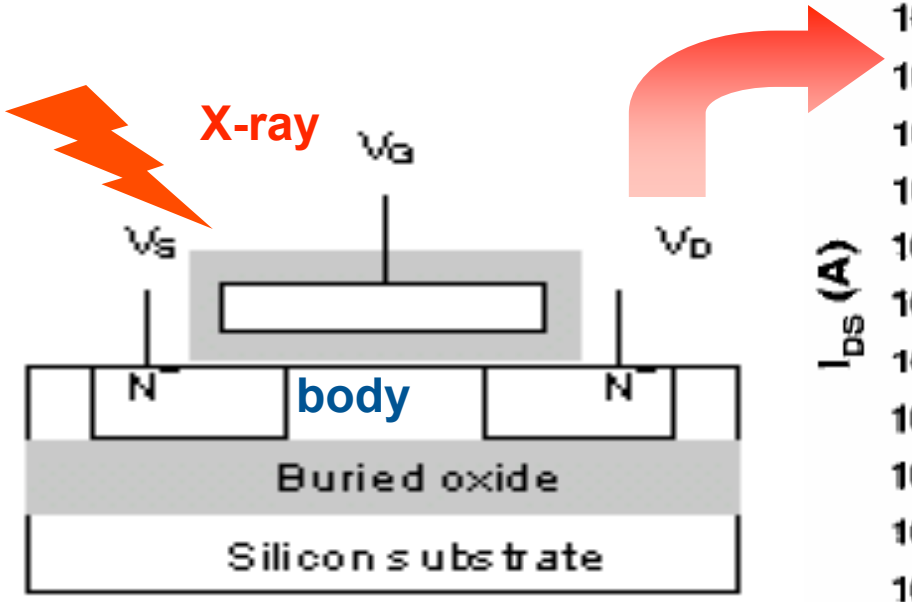
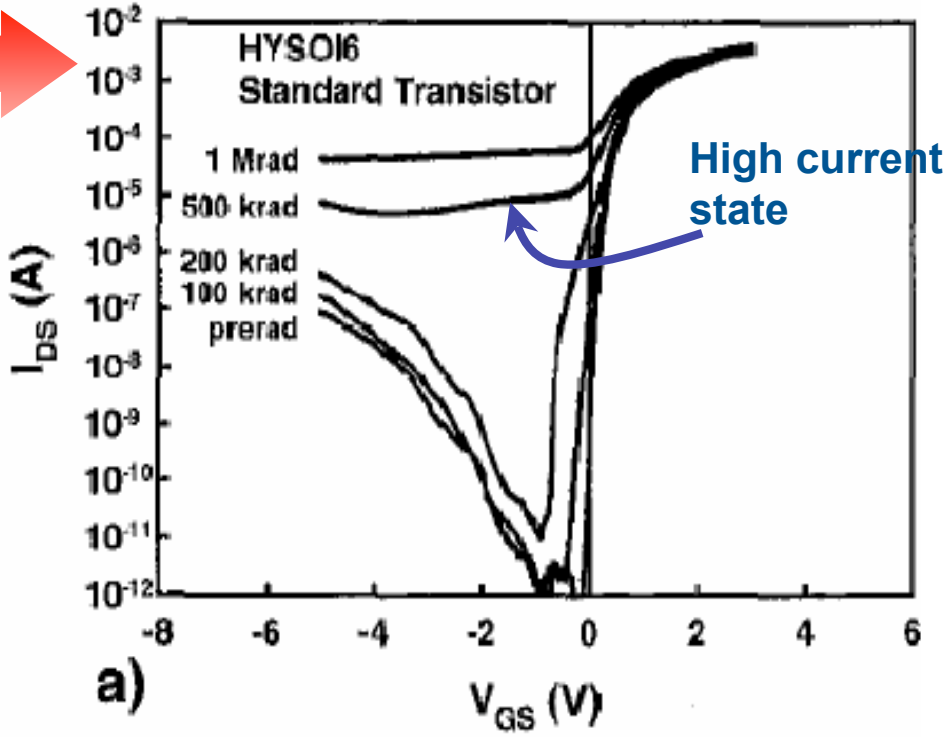
Gate-Length and Drain-Bias Dependence of Band-To-Band Tunneling (BTB) Induced Drain Leakage in Irradiated Fully Depleted SOI Devices

F. E. Mamouni, S. K. Dixit, M. L. McLain, R. D. Schrimpf, H. J. Barnaby, P. C. Adell, and W. Xiong

Context





What is the actual reason for the high current regime?

Figure 1: I-V curves for a closed-geometry top-gate [1].

[1]: J. R. Schwank, M. R. Shaneyfelt, P. E. Dodd, J. A. Burns, C. L. Keast, and P. W. Wyatt, "New insights into fully-depleted SOI transistor response after total-dose irradiation," *IEEE Trans. Nucl. Sci.*, vol. 47, pp. 604-612, 2000.

Objective

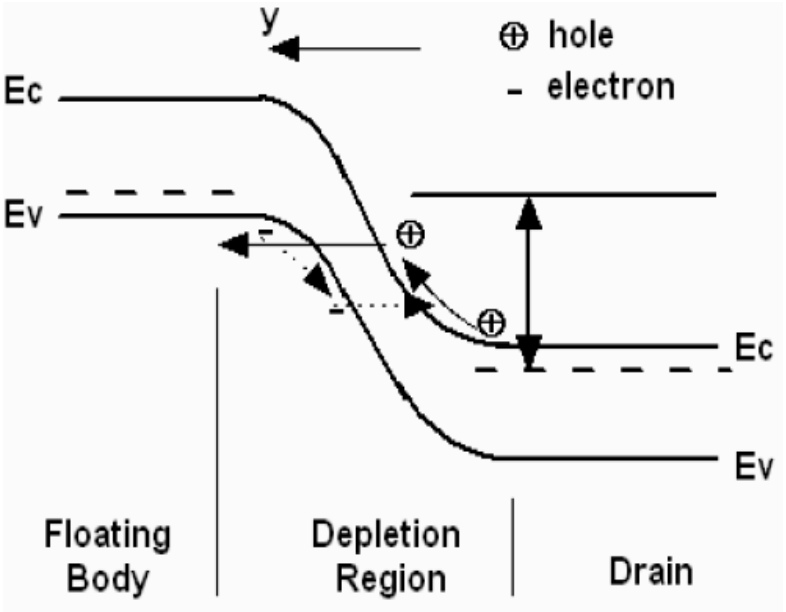


Figure 2: energy band diagram for band to band tunneling [2] .

J. H. Chen, S. C. Wong, and Y. H. Wang, "An Analytic Three-Terminal Band-to-Band Tunneling Model on GIDL in MOSFET", IEEE Trans. Nucl. Sci. , vol. 48, NO. 7, JULY 2001.

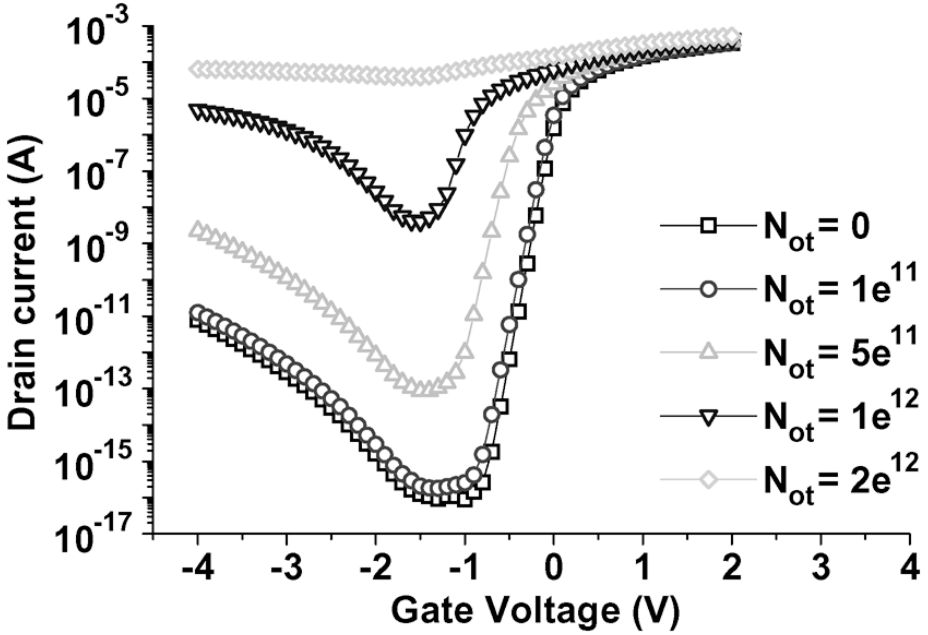


Figure 3: Simulated FD SOI Id vs. Vgs with BTB tunneling turned ON and impact ionization turned OFF [3].

