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Layout Dependence of Total Ionizing Dose Effects on 12-nm Bulk FinFET Digital Structures

Trace Wallace, *Student Member IEEE*

Arizona State University, Tempe, AZ

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Co-Authors

M. Spear, *Student Member*, *IEEE,*
A. Privat, *Member, IEEE*
J. Neuendank, *Student Member*, *IEEE,*
G. Irumva
D. Wilson, *Student Member*, *IEEE*
I. Sanchez Esqueda, *Senior Member, IEEE*
H. J. Barnaby, *Fellow*, *IEEE*
M. Turowski, *Senior Member IEEE,*
E. Mikkola,
D. Hughart, *Member, IEEE*
M. J. Marinella, *Senior Member, IEEE*
A. Gutierrez, *Senior Member IEEE*
R. Von Niederhausern
S. Holloway, *Student Member, IEEE*
D. Beltran
J. L. Taggart, *Member, IEEE*

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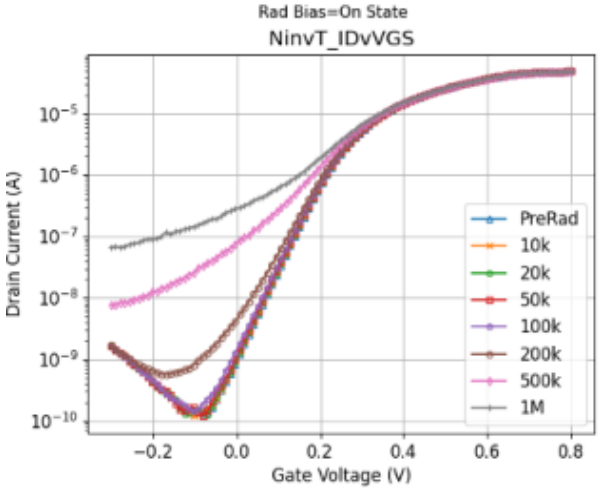
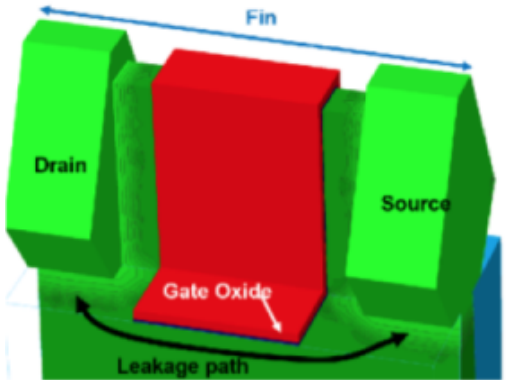
Introduction

- Explored impact of total ionizing dose (TID) on 12nm FinFET technology
- Data collected on digital FinFET structures designed at ASU for Sandia SEEEC program
- All FETs tested are the regular threshold voltage (RVT) variant
- Structures exhibited susceptibility to TID, dependant on layout



