High-Energy Proton Damage Assessment of 90 nm Node Multiple Gate Oxide Thickness Transistors

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SEEDS FOR TOMORROW'S WORLD

OUTLINE

- Goal of the work
- Introduction: multiple gate oxides for System-on-Chip
- Experimental: devices and irradiation conditions
- Results and discussion: linear I_S, I_D, I_B and I_G
- Conclusions

Goal

- To study potential degradation mechanism by ionizing irradiation. Total Ionizing Dose (TID) degradation may result from e-h pair generation in the gate and isolation dielectrics.

- Part of the particle energy is dissipated in atomic displacements, generating defects in the silicon substrate. Do we see some effects on the device behavior?

- Is there any difference in the degradation behaviour of thin oxides grown on F or N implanted silicon?

Introduction

- System-on-Chip applications require transistors with different functionality.
  - Logic and high-speed →maximum performance (thin oxide)
  - Low power/low voltage (analog; RF) →thicker gate oxide
  - I/O electronics: high power →thick oxide
- Several approaches are under development:
  - Oxidation and etch-back
  - Local implantation of N or F (I/I) in the substrate
  - N gives rise to a retardation of the oxidation rate
  - F gives rise to an enhancement of the oxidation rate
- The use of multiple thickness gate oxides may give rise to a total-dose issue.

Experimental

- **Wafer 4: The high-performance (HP) devices have been fabricated using Shallow Trench Isolation (STI) and a 1.5 nm Rapid Thermal Oxidation (RTO) gate dielectric, with nominal length 1.5 nm. A polysilicon gate was used and dopant activation was achieved by a 1100 ^{o}C, 1 s spike anneal.**
- **Wafer 6: 2 nm RTO gate oxide (low-power/low voltage reference).**
- **Wafer 8: 8 keV F implantation at $5x10^{14}$ cm^{-2} dose in the active regions, followed by a 1.5 nm RTO oxide. This should result in a thicker oxide due to SiO_2 swelling and enhanced oxidation rate by the presence of fluorine.**
- **Wafer 10: 8 keV N implantation at $3x10^{15}$ cm^{-2} dose in the active regions, followed by a 2 nm RTO. This should result in a thinner oxide (< 2 nm), due to a retarded oxidation rate.**

Experimental

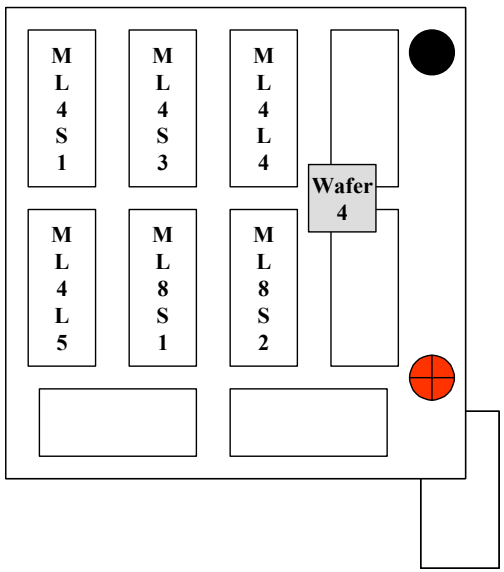
From the accumulation capacitance of a high-frequency C-V measurement on a large-area (100 μmx100 μm) MOS capacitor, the following effective oxide thickness (in nm) have been derived:

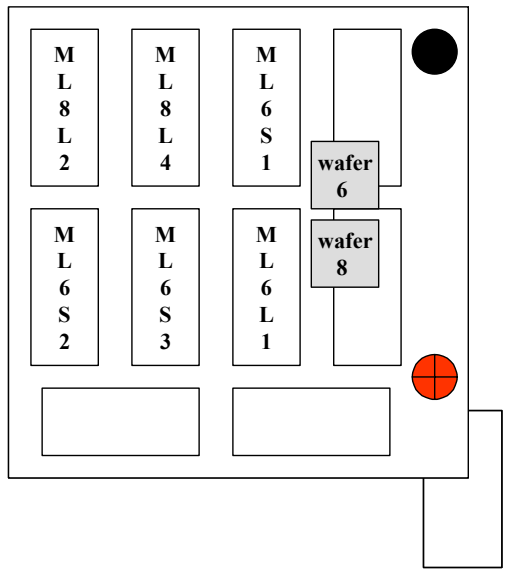
	no	F I/I	no	N I/I
RTO 1.5 nm:	1.7	2.3	--	--
RTO 2 nm:	--	--	2.2	1.94

Radiation Matrix: Round 1

Proton Energy: 67 MeV; Fluence: $3x10^{12}$ cm^{-2}

Bias: +1.2 V on n-type gates; 0 V on other terminals





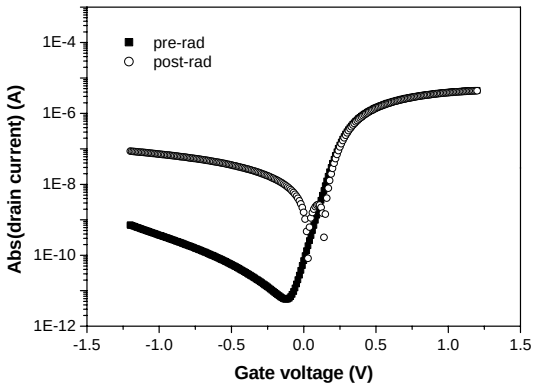
Pre- and Post-rad Testing

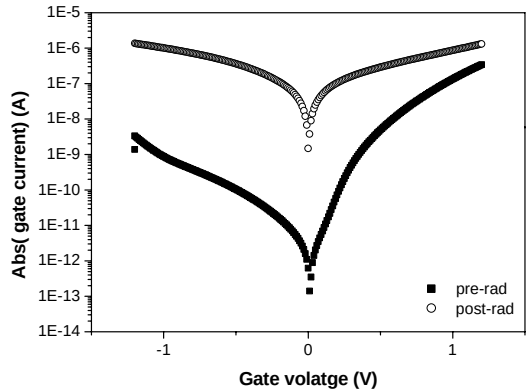
The width of the MOSFETs is fixed at 10 μm.
Both long (L) and short (S) arrays have been studied:

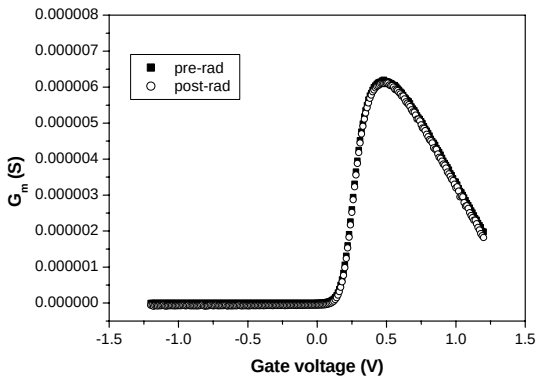
Long array (L): 0.35 μm, 0.5 μm, 1 μm, 3 μm, 10 μm
Short array (S): 0.07 μm, 0.08 μm, 0.09 μm, 0.10 μm, 0.11 μm.

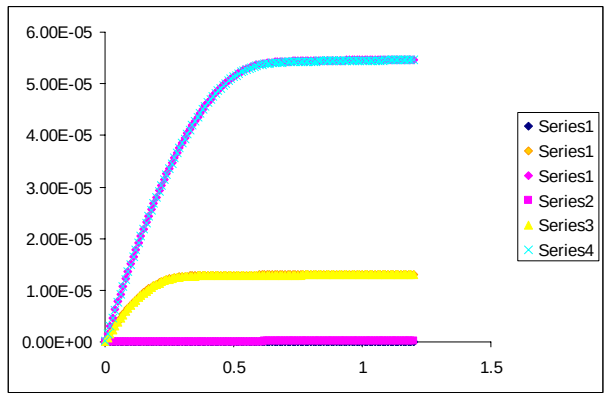
input: from –1.2 to 1.2 V (n-) or +1.2 to –1.2 V (p-MOSFET) at $|V_{DS}|$=0.025 and 1.2 V (supply voltage).
output: $|V_{DS}|$ from 0 to 1.2 V and $|V_{GS}|$ from 0.2 to 1.2 V (step 0.2 V)