P. C. Adell, H. J. Barnaby, R. D. Schrimpf, and B. Vermeire, "Band-to-band tunneling (BBT) induced leakage current enhancement in irradiated fully depleted SOI deviccs," IEEE Trans. Nucl. Sci., vol. 54, pp. 2174-2180, 2007.

The objective of this work was: To validate experimentally these results by physically irradiating a FDSOI MOSFET transistor. Drain voltage and gate length dependencies were performed as well.

Previous work

At low dose level and high drain voltage

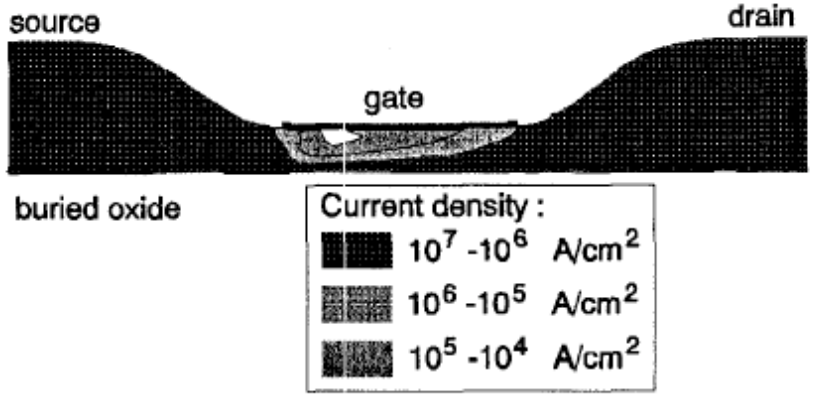
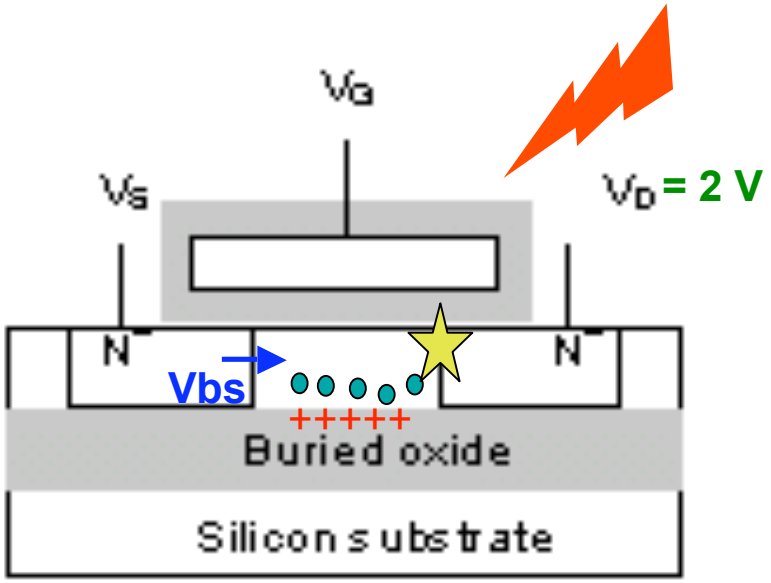


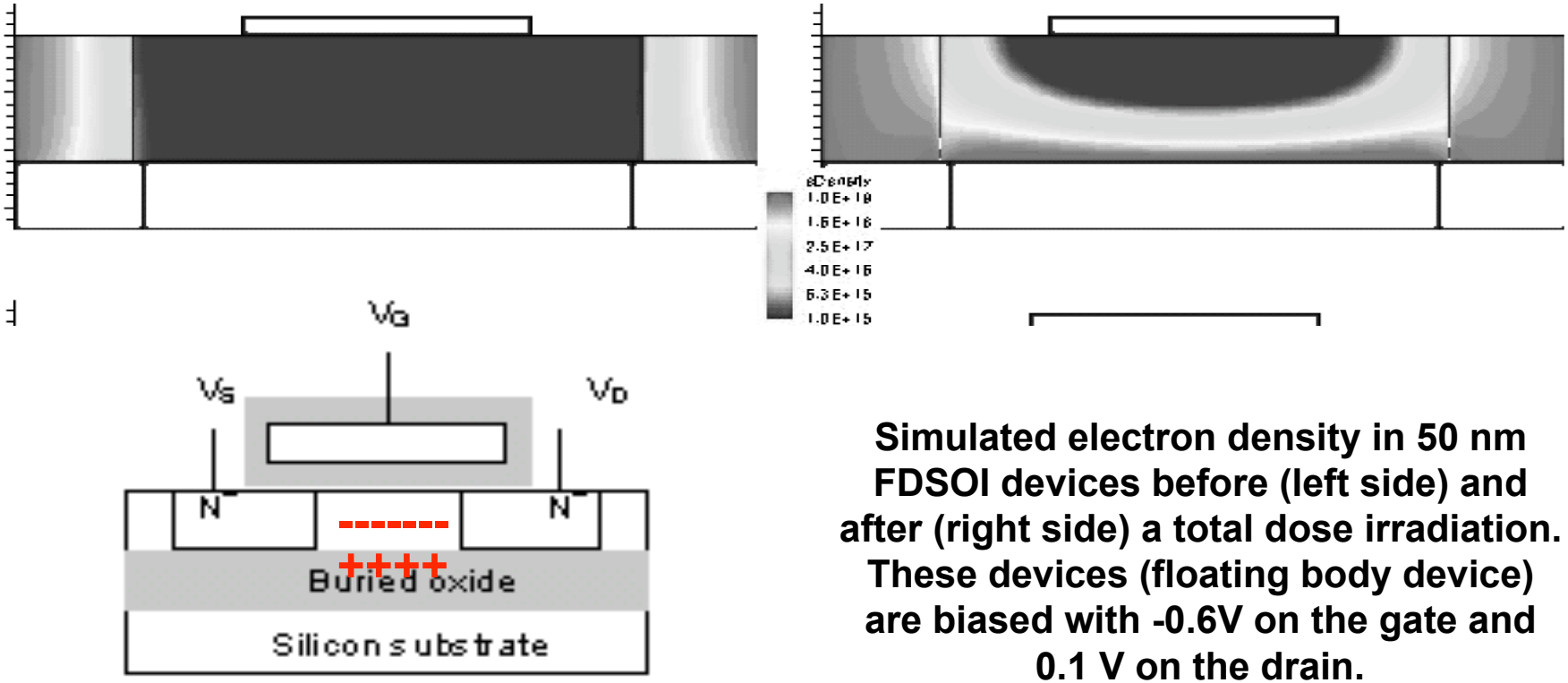
Figure 6: Simulation of the current density in an off-state (Vg = 0 V) FD NMOS/SOI transistor on a standard SIMOX substrate at high drain voltage (Vd = 2 V). A N_{ox} value of 10^{12} cm^{-2} at the silicon film-buried oxide interface is used to simulate the total dose irradiation.



V. Ferlet-Cavrois, S. Quoizola, O. Musseau, O. Flament, J. L. Leray, J. L. Pelloie, C. Raynaud, and O. Faynot, "Total dose induced latch in short channel NMOS/SOI transistors," Ieee Transactions on Nuclear Science, vol. 45, pp. 2458-2466, 1998.

