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Total Ionizing Dose Effects on Gallium Oxide MOSFETs

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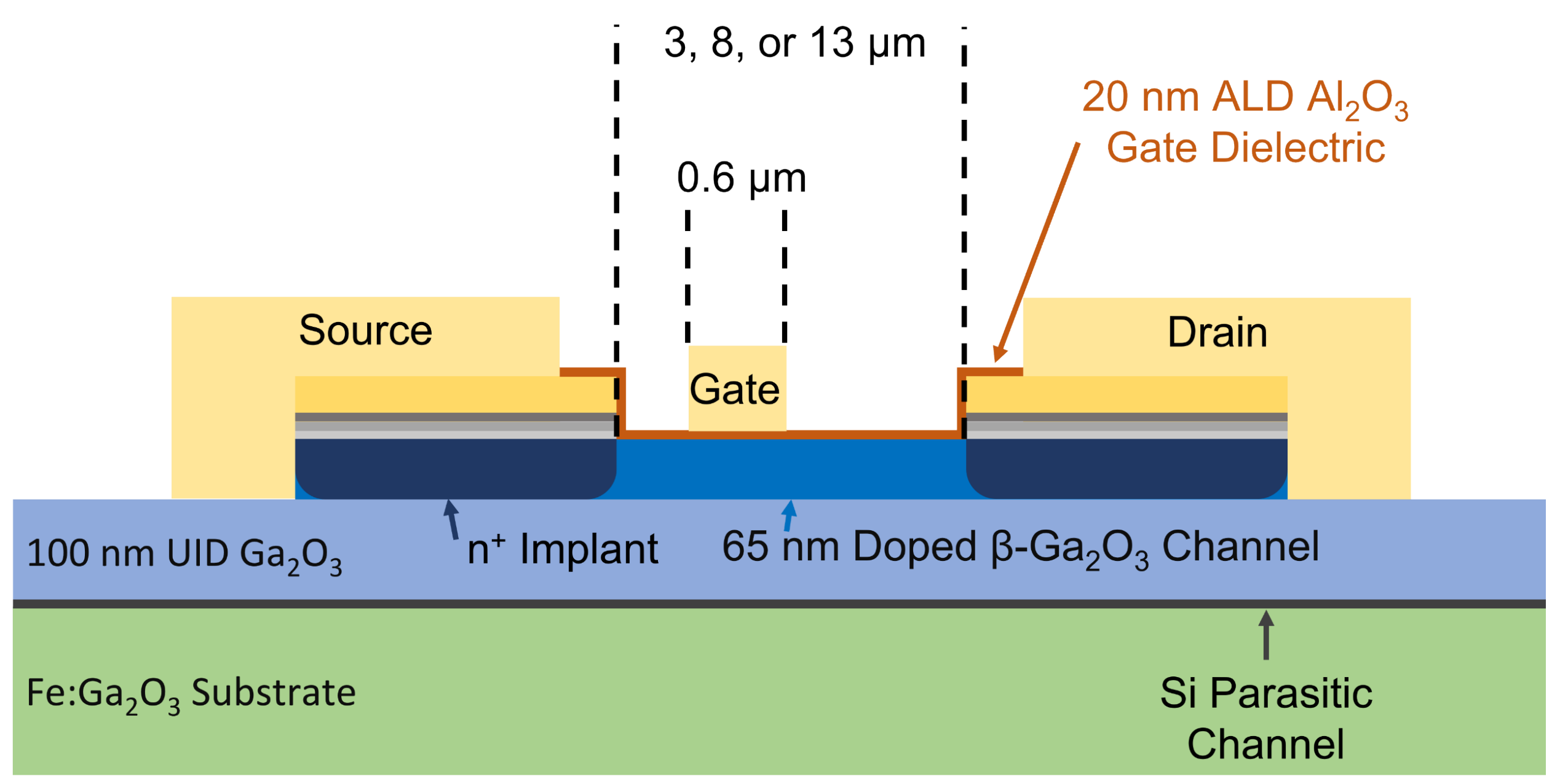
Abstract

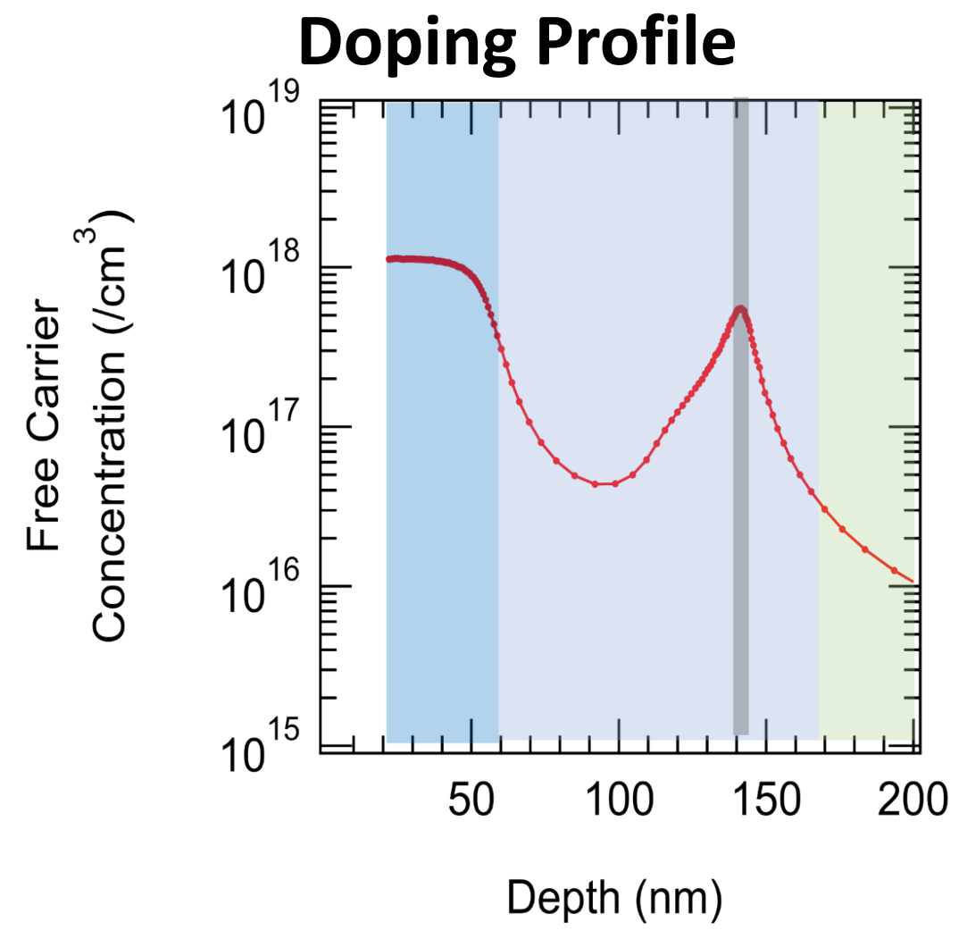
β-Ga_2O_3 lateral MOSFETs were irradiated with 10 keV x-rays. Negative threshold voltage shifts were observed. After room-temperature annealing for several weeks, the threshold voltage became more positive than the pre-irradiation value. Technology Computer Aided Design (TCAD) simulations of the surface potential at the oxide/semiconductor interface show a threshold voltage shift from trapped charges that aligns with those experimentally observed.