Biased irr.; chip M4L5 – L=10 μm





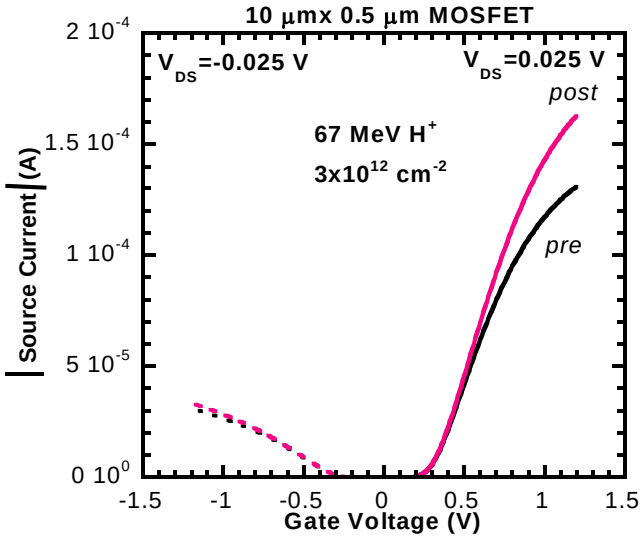


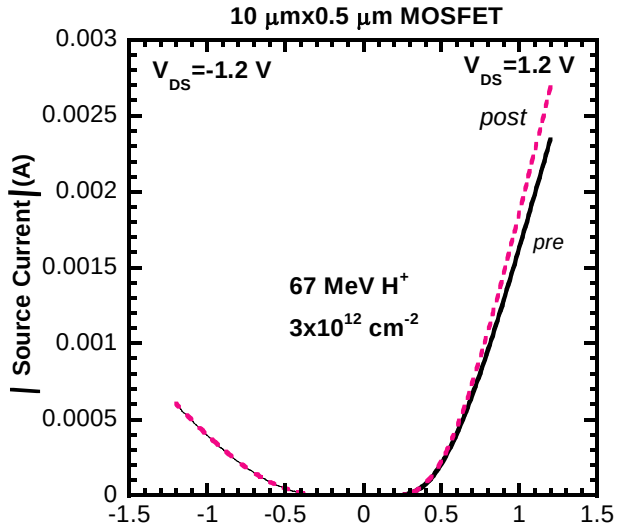


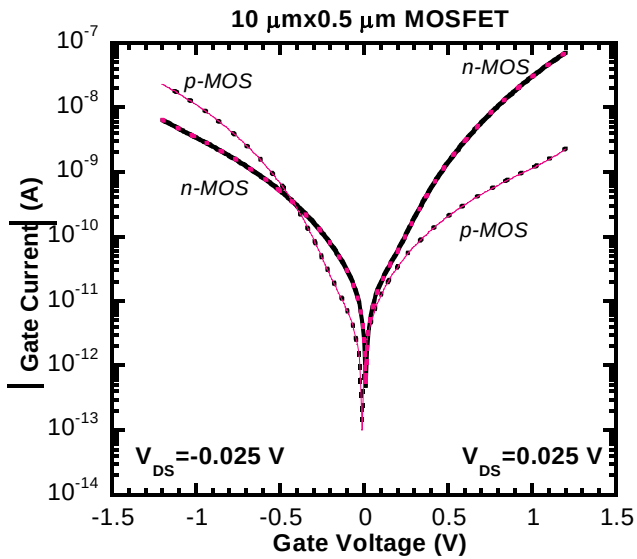
Summary biased irradiations

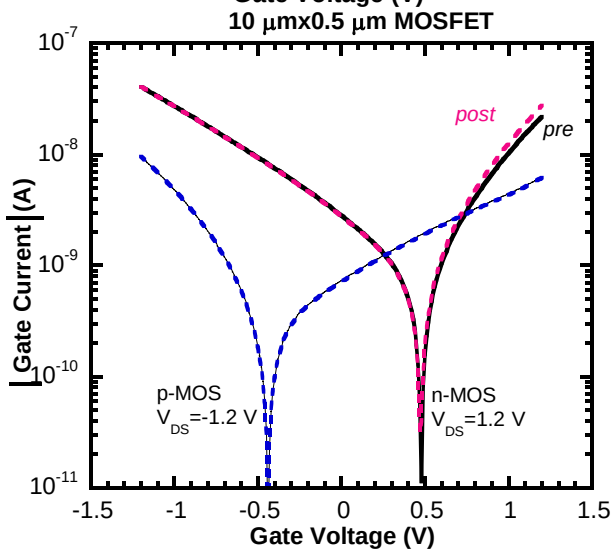
- Most long devices did not survive and showed excessive gate leakage current
- Short devices showed less dramatic degradation: mainly the gate leakage current and subthreshold S/D leakage increased
- No strong changes found in the normal static device characteristics
- Electrical stress measurements of long devices did not exhibit any degradation of the gate current
- Is there a synergistic effect between I_G and the proton irradiation (current)?