Radiation + impact ionization --> holes excess in the body --> s/b junction is forward biased --> parasitic NPN transistor

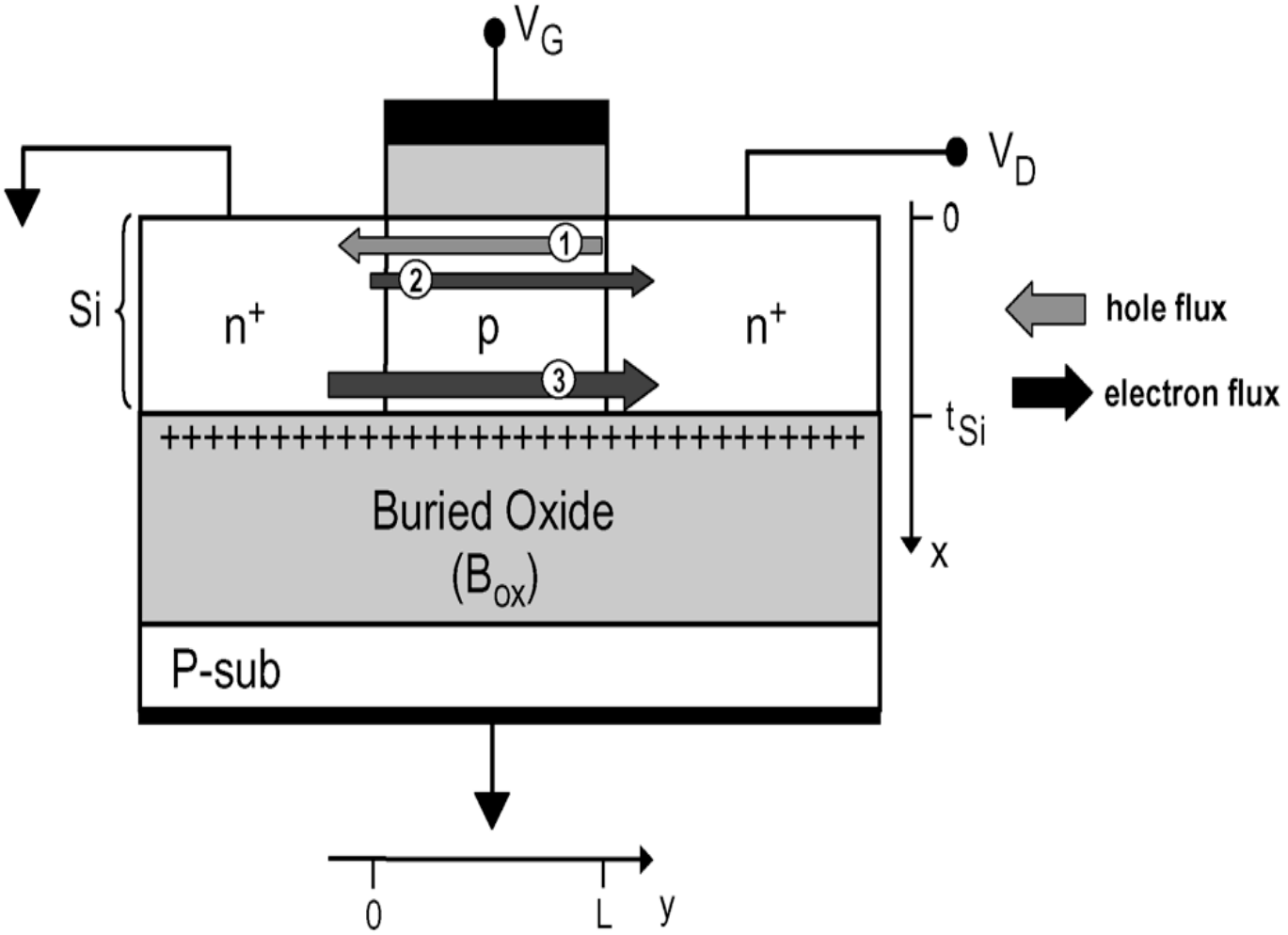
At high dose level and low drain voltage



Simulated electron density in 50 nm FDSOI devices before (left side) and after (right side) a total dose irradiation. These devices (floating body device) are biased with -0.6V on the gate and 0.1 V on the drain.

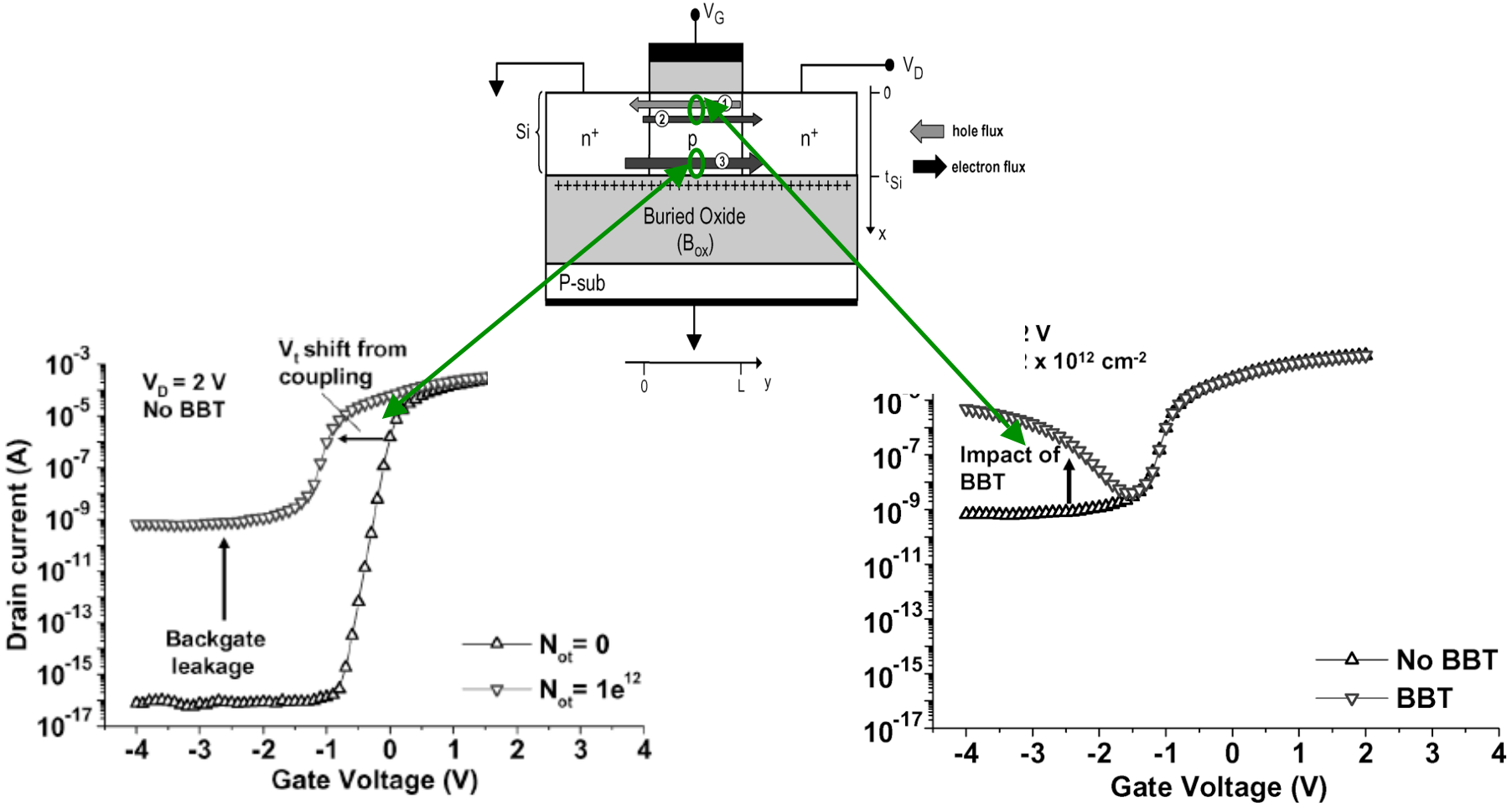
P. Paillet, M. Gaillardin, V. Ferlet-Cavrois, A. Torres, O. Faynot, C. Jahan, L. Tosti, and S. Cristoloveanu, "Total ionizing dose effects on deca-nanometer fully depleted SOI devices," IEEE Trans. Nucl. Sc. , vol. 52, pp. 2345-2352, DEC 2005.