Experimental Setup

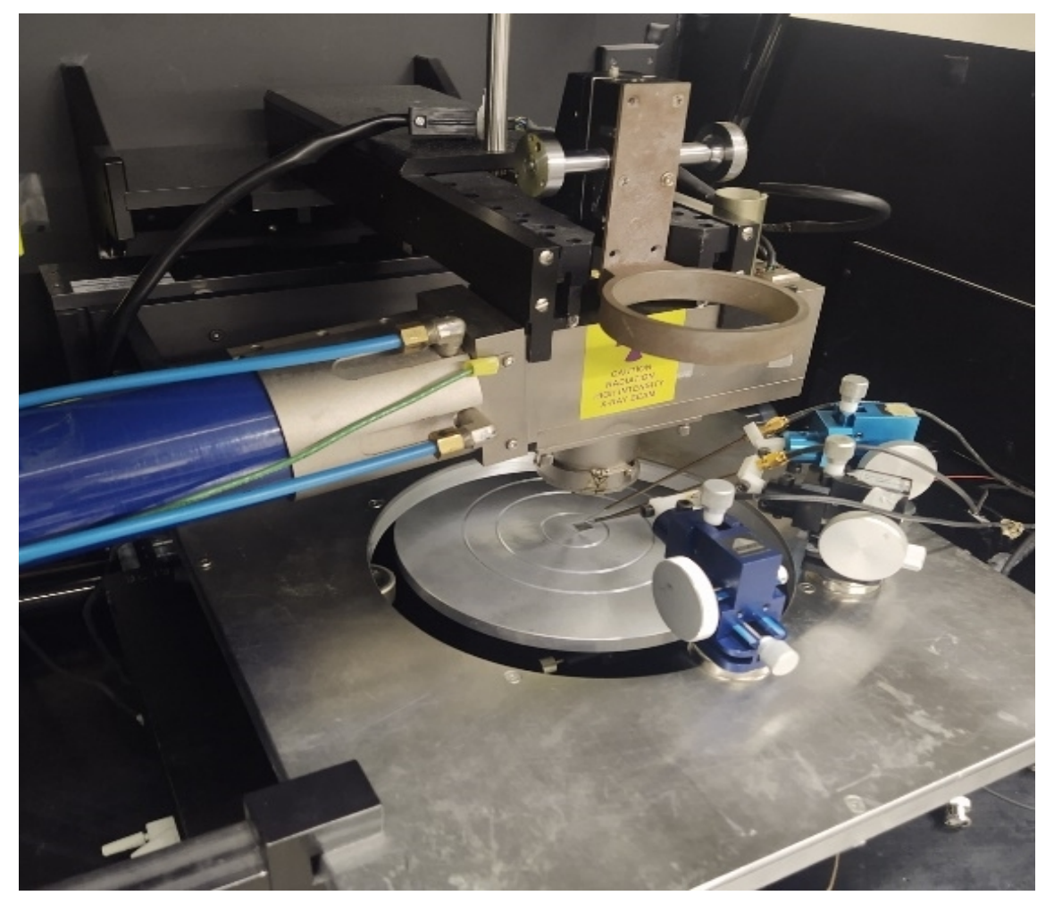


- β-Ga_2O_3 MOSFETs manufactured by AFRL were tested (above).
- Epitaxial structure grown in Cornell University's MOCVD.
- Devices tested had a source-to-drain length of 3 µm or 13 µm and a gate length of 0.6 µm.
- The MOCVD grown epitaxial layer consisted of a 65 nm 1 x 10^{18} /cm^3 channel on top of the 100 nm unintentionally doped (UID) buffer. A free carrier spike is observed at the substrate-epitaxial interface (bottom left).
- Total Ionizing Dose (TID) tests were done with 10 keV X-rays using the Aracor 4100 test system (bottom right).
- Devices were irradiated at a dose rate of 25.08 krad(SiO_2)/min.
- Source, gate, and drain were grounded, and the terminals were probed.
- Gate sweeps were performed after each irradiation step with the drain biased at 8 V.