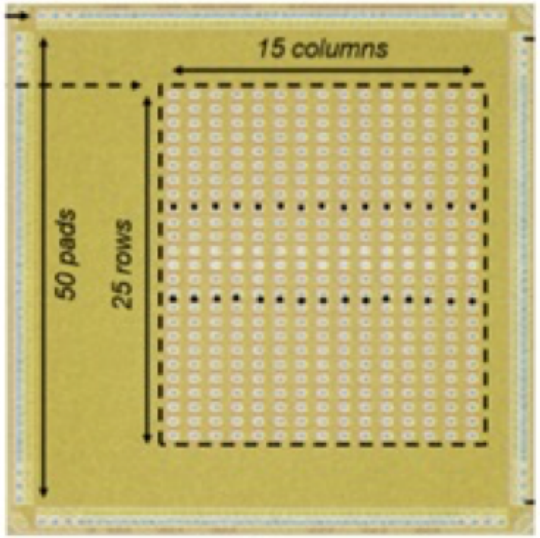


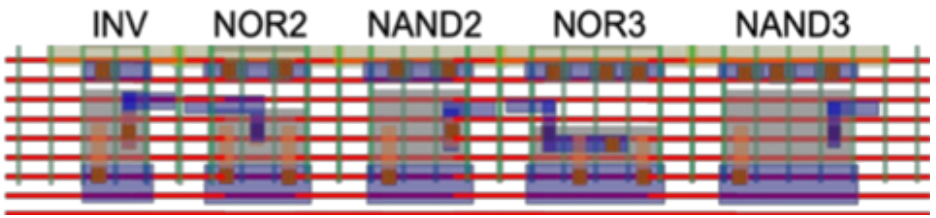
Outline

- Experimental details
- TID results and discussion
- Conclusions

Experimental Details

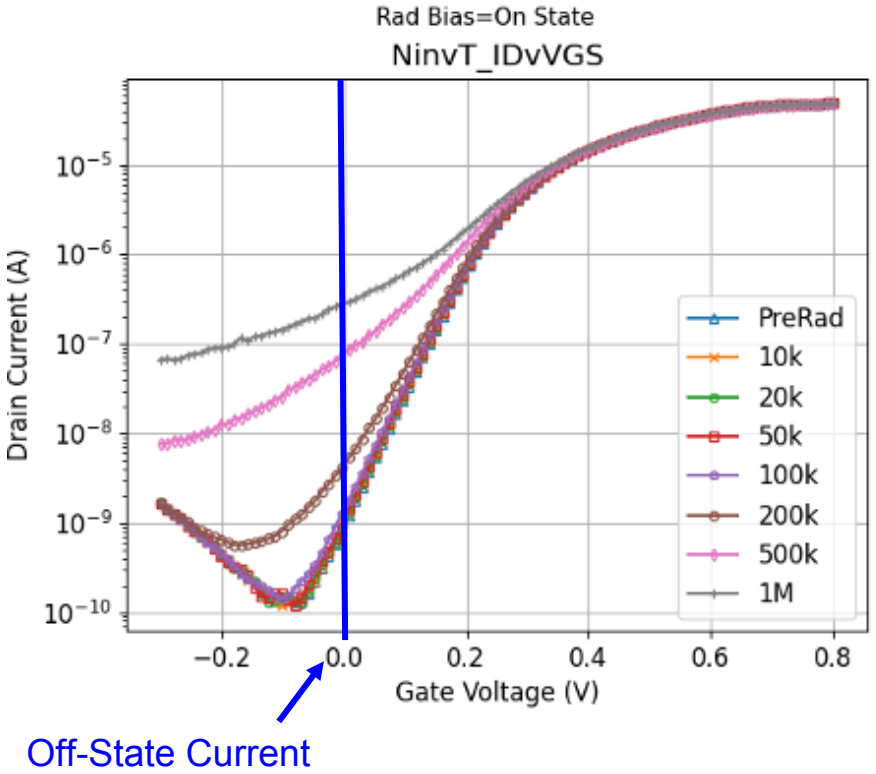
- Experiments performed on 12nm RVT FinFET test structures
- Test structures are nFET pull-down networks of various logic gates
- Devices tested under both X-rays and gamma rays
- X-ray source was a 60keV ARACOR at AFRL in ABQ, NM
- Gamma source was 63.6 rad/s source used at Sandia in ABQ, NM