At low dose level and low drain voltage 1/2



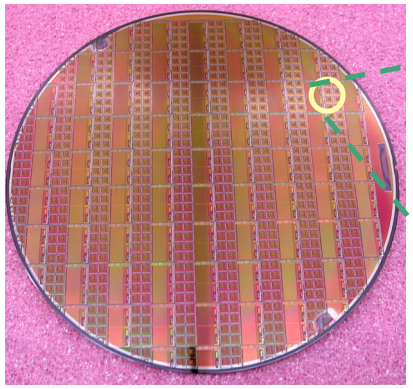
[3]: P. C. Adell, H. J. Barnaby, R. D. Schrimpf, and B. Vermeire, "Band-to-band tunneling (BBT) induced leakage current enhancement in irradiated fully depleted SOI devices," *IEEE Trans. Nucl. Sci.*, vol. 54, pp. 2174-2180, 2007.

At low dose level and low drain voltage 2/2

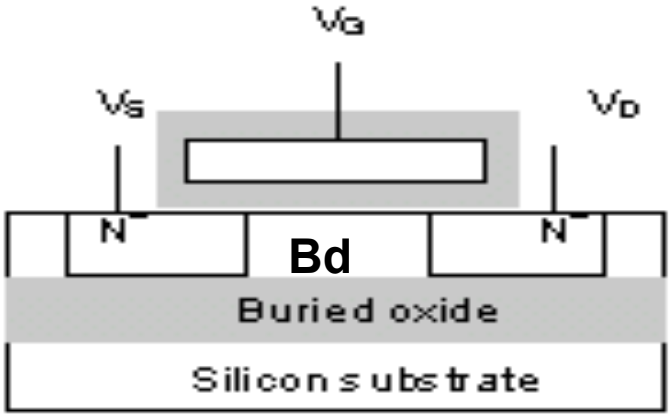


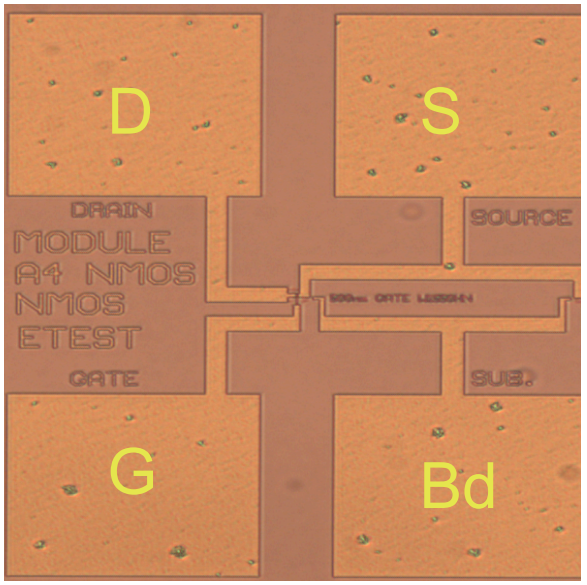
P. C. Adell, H. J. Barnaby, R. D. Schrimpf, and B. Vermeire, "Band-to-band tunneling (BBT) induced leakage current enhancement in irradiated fully depleted SOI deviccs," *IEEE Trans. Nucl. Sci.*, vol. 54, pp. 2174-2180, 2007.

Experimental details 1/2



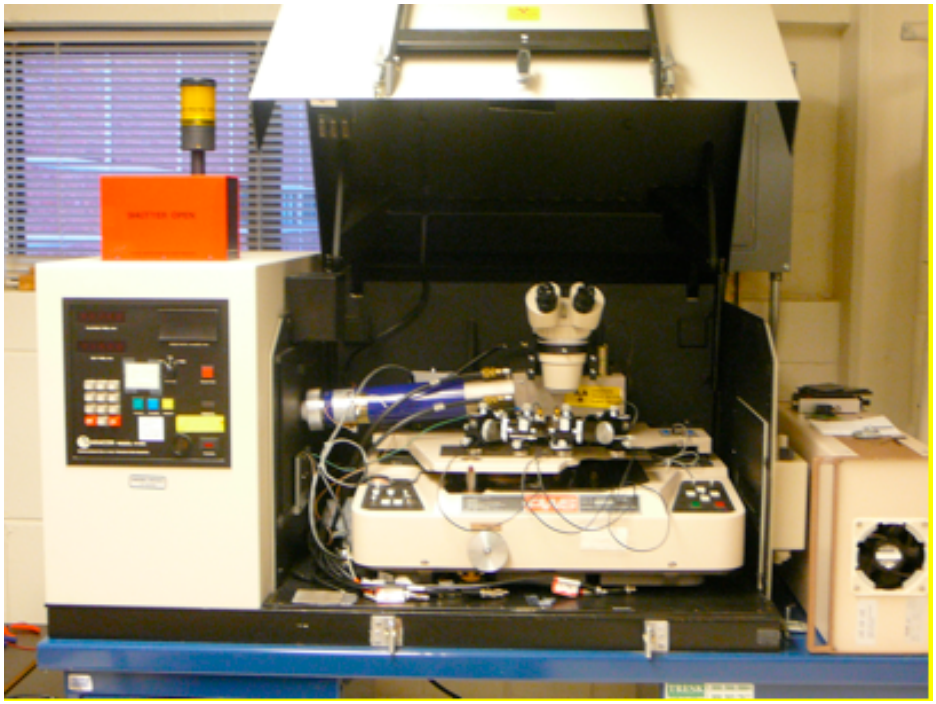
12”





- All the measurements were performed with floating body.
- Gate oxide: SiO2 =1.8-2nm.
- Gate width: 0.15µm.