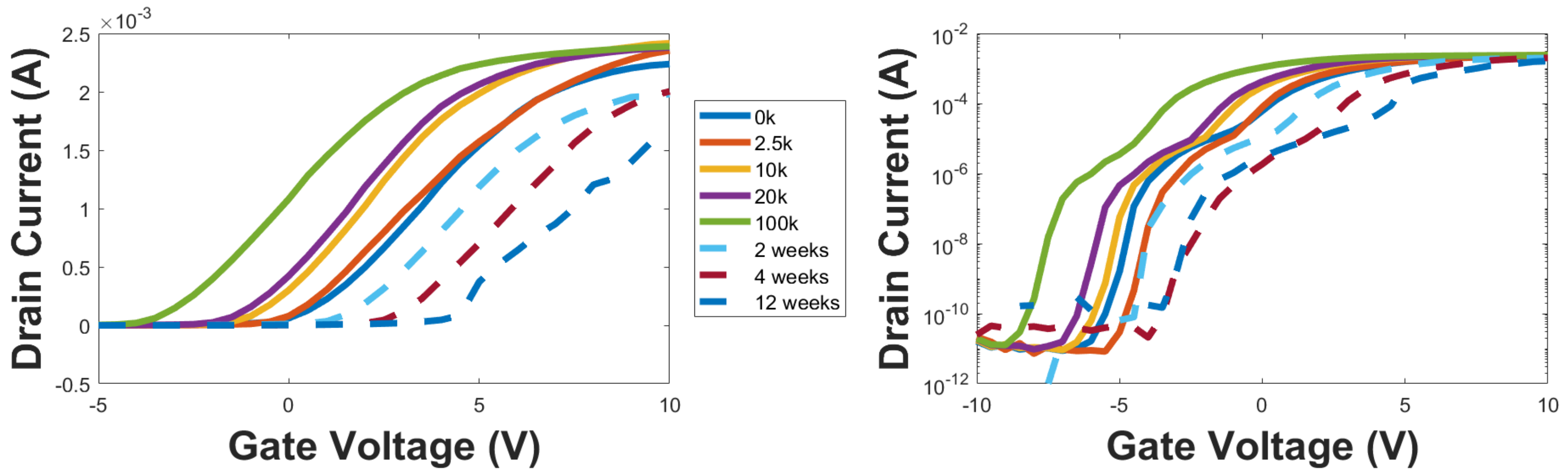
Doping Profile



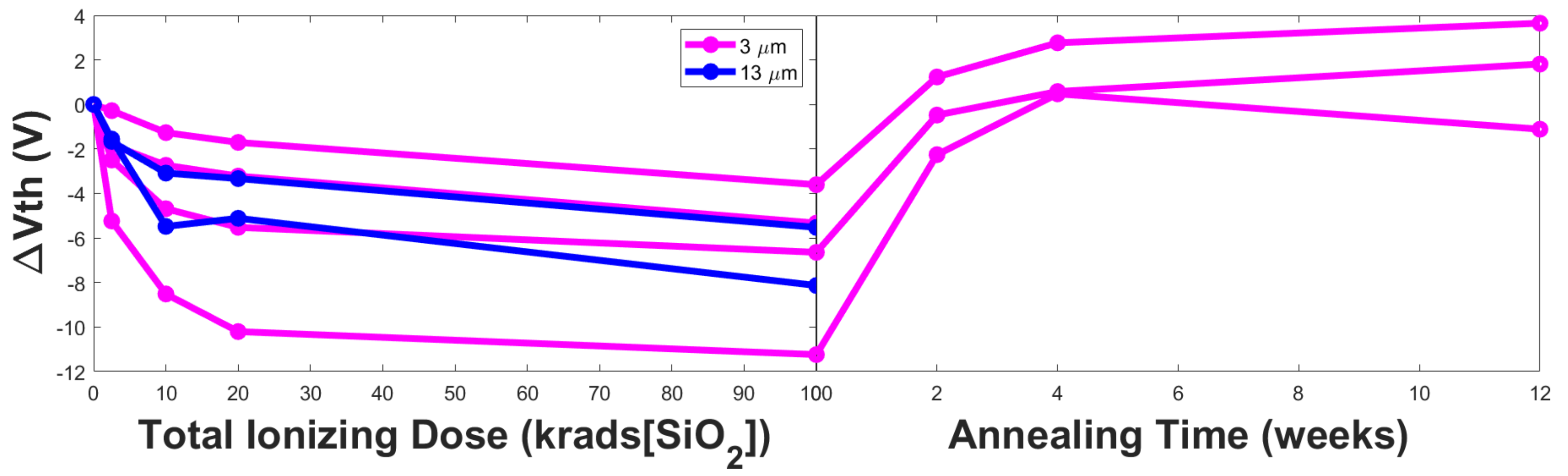
Aracor Setup



Experimental Results



- Transfer characteristics were measured after a series of irradiations up to 100 krad (SiO_2) (one device shown above). These show a typical negative threshold voltage shift with increasing dose [1].
