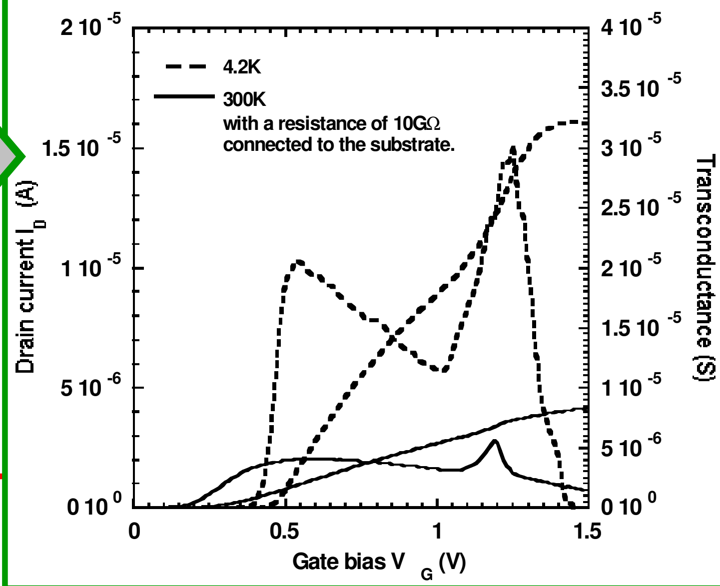


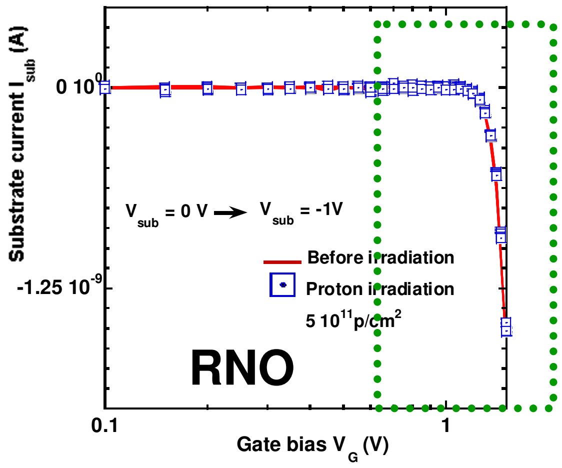
V_T roll up controlled
by pile up
concentration
N_{pile}

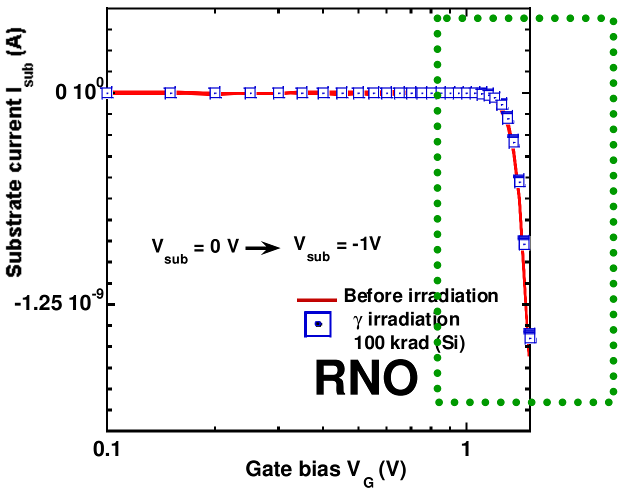
Doping profile variation induced by displacement damage ?

Substrate current and self biasing substrate









Common gate structure !

No variations in the Substrate current

Conclusions

- This scaled technology can withstand proton and gamma space irradiation

- I-V, C-V and noise measurements show no substantial degradation of the STI and the gate oxide for **IMEC technology**

- The transconductance increases for short channel n-MOSFETs irradiated under bias

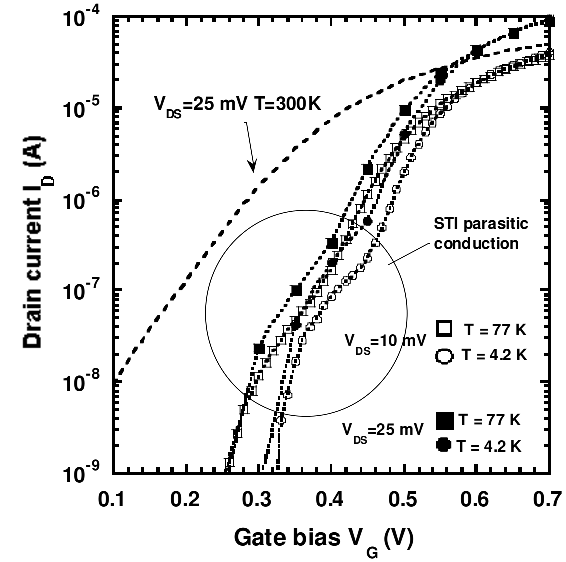
- The variations of G_m an V_T of n-MOSFETs irradiated without bias show complex rebound behavior

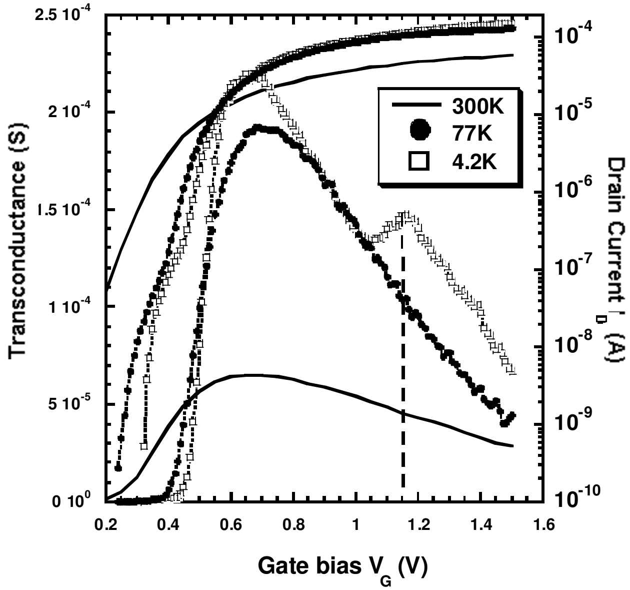
These small variations could be related to substrate damage and specific to the common gate test structure ?

Devices from IMEC 0.13 µm technology are radiation hard

But need for experimental results on circuits level (SEU ?)

Perspectives :
Low temperature irradiation





Next low temperature irradiation matrix should give insights on

1/ STI degradation

2/ Substrate degradation

At low temperature (4.2K) the substrate freeze out can induce a substrate self bias