Experimental details 2/2



Irradiation conditions

10 keV X-rays

Dose rate: 31.5 krad (SiO_2)/min

Bias : V = 0.8 V, V = Vg

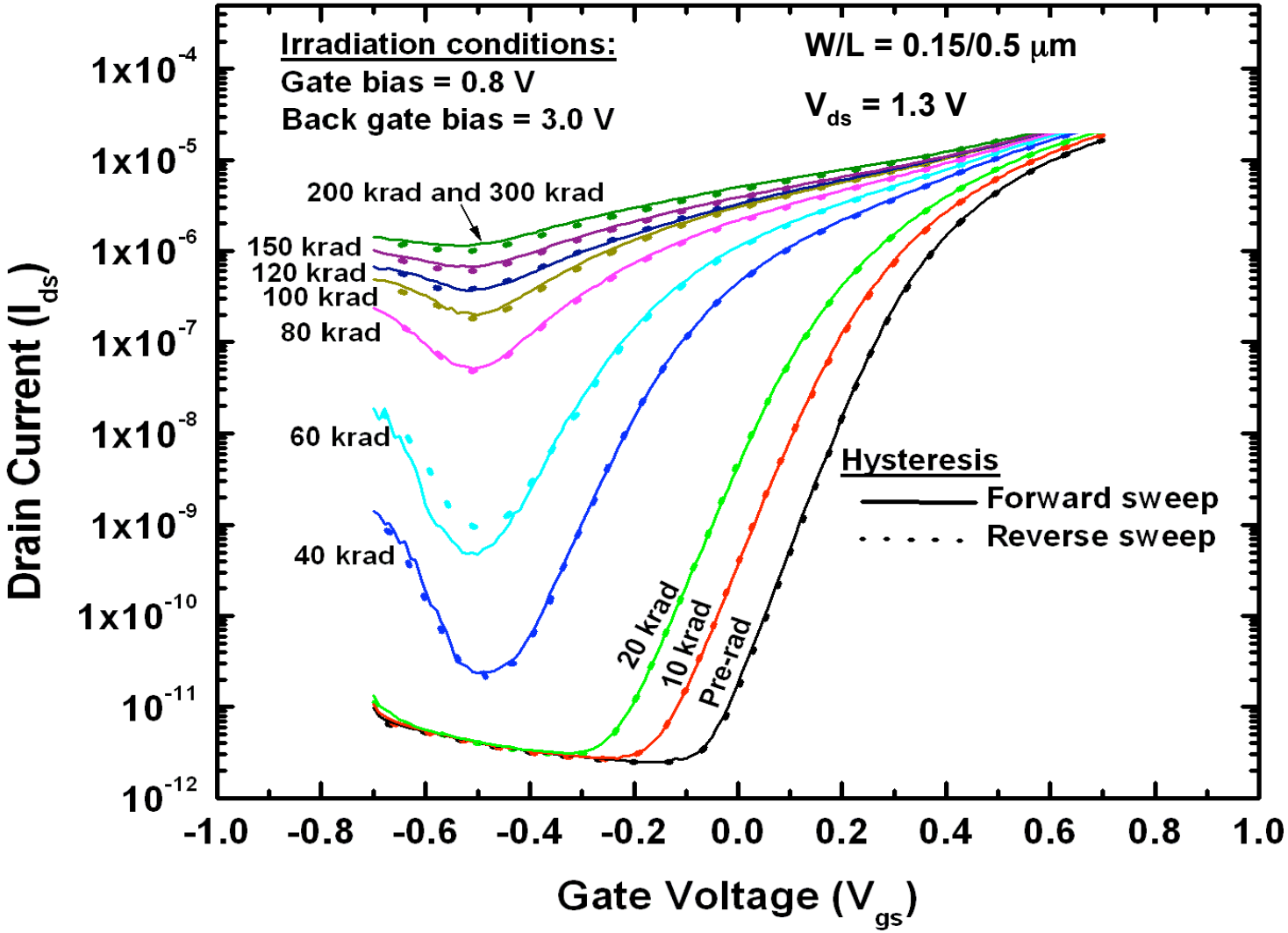
V = 3 V, V = Vsub

V = 0 V, else

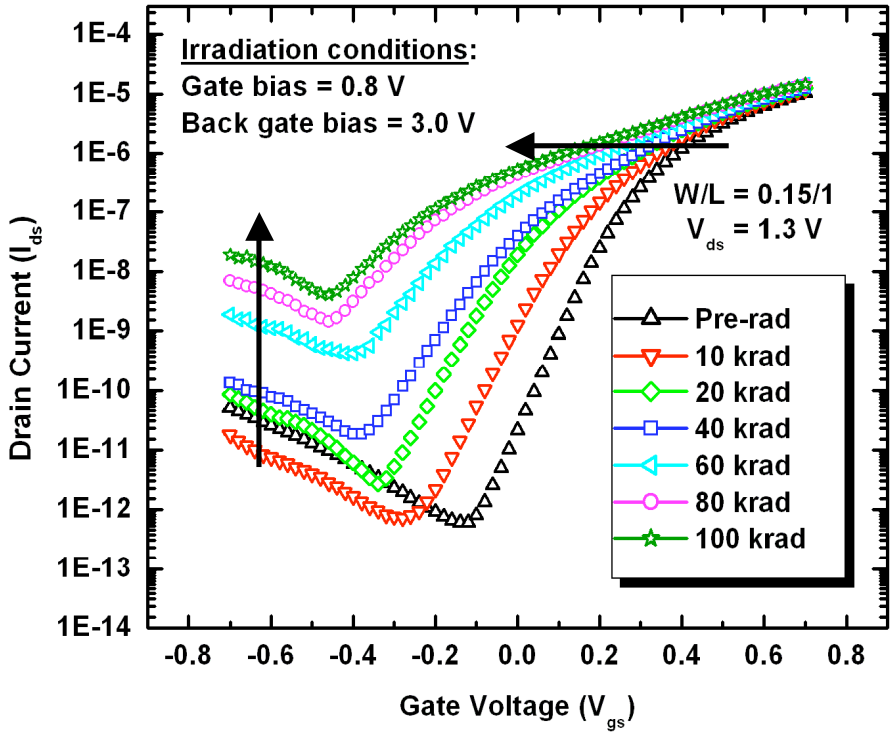
All irradiations and measurements were performed in-situ at wafer level

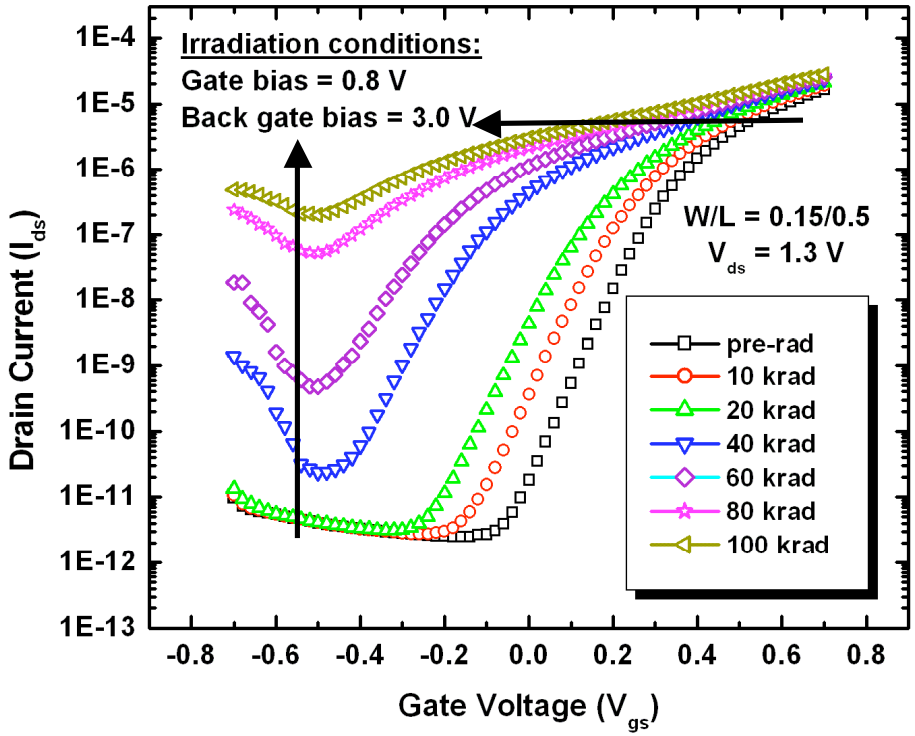
Experimental results

Results 1/3


Irradiation conditions:
Gate bias = 0.8 V
Back gate bias = 3.0 V
W/L = 0.15/0.5 μm
V_{ds} = 1.3 V
200 krad and 300 krad
150 krad
120 krad
100 krad
80 krad
60 krad
40 krad
20 krad
10 krad
Pre-rad
Hysteresis
Forward sweep
Reverse sweep
Drain Current (I_{ds})
Gate Voltage (V_{gs})
1x10^-4
1x10^-5
1x10^-6
1x10^-7
1x10^-8
1x10^-9
1x10^-10
10^-11
10^-12
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0