- There are two noticeable turn-on regions in the subthreshold current. The first turn-on (at lower gate voltage) is caused by the parasitic Si channel [2].
- Threshold voltage shifts were extracted from intercept of the square root of the transfer curve for each device after each irradiation (results shown below).
- Two weeks after the initial irradiation, the threshold voltage of the devices shifted back to approximately the pre-irradiation value. After four weeks, it shifted even further positive.
- Threshold voltage shifts follow a consistent trend across irradiation, annealing, and device width.
- In between annealing measurements, devices were stored unbiased in an ESD gel pack box.



Acknowledgments

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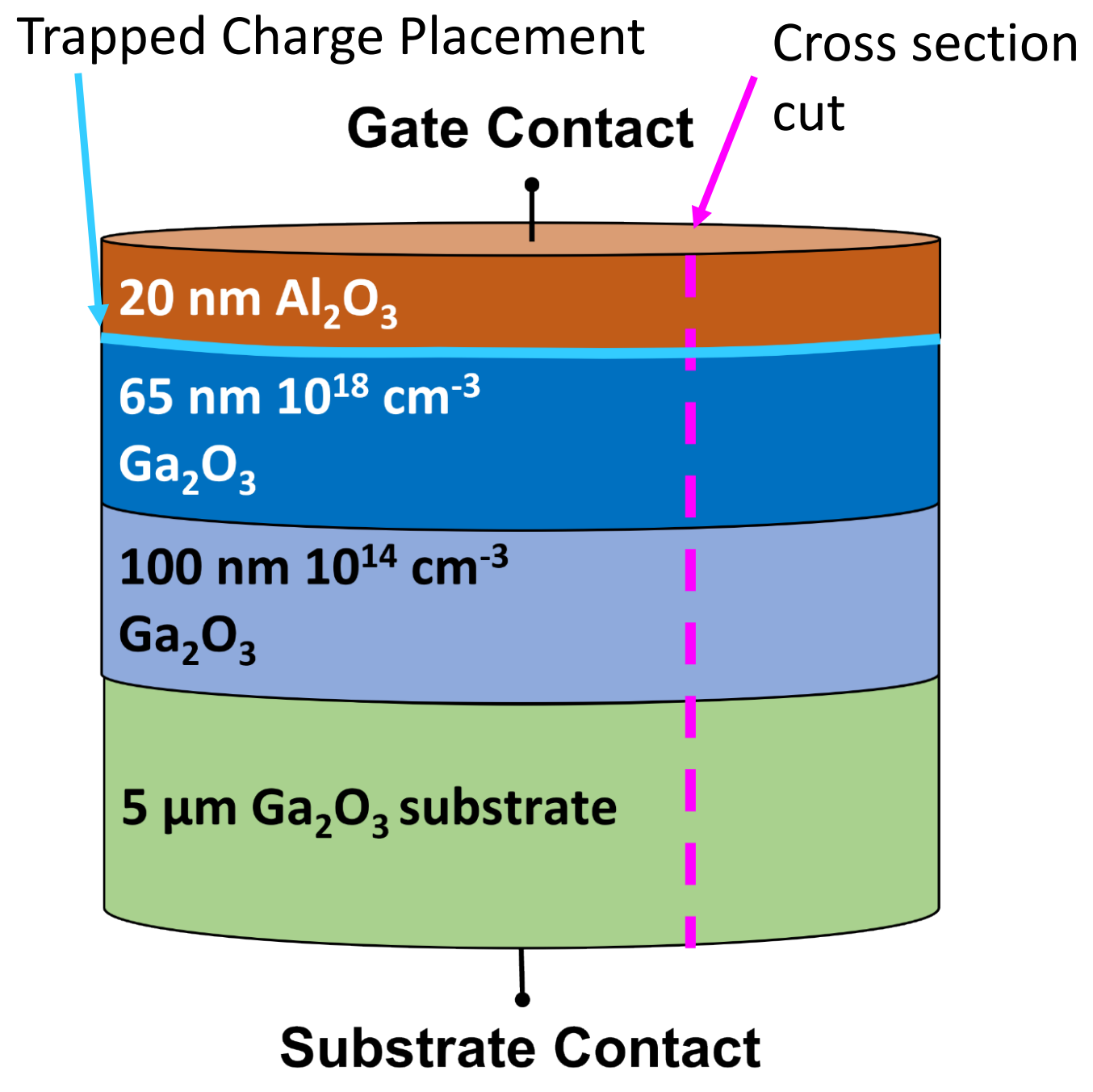
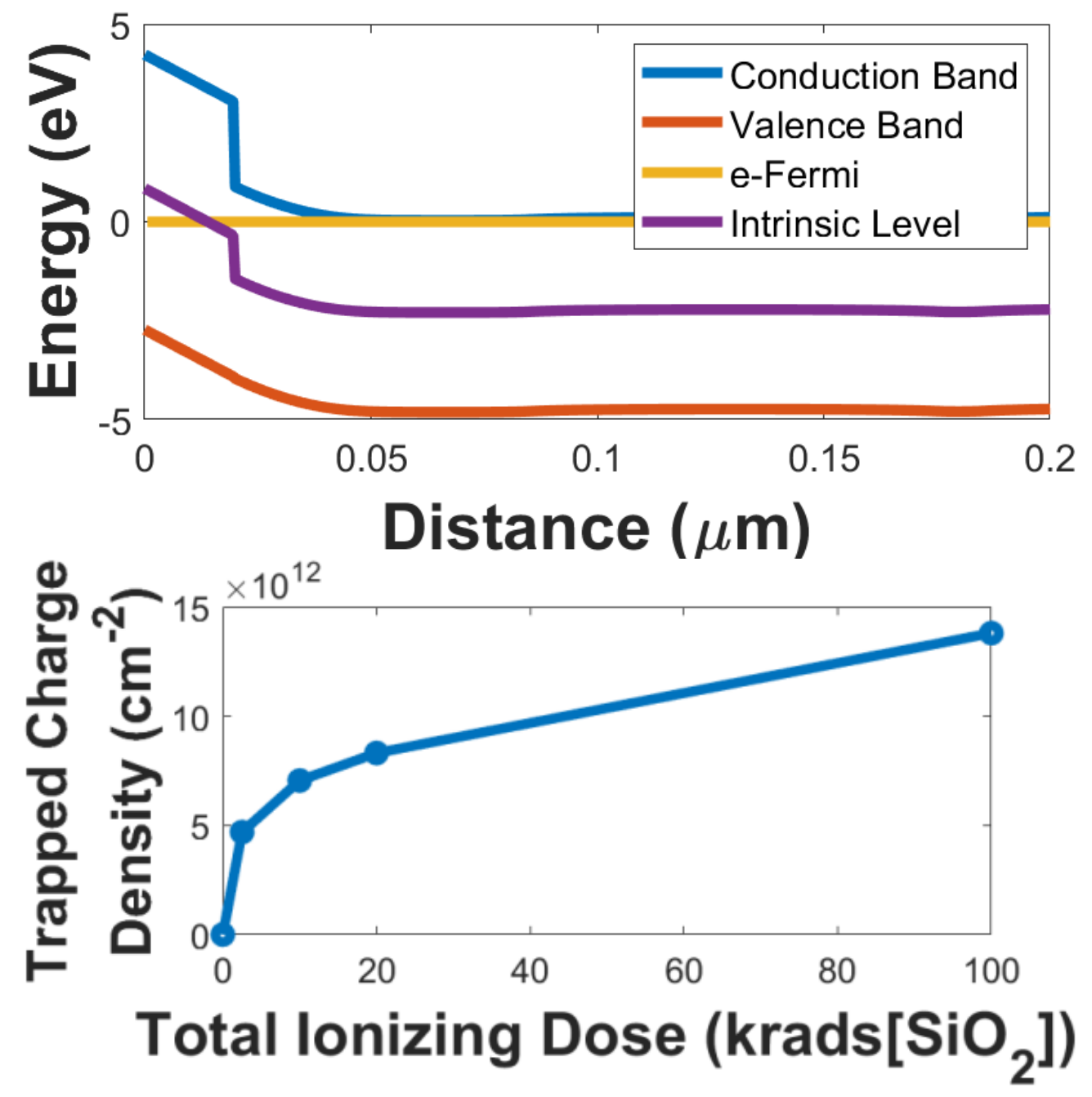
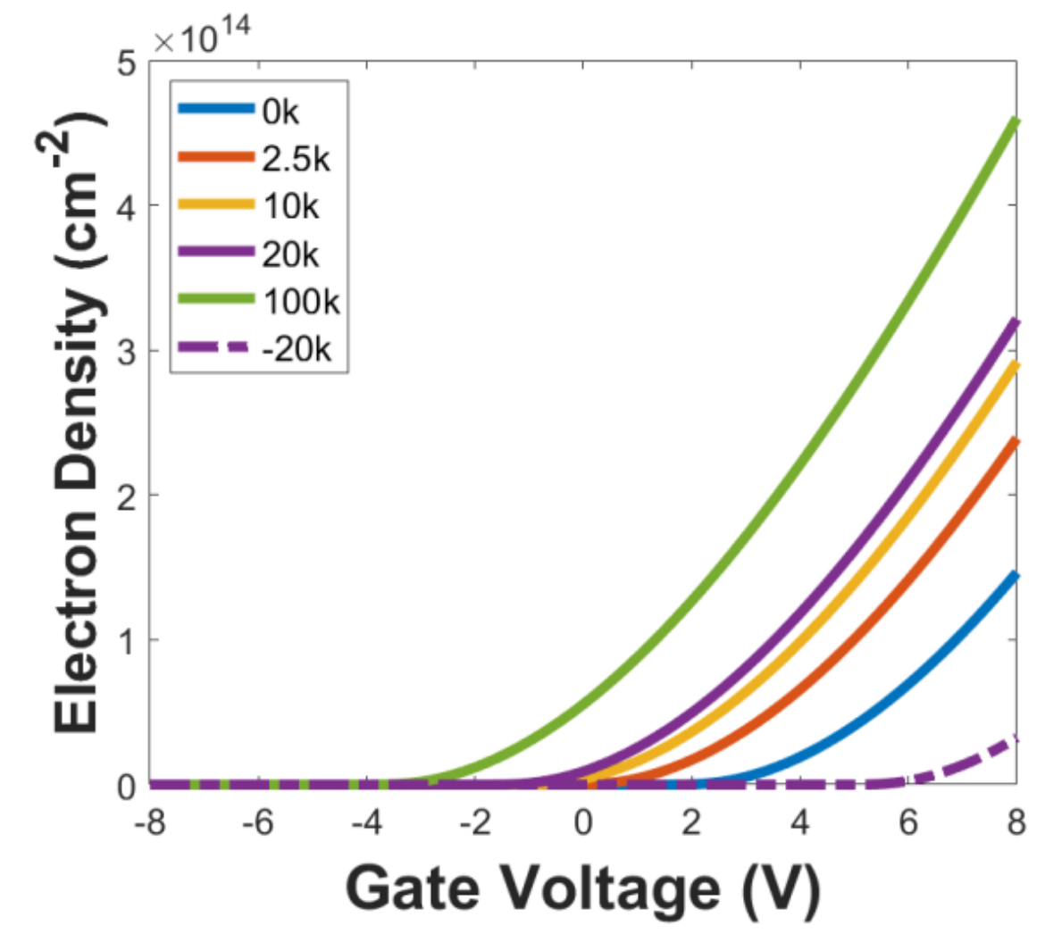
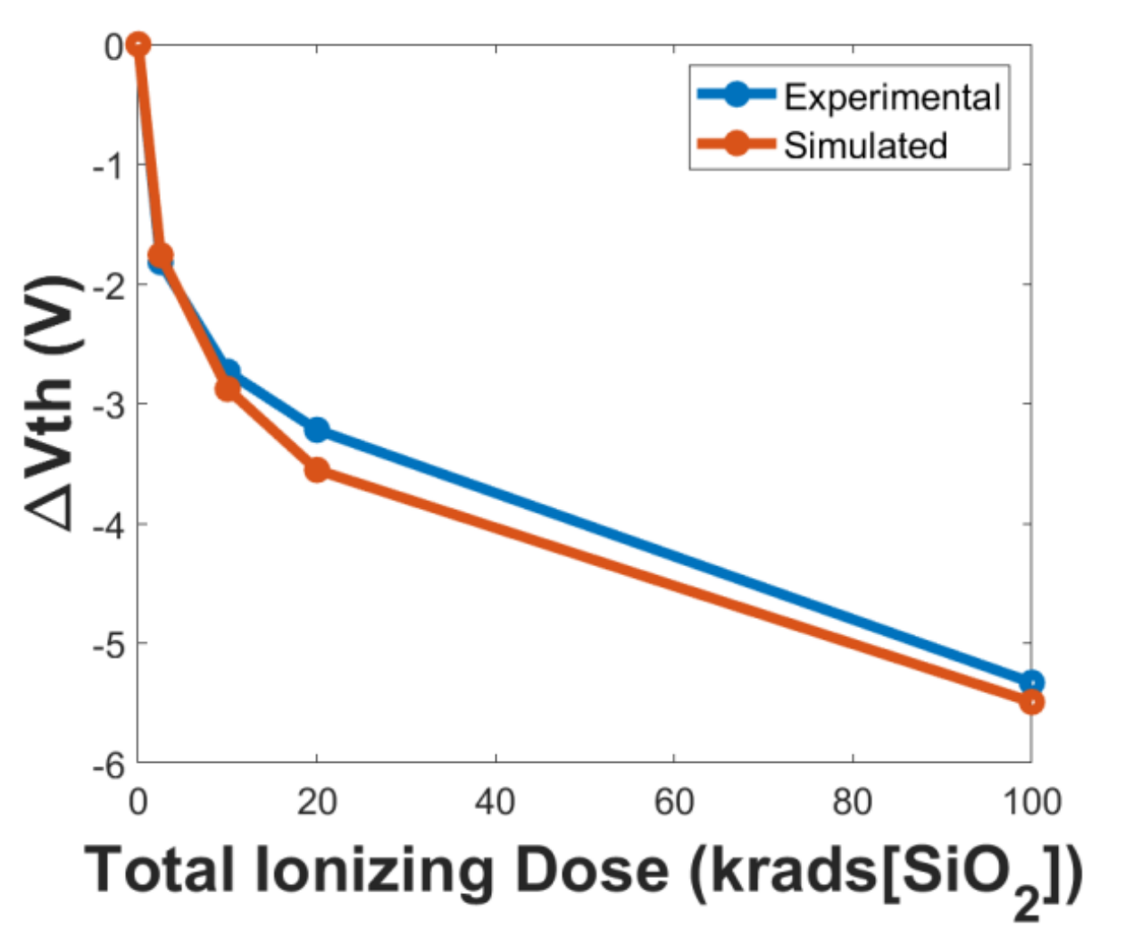
Simulation Results





- A TCAD 2D simulation of the gate region was developed in Synopsis Sentaurus [3].
- Bandgaps, band offsets, electron mobilities, and permittivities for Ga_2O_3 and Al_2O_3 were taken from the literature [4], [5].
- The energy band diagram shows a cut vertically through the gate region at 0V bias.
- The band diagram indicates the devices are close to depletion mode devices and can become so with increased charge at the interface.
- Trapped charge calculations were done for the devices using methods from [1] and were represented in the TCAD simulation as a sheet of trapped charge at the oxide/semiconductor interface.
- These simulations were used to model the electron density per unit area as if it were located as a sheet charge under the gate oxide.
- The shifts in the electron density was compared to the experimental data and used to infer the trapped charge as a function of TID.
- With time, the hole trapping is neutralized and eventually overcome by the introduction of deep electron trapping [3]. This is highlighted by the dashed line meant to represent electron trapping.





Conclusion

Negative threshold voltage shifts were observed in β-Ga_2O_3 MOSFETs after being irradiated with 10 keV x-rays. Room-temperature annealing resulted in a threshold voltage that was more positive than the pre-irradiation values. TCAD simulations corroborate the notion that an increase in trapped charges as seen at the interface between the semiconductor and oxide lead to a negative threshold voltage shift.