Unbiased irradiations: input characteristics

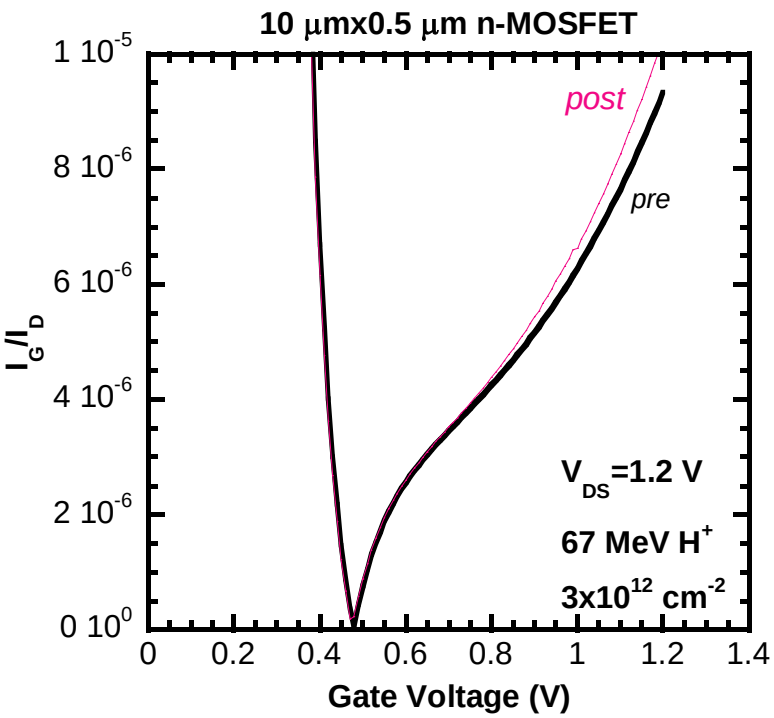


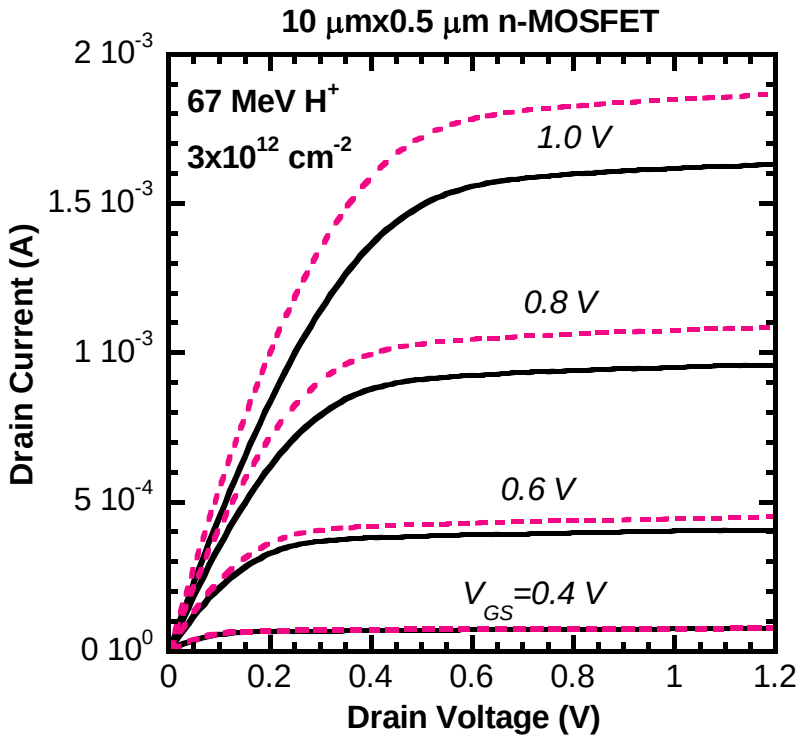






Unbiased irradiations: output characteristics





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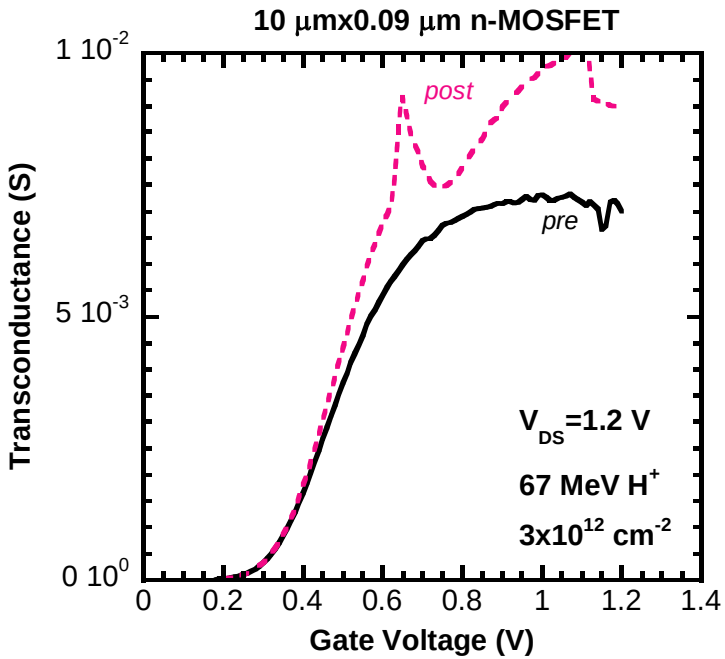
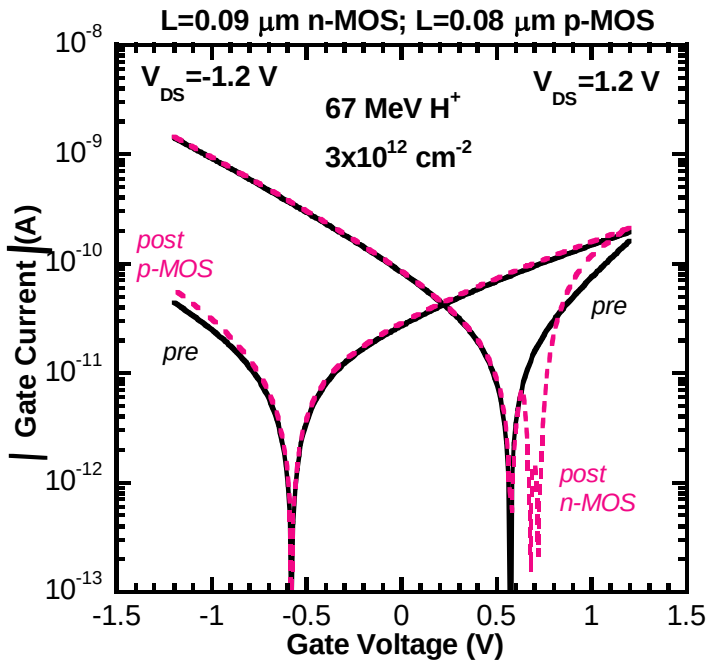




Conclusions Round 1

- Unbiased irradiations showed less pronounced increases in I_G.
- An unusual change in the characteristics at large V_{DS} was found, which was reflected in the output characteristics.
- Little changes were found in the normal linear characteristics.
- It appears that the reference wafer 4 (and 6) short devices exhibit this degradation more than wafer 8 (F I/I).

Radiation Matrix Round 2

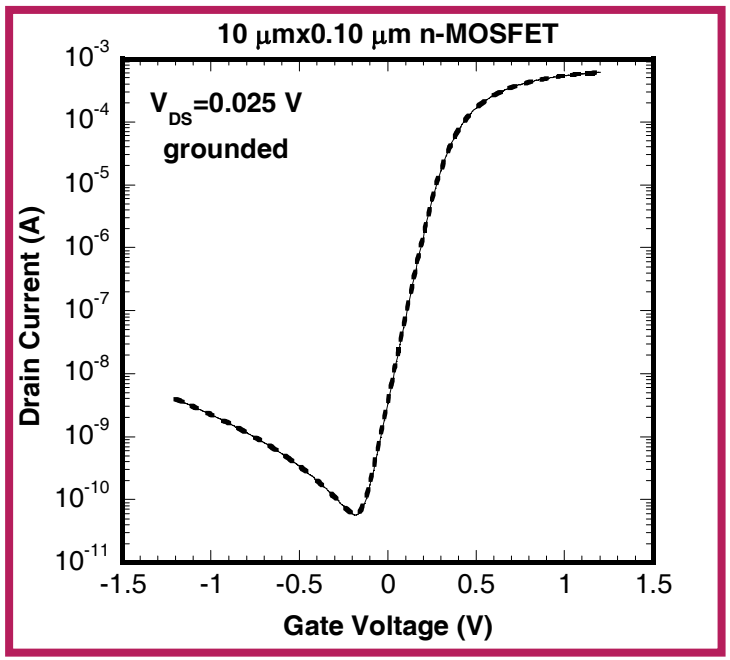
- Biased irradiations have been performed on 6 packaged devices. Some of the n-MOSFETs of the same array (separate gate and drain contacts) had a gate at 0 V (no gate current flowing), others were at +1.2 V.