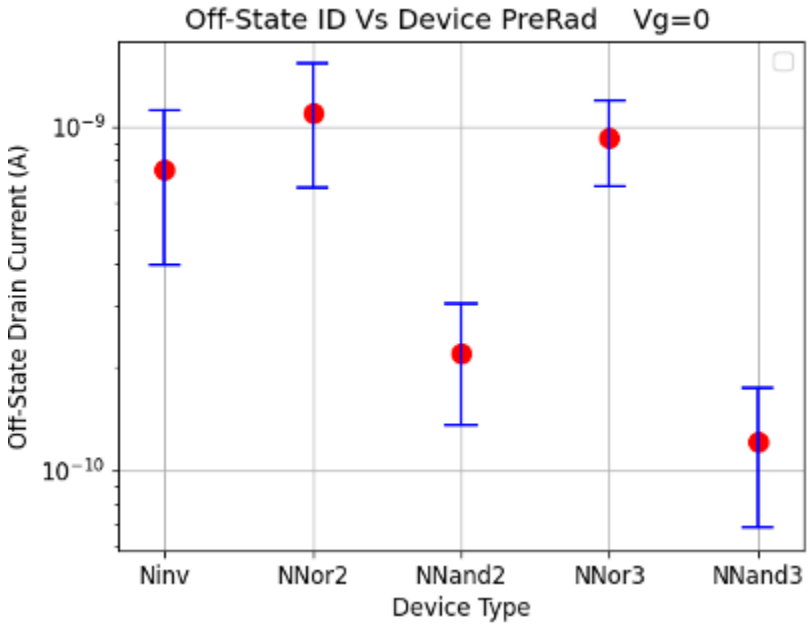
Experimental Results - X-ray NINV

- Graph shows TID response of one representative INV structure exposed to X-rays
- Difference between Pre-rad and 1 Mrad(Si) off-state current is 2 orders of magnitude!
- Blue line represents off-state current value



Experimental Results - Pre-Rad

- Pre-rad off-state current trends analyzed
- Graph markers represent average of 38 data points across 11 chips
- Data show off-state drain current scales with W/L

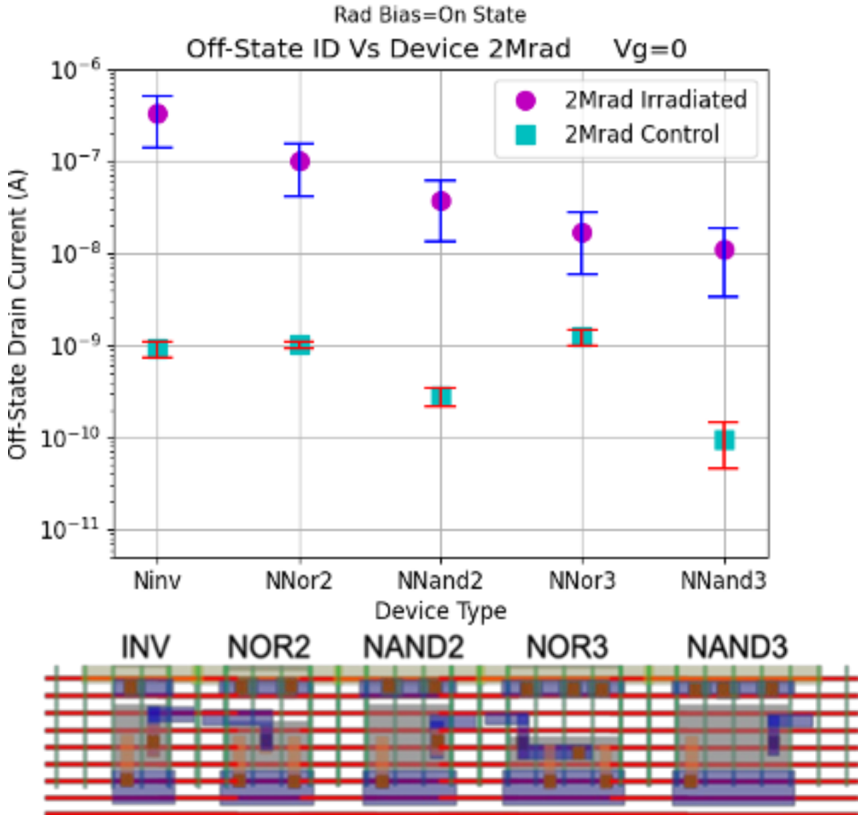


Normalized W/L for nFET configurations

Config.	#fin	#parallel	#series	W/L (norm)
INV	4	1	1	4
NOR2	3	2	1	6
NAND2	4	1	2	2
NOR3	2	3	1	6
NAND3	4	1	3	4/3

