Radiation tolerance studies of the HV-mux GaNFETs for the HL-LHC ATLAS ITk Strip Detector

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ATLAS ITk Strip Detector

The current ATLAS inner detector will be upgraded with the Inner Tracker (ITk), an all-silicon based tracking system consisting of two subsystems: ITk Pixel and ITk Strip.

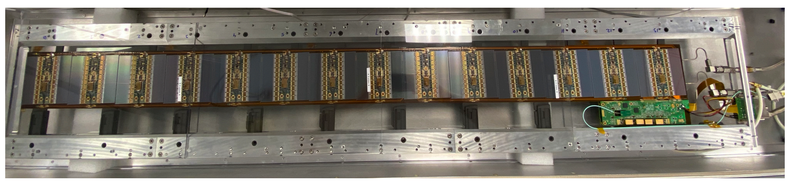

Fig. 1: Master side of ITk Strip stave built at Brookhaven National Laboratory

A module houses ASICs responsible for data readout: ATLAS Binary Chip (ABC) and Hybrid Control Chip (HCC). and monitoring and control via an Autonomous Monitoring and Control Chip (AMAC) and a GaNFET.

Module powerboards are capable of monitoring and control via an Autonomous Monitoring and Control Chip (AMAC) and a GaNFET.

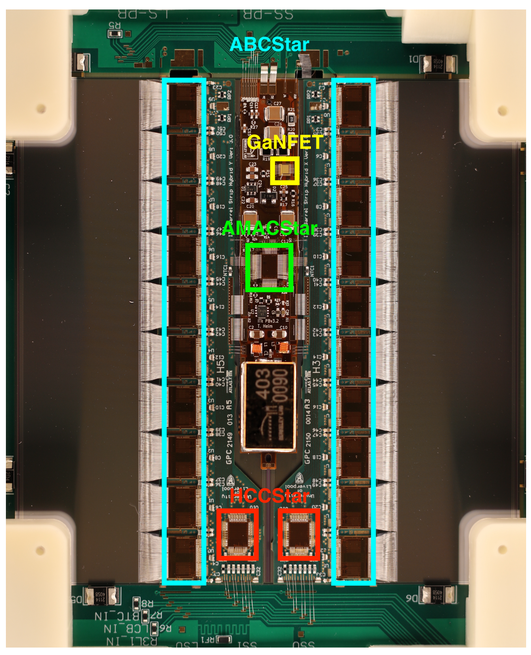

Fig. 2: Short strip module built at Brookhaven National Laboratory

GaNFETs for ATLAS ITk Strip Detector

Due to space constraints, up to 4 modules share a single high voltage (HV) bias line. GaNFETs are radiation-tolerant transistors that will be placed on every module for switching off high voltage to malfunctioning silicon sensors on the ATLAS ITk Strip detector to avoid interruptions of the HV to neighboring modules.

AMACs will control the GaNFET gate-source voltage with an oscillating 3.3V output voltage via a high voltage multiplexing circuitry (HV-Mux).

At the end of the ITk Strip detector lifetime, GaNFETs need to tolerate a drain-source voltage near 500V.

References

1. ATLAS Collaboration, *Technical Design Report for the ATLAS Inner Tracker Strip Detector,* Tech. Rep. CERN-LHCC-2017-005, 2017.
2. E.G. Villani et al., *HVMUX, the High Voltage Multiplexing for the ATLAS Tracker Upgrade,* JINST 12 C01076, 2017.
3. F. Faccio and G. Cervelli, *Radiation-induced edge effects in deep submicron CMOS transistors,* Nucl. Sci. IEEE Trans., 52(6): 2413-2420, 2005.
4. T.R. Oldham, *Ionizing Radiation Effects in MOS Oxides,* International Series on Advances in Solid State Electronics and Technology: World Scientific, 2000.
5. ATLAS Collaboration, *ITk Strip GaNFETs Irradiation,* ITK-2022-003, 2022. Plots available online at https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2022-003/

GaNFETs Irradiation

80 GaNFETs were irradiated with gammas from a Co^{60} source at BNL for a total ionizing dose (TID) of 50 Mrad at a rate of 27.6-29.4 krad/hr.

60 GaNFETs were irradiated in the on-state and 20 GaNFETs were irradiated in the off-state, with a drain-source voltage of 500V. The GaNFET's state was inverted every 3 hours to verify the device was still operating.

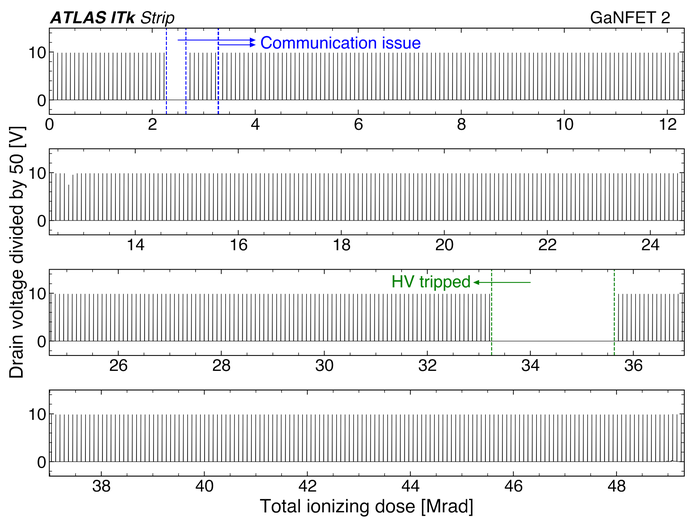

Fig. 3: Example of an on-state GaNFET monitoring. [ITK-2022-003]