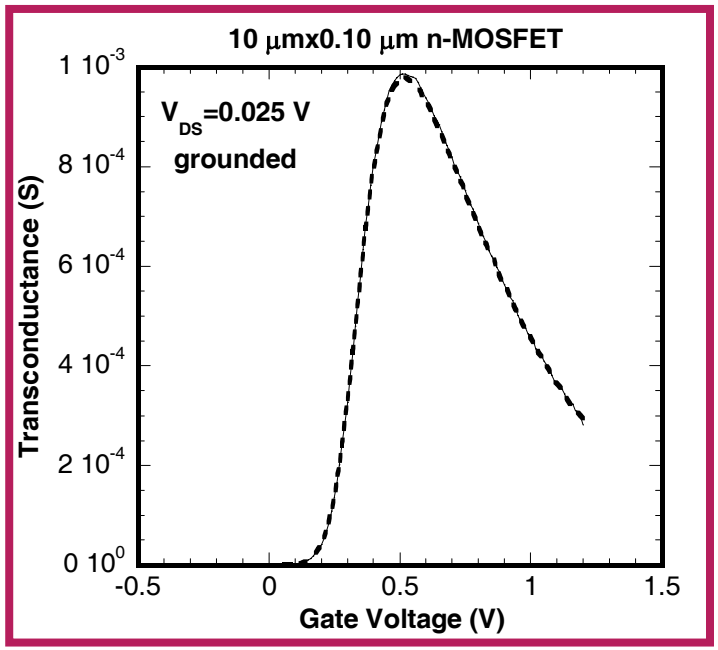
- Fluence was at $3x10^{12}$ 60 MeV p/cm^2.

- In addition, a number of non-packaged chips were exposed as well (contacts floating).

Results Round 2

For 0 V on the gate: no degradation whatsoever





Results Round 2

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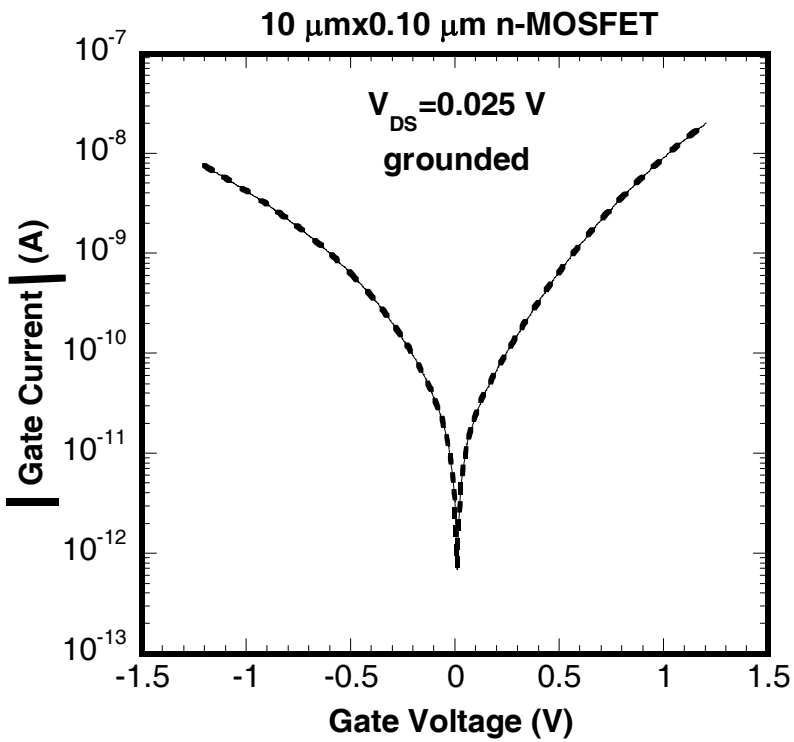
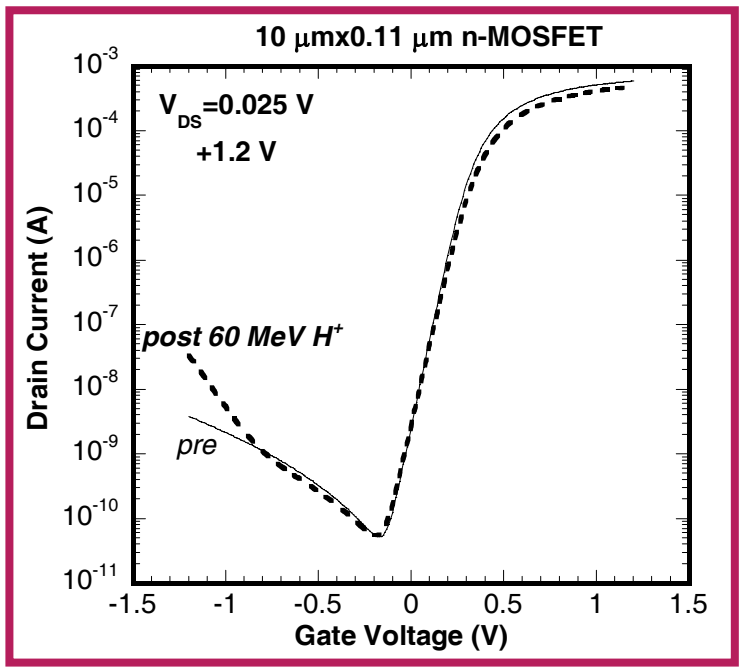
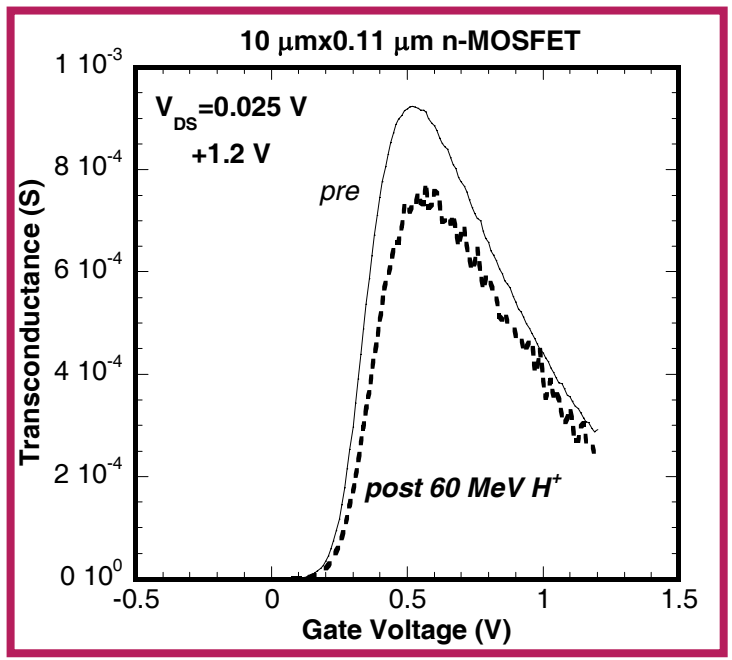