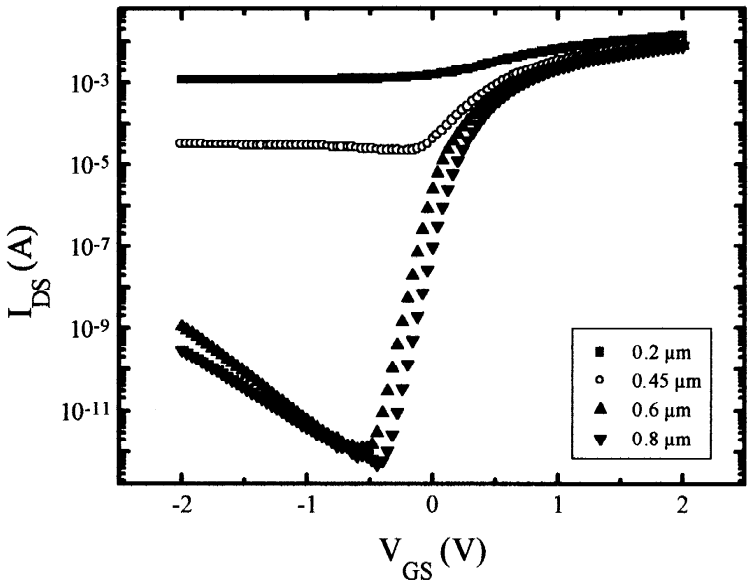
Results, gate length dependency 2/3



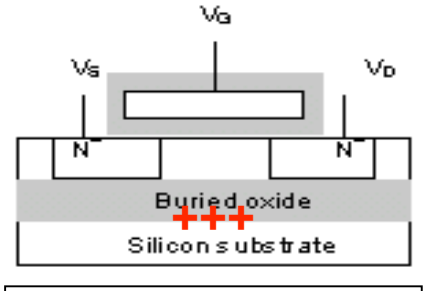


Increased drain leakage current for SOI MOSFETs with shorter channels

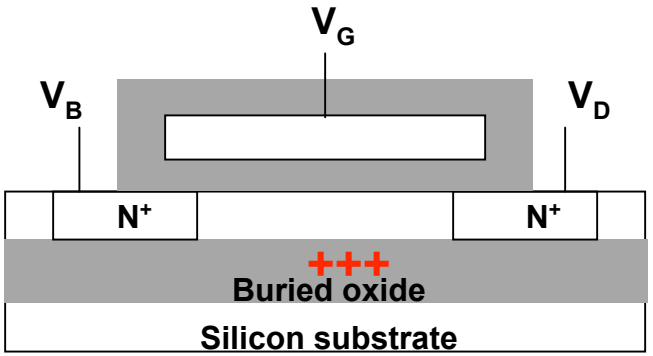
Discussion, gate length dependency



O. Flament, A. Torres, and V. Ferlet-Cavrois, "Bias dependence of FD transistor response to total dose irradiation," IEEE Trans. Nucl. Sc., vol. 50, pp. 2316-2321, DEC 2003.



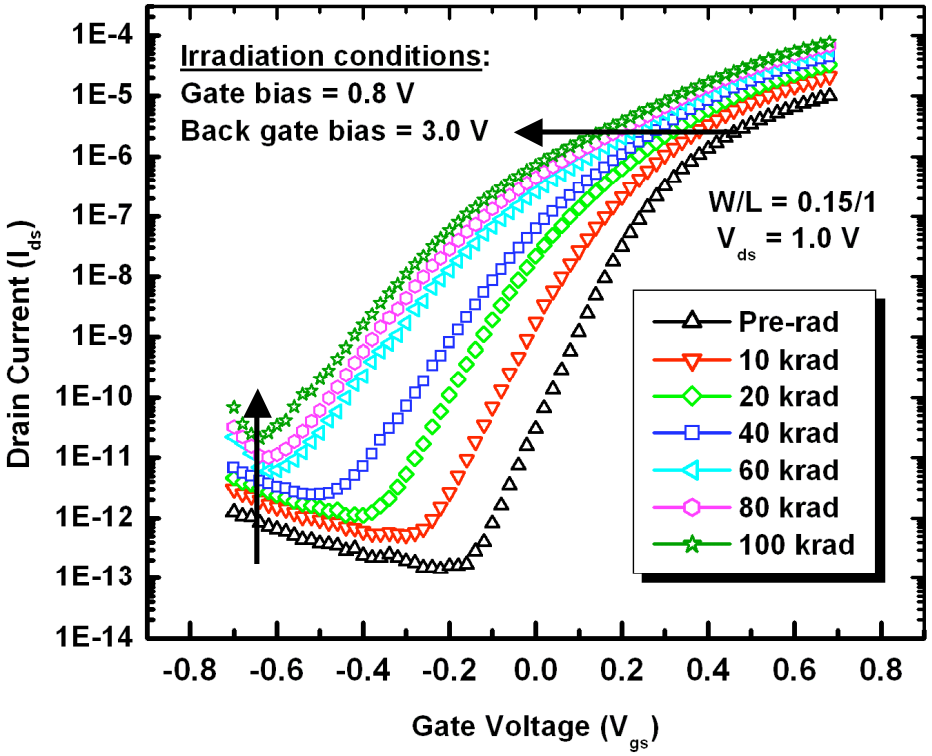
Short channel device

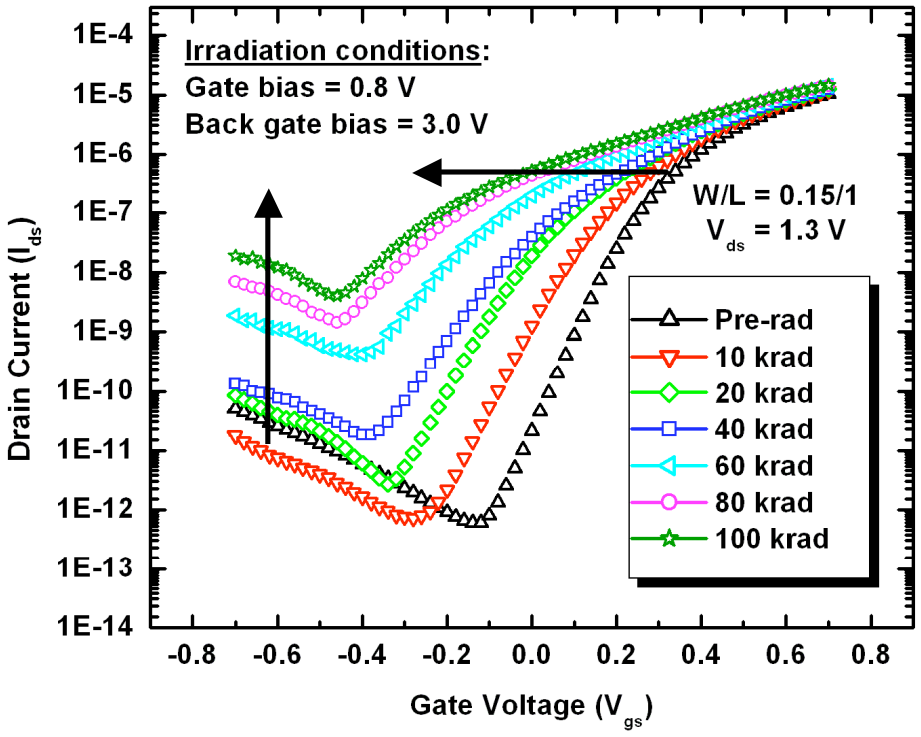


Long channel device

The increased leakage current in the shorter gate length devices were attributed to a higher source to drain electric field which enhances the amount of positive trapped charge in the buried oxide