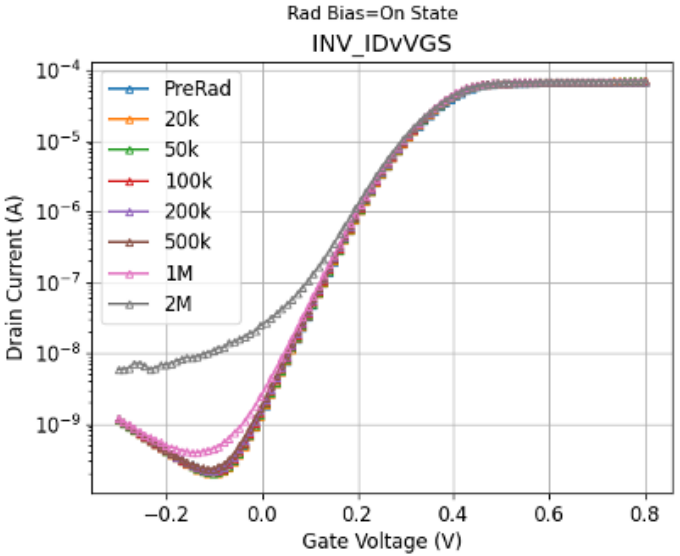
Experimental Results - 2Mrad X-ray

- Control data and pre-rad off-state currents follow trends consistent with relative W/L
- Post-irradiation magnitude of off-state current correlates with the position of the device in the layout
- Symbols are average of 20 data points across 5 chips for irradiated data and 8 points across 2 chips for control data



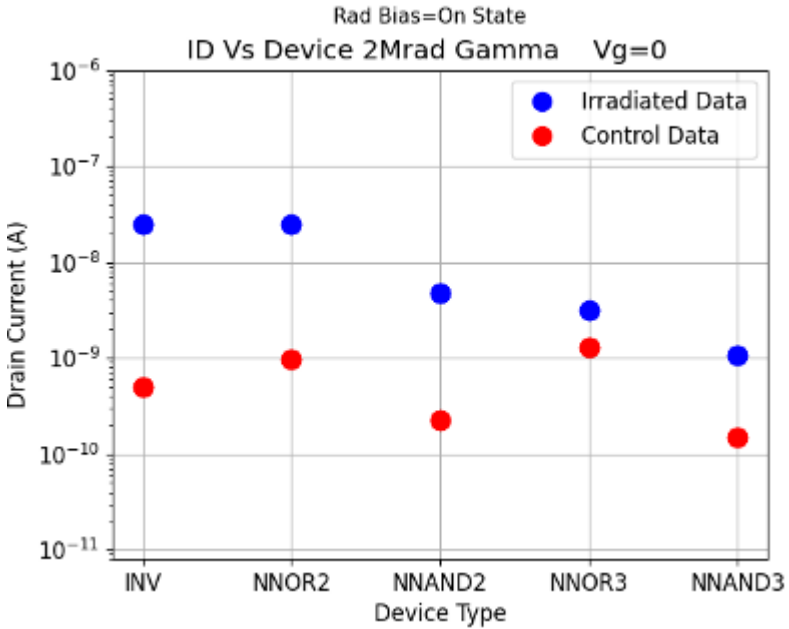
Experimental Results - Gamma NINV

- To examine the effect of TID on these devices further data was taken under gamma radiation
- Devices did not exhibit as much off-state current increase
- Still significant change at a dose of 2Mrad