Results Round 2

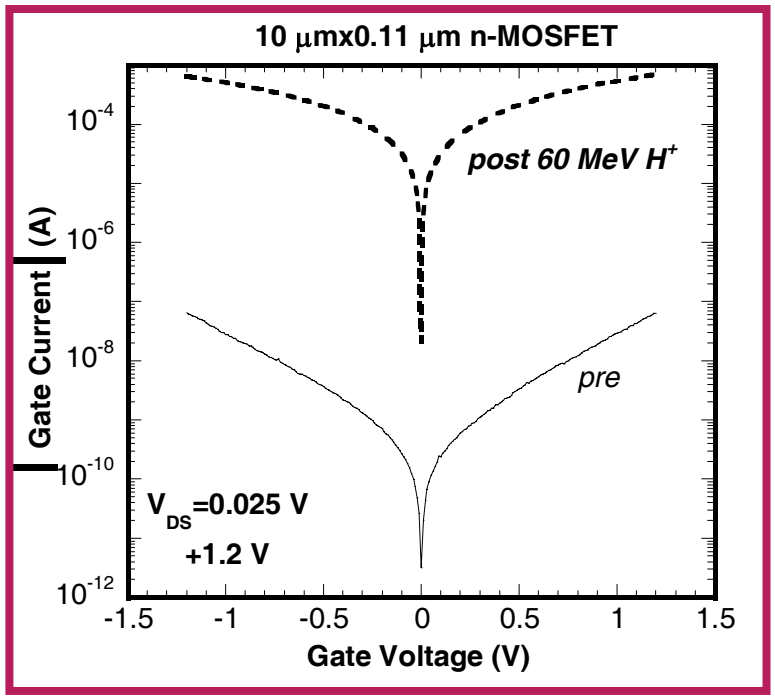
For 1.2 V on the gate: most devices exhibit a marked degradation