Results, drain voltage dependency 3/3

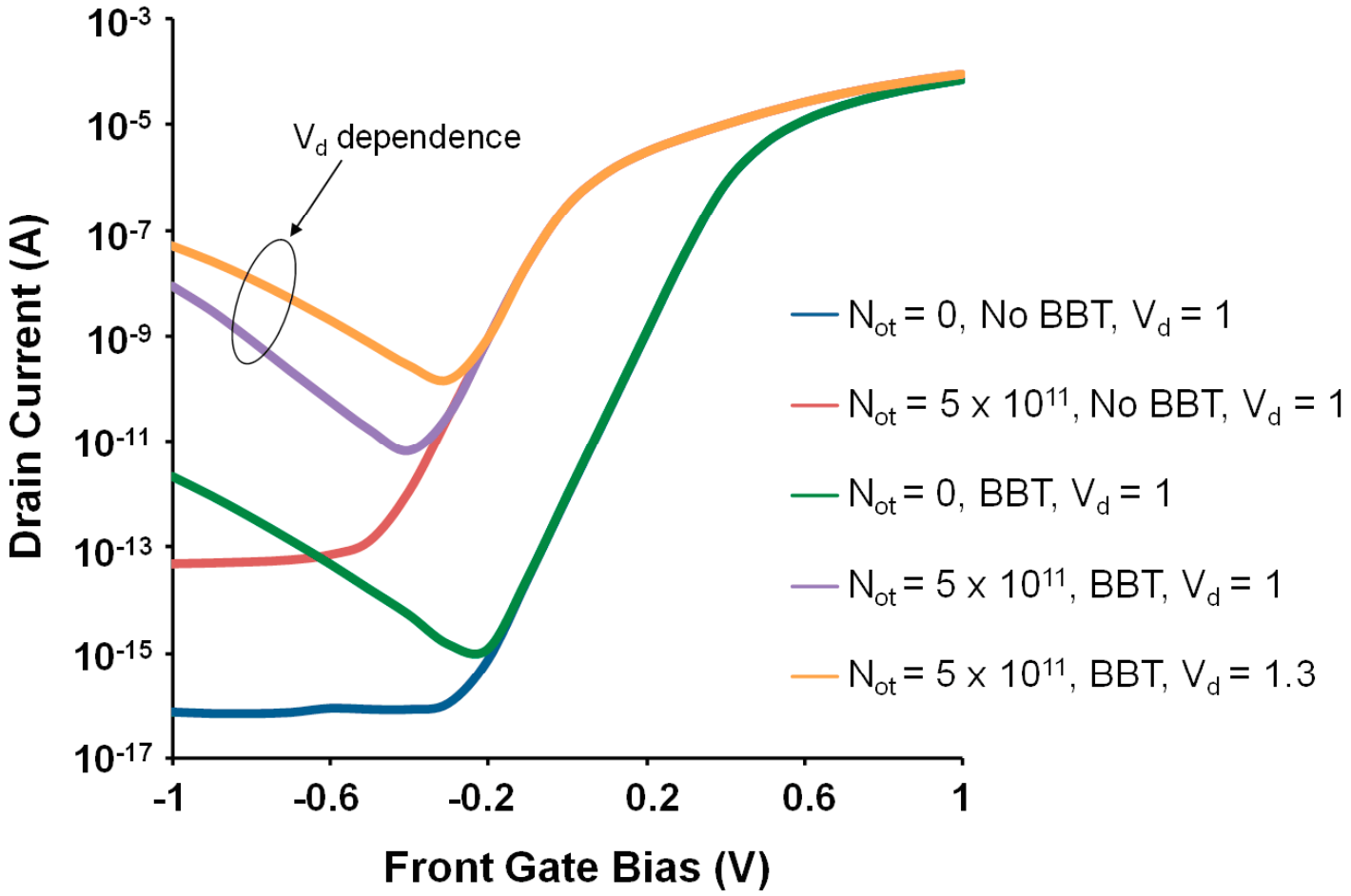




Increased drain leakage current at higher drain voltages, resulting from greater field-induced BBT tunneling.

Simulation results

Discussion, drain voltage dependency



Conclusion

To summarize, the experimental results presented here are explained by:

- Enhancement in the drain leakage current from the combined effect of BBT and trapped charge in the buried oxide [3].
- Insignificant contribution of the impact ionization in the drain leakage enhancement.
- Increased drain leakage current at higher drain voltages, resulting from greater field-induced BBT tunneling.
- Increased drain leakage current for SOI MOSFETs with shorter channels resulting from greater N_{ot} buildup in the buried oxide following irradiation [8,12].

The future experiments will be performed over bigger ranges of both drain voltage and gate length.

Backup slides

SOI technologies

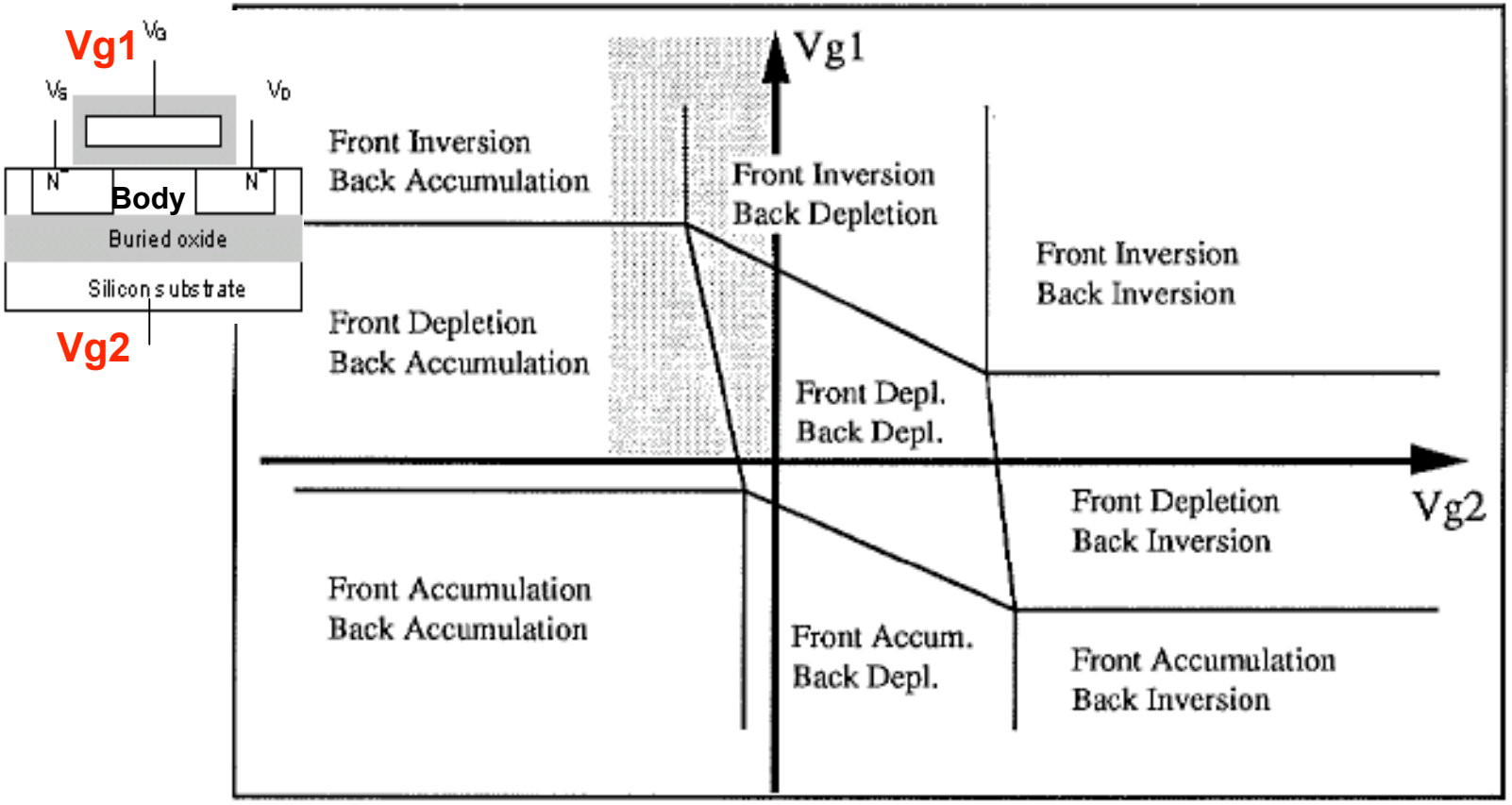
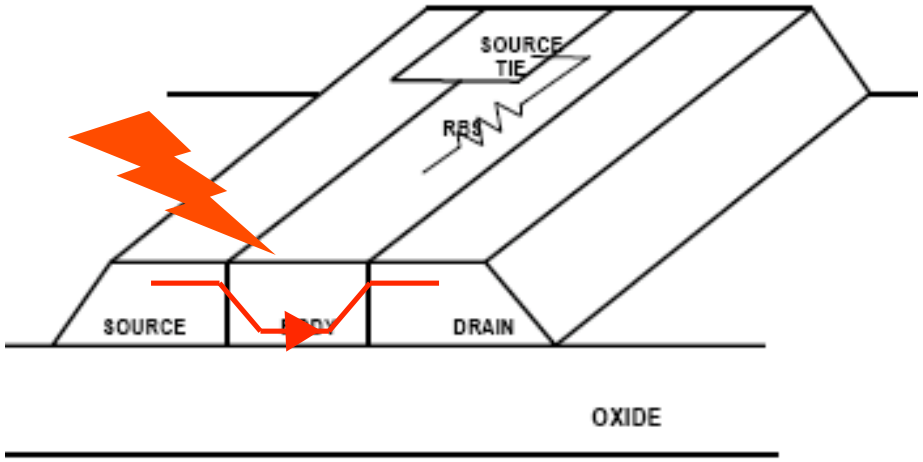
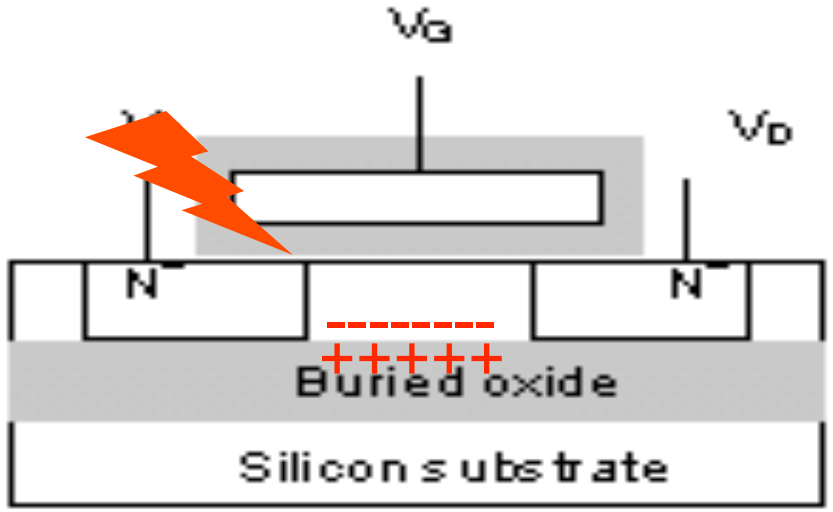