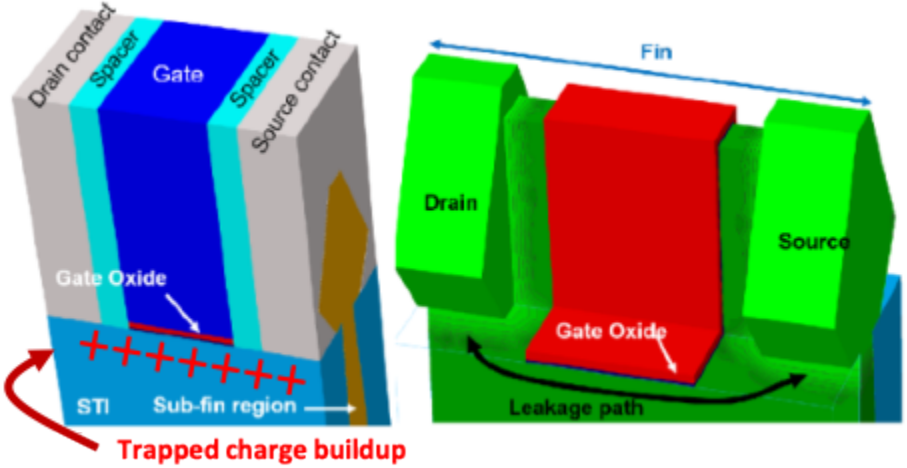
Experimental Results - 2 Mrad gamma-ray

- Same as X-ray data, control and pre-rad follow trends consistent with relative W/L
- Post-irradiation magnitude of off-state current also correlates to the structure order in the layout!



TCAD Structure - Leakage Path

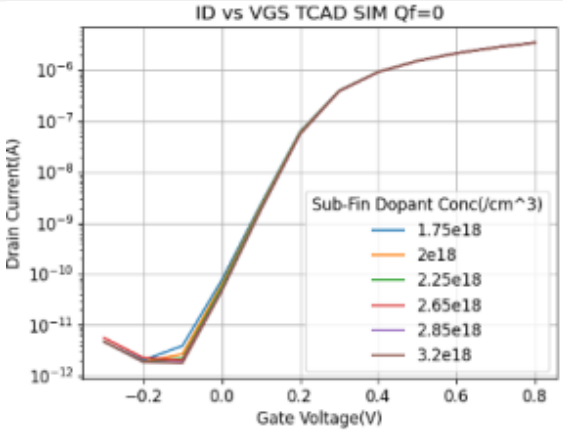
- Method of leakage via a created channel in the sub fin region of the device
- Trapped charge accumulates in the Shallow Trench Isolation Oxide (STI)



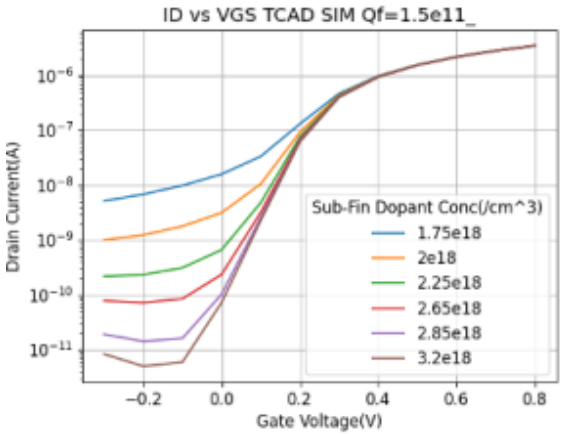
TCAD Simulation

- TCAD simulations were run to examine effect of sub-fin doping on off-state leakage
- Leakage current is HIGHLY dependant on p-type doping concentration in sub-fin region

If there is relationship between sub-fin doping and layout, this may partially explain TID response



Pre-Rad



Post-Rad

Conclusion

- All devices showed similar TID susceptibility trends
- Pre-irradiation off-state and subthreshold currents scaled to relative sizes of devices
- After irradiation, above 500 krad, positioning of devices in digital structure layout began to appear as the dominant factor in TID response
- Sub-fin doping may be a factor in TID dependance on layout, but this still needs to be investigated