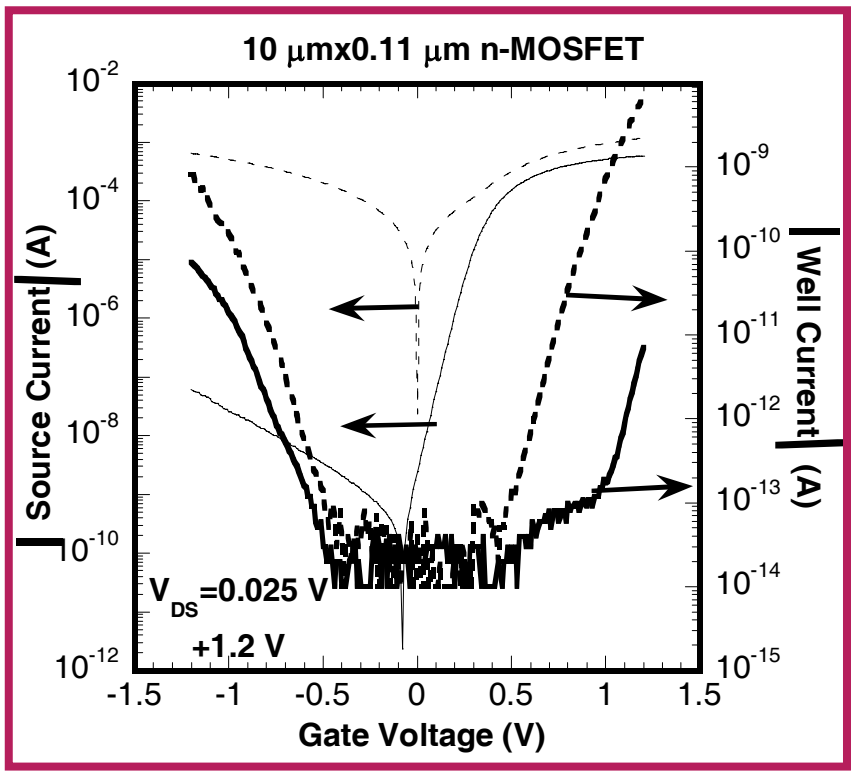
Results Round 2

For 1.2 V on the gate: most devices exhibit a marked degradation; the gate is a resistor.



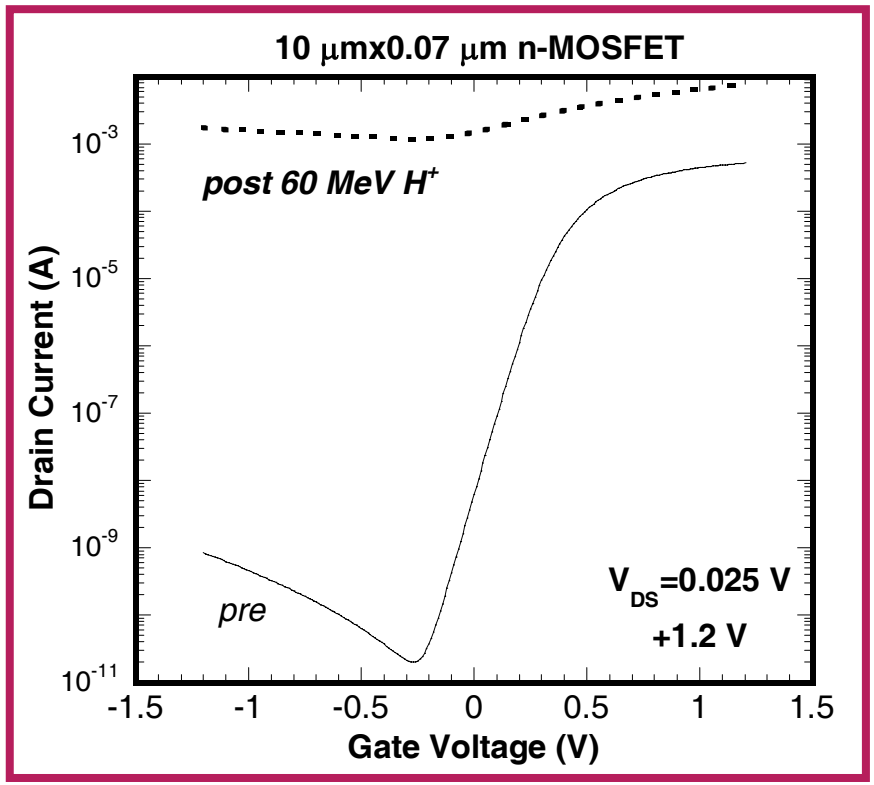
Results Round 2

Some n-channel devices break down at the source contact.



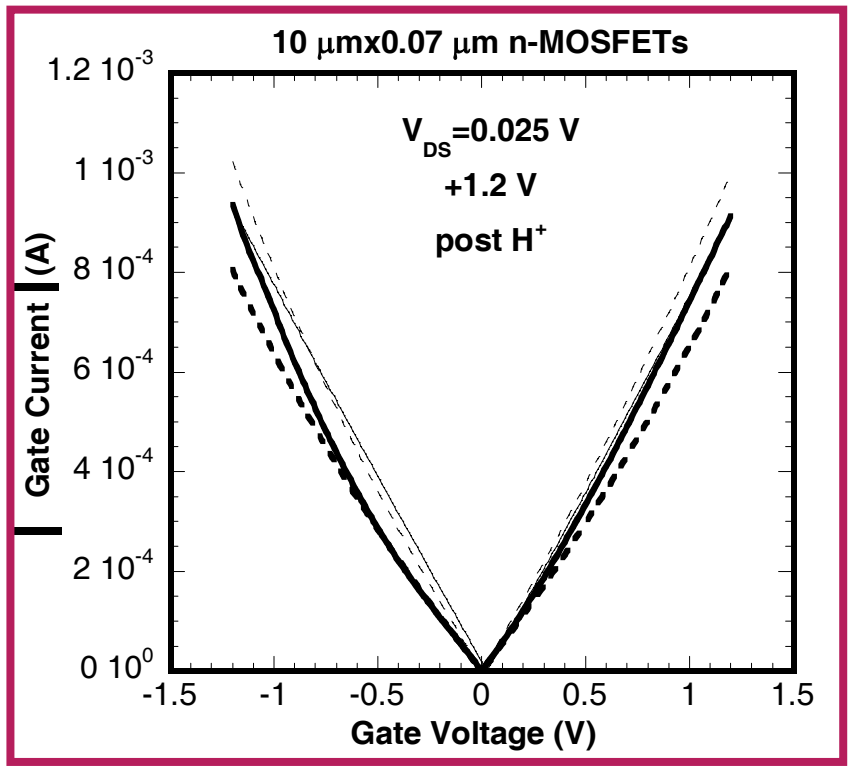
Results Round 2

Some n-channel devices break down at the gate-drain junction.