Figure 5.2.2: Different operating modes of a thin-film SOI n-channel MOS transistor as a function of front-gate bias (V_{G1}) and back-gate bias (V_{G2}) - (linear regime, low drain voltage). The shaded area represents the normal mode of operation.

SOI technologies, disadvantages (3/3)

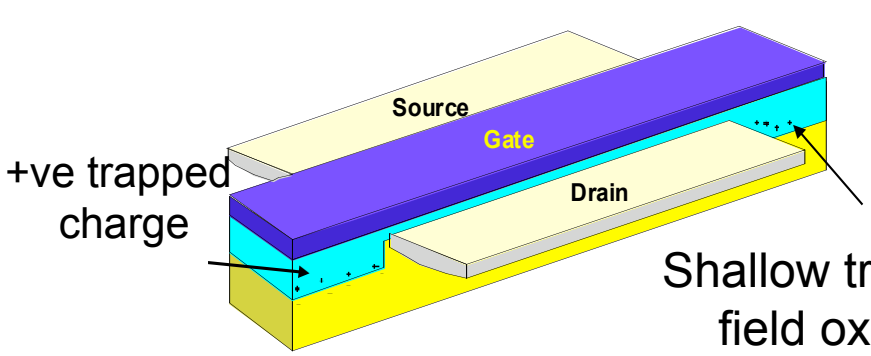


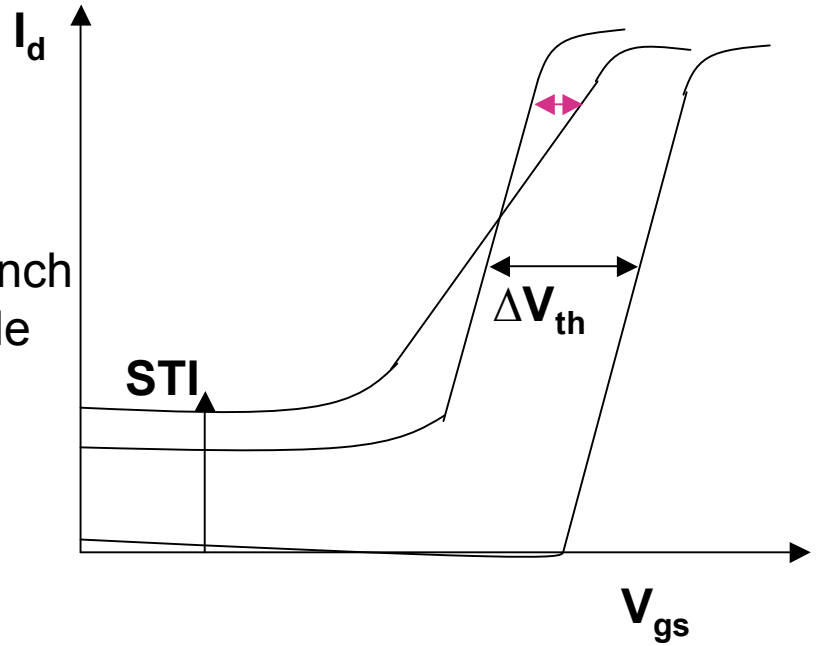
Parasitic NPN bipolar transistor [5].

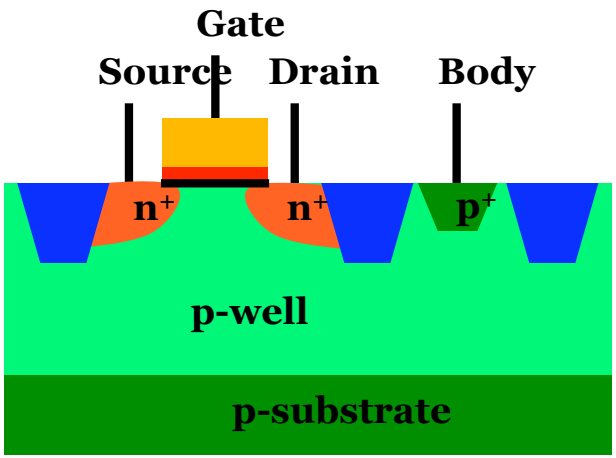


Parasitic NMOS transistor [6].

Radiation induced degradation [6]







$$Ids = \frac{\mu C_{ox} W}{2L}(V_{gs} - V_{th})^2$$

References

[1]: J. R. Schwank, M. R. Shaneyfelt, P. E. Dodd, J. A. Burns, C. L. Keast, and P. W. Wyatt, "New insights into fully-depleted SOI transistor response after total-dose irradiation," *IEEE Trans. Nucl. Sci.*, vol. 47, pp. 604-612, 2000.

[2]: J. H. Chen, S. C. Wong, and Y. H. Wang, "An Analytic Three-Terminal Band-to-Band Tunneling Model on GIDL in MOSFET", IEEE Trans. Nucl. Sci. , vol. 48, NO. 7, JULY 2001.

[3]: P. C. Adell, H. J. Barnaby, R. D. Schrimpf, and B. Vermeire, "Band-to-band tunneling (BBT) induced leakage current enhancement in irradiated fully depleted SOI deviccs," *IEEE Trans. Nucl. Sci.*, vol. 54, pp. 2174-2180, 2007.

[4] : SOI Overview in the Context of CMOS Scaling: Technology and Circuit Design Issues Koushik K Das, *SSEL, The University of Michigan, Ann Arbor. Presentation found on line.*

[5] : Dr. Massengilll's lectures (5 and 6).

[6] : Dr. Fleetwood's lecture.

[7] : Bongim et al,"Temperature Dependence of Off-State Drain Leakage in X-Rays Irradiated 130 nm CMOS Devices.

[8] : V. Ferlet-Cavrois, S. Quoizola, O. Musseau, O. Flament, J. L. Leray, J. L. Pelloie, C. Raynaud, and O. Faynot, "Total dose induced latch in short channel NMOS/SOI transistors," Ieee Transactions on Nuclear Science, vol. 45, pp. 2458-2466, 1998.

[10] : [1] J.-P. Colinge, Silicon-on-Insulator Technology: Materials to VLSI, first ed.: Kluwer Academic Publishers.

[11] : P. Paillet, M. Gaillardin, V. Ferlet-Cavrois, A. Torres, O. Faynot, C. Jahan, L. Tosti, and S. Cristoloveanu, "Total ionizing dose effects on deca-nanometer fully depleted SOI devices," IEEE Trans. Nucl. Sc. , vol. 52, pp. 2345-2352, DEC 2005.

[12] : O. Flament, A. Torres, and V. Ferlet-Cavrois, "Bias dependence of FD transistor response to total dose irradiation," IEEE Trans. Nucl. Sc., vol. 50, pp. 2316-2321, DEC 2003.