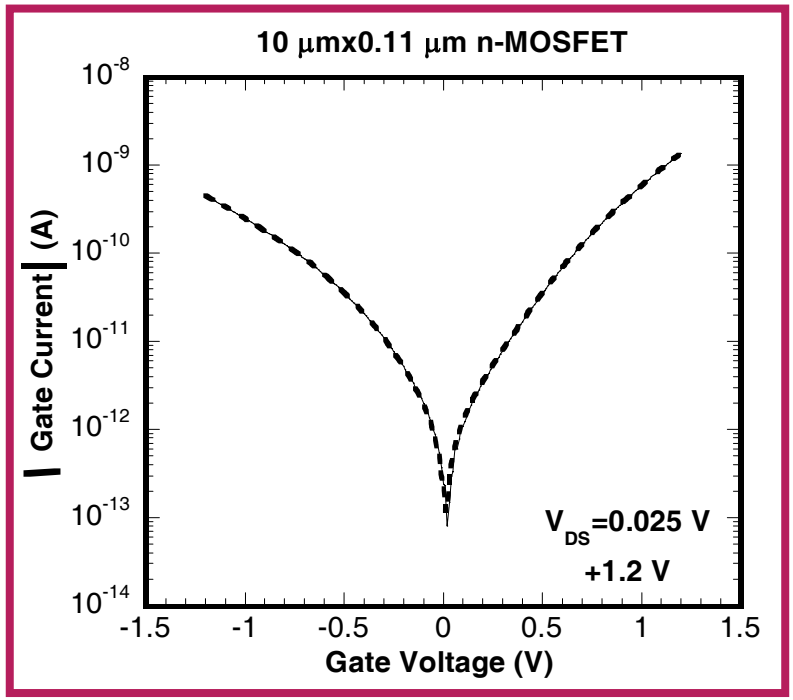
Results Round 2

The gate of the broken devices behaves like a resistor.



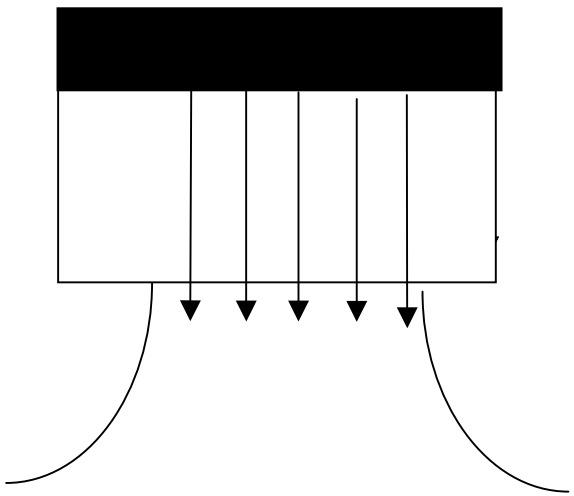
Results Round 2

Statistics: 2 out of 9 biased short-channel transistors were not degraded. None of the 0 V biased devices were degraded in round 2.

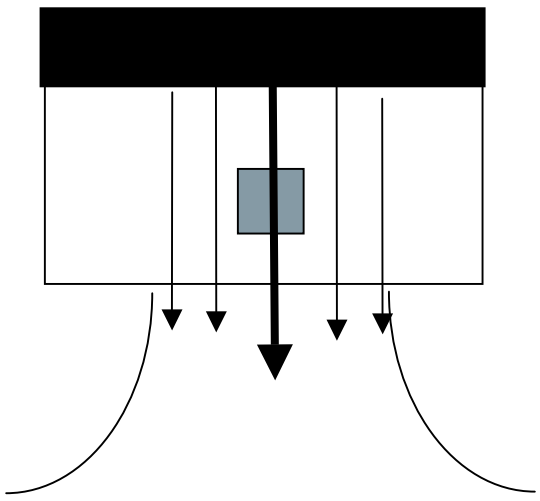


Interpretation

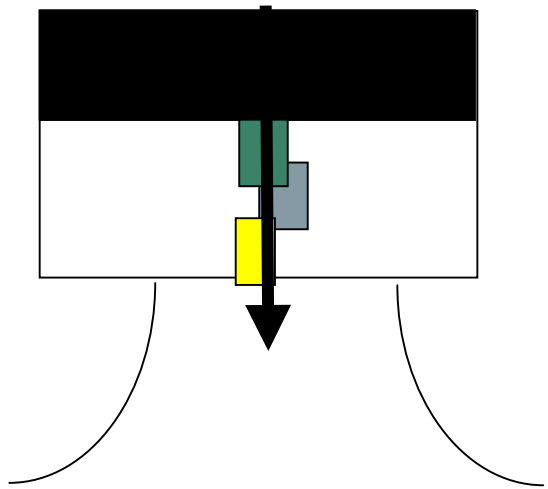
Uniform gate current flow



Trap-assisted RILC



Gate current flow through radiation-induced leakage path



General Conclusions

- There appears to be a bias dependence of the radiation response of 90 nm (n-)MOSFETs. Particularly large-area transistors are broken after a high fluence of $3x10^{12}$ p/cm^2.

- Statistics (microdosimetry) also plays an important role: some of the biased transistors survive the irradiation without any degradation.

- The observations are tentatively interpreted in terms of a synergy between gate current flow and high-energy proton irradiation. Created defects (or latent defects) may give rise to a catastrophic failure of the gate by forming a preferential path for gate current flow.