4 GaNFETs irradiated in the off-state switched to a constant on-state at a minimum TID of 30.7 Mrad.

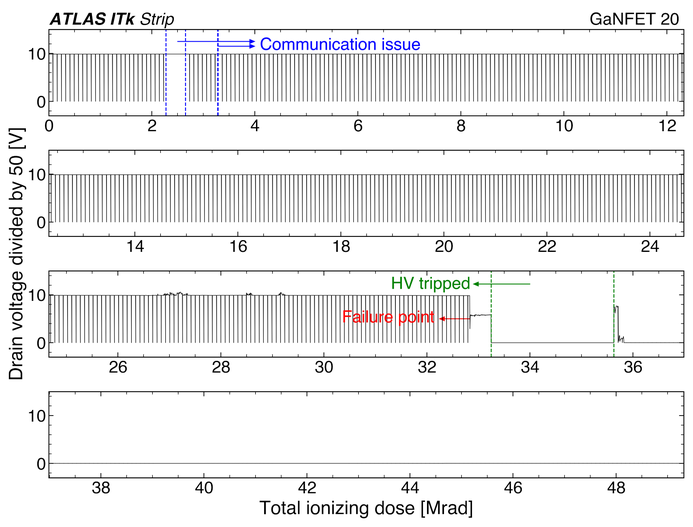

Fig. 4: Example of an off-state GaNFET monitoring. [ITK-2022-003]

2 of the 4 GaNFETs that switch to a constant state mid-irradiation showed signs of a single event burnout (SEB).

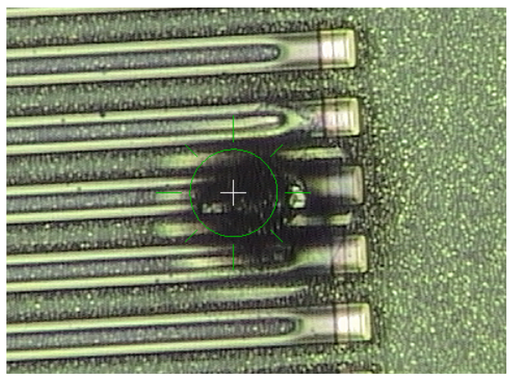

Fig. 5: GaNFET 20 SEB

Conclusions and Outlook

1. Slight decrease in voltage threshold by an average of 3.5%.
2. Increase in current leakage by an average of 66.6%.
3. All GaNFETs irradiated in the on-state remained operational up to 50 Mrad.
4. 20% GaNFETs irradiated in the uncommon off-state failed after at least 30.7 Mrad.
5. 2 GaNFETs showed visible single event burnouts.
6. GaNFETs will only operate in the off-state if a sensor goes into breakdown.

GaNFETs Analysis

The GaNFET voltage threshold needs to be significantly below 3.3V to avoid losing control of the sensor high voltage.

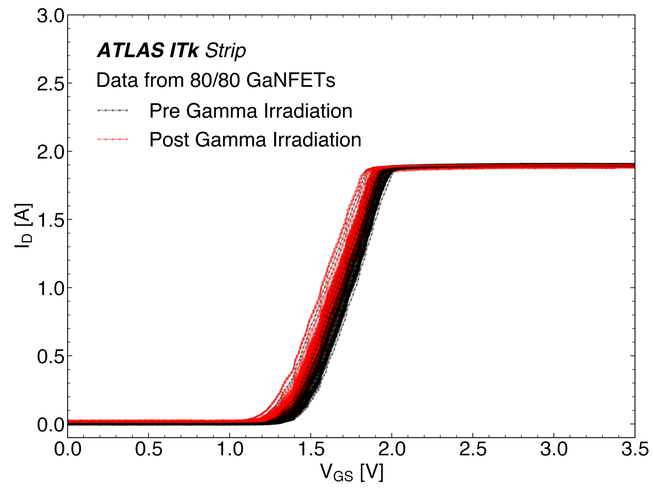

Fig. 6: GaNFET voltage threshold pre-, post-irradiation. [ITK-2022-003]

GaNFETs voltage threshold shift by up to 100mV with an average shift of -3.5%.

Total current leakage across the GaNFET gate and source increased on average by 66.6% with a maximum current leakage of about 485 nA.

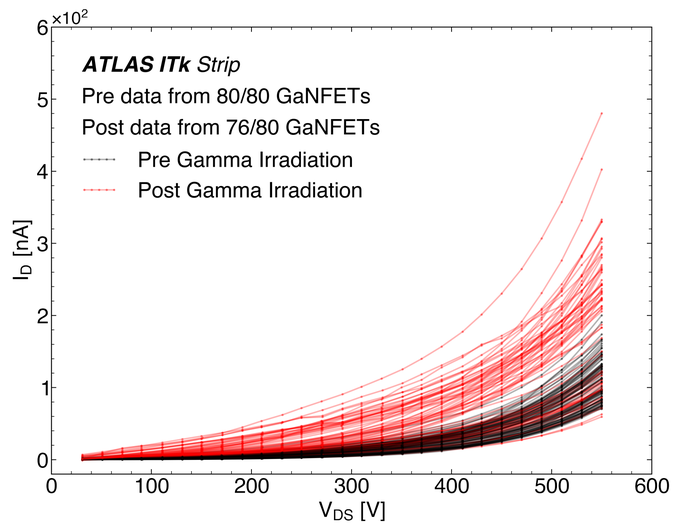

Fig. 7: GaNFET current leakage pre-, post-irradiation. [ITK-2022-003]

The GaNFET performance with currents to simulate a new and fully irradiated detector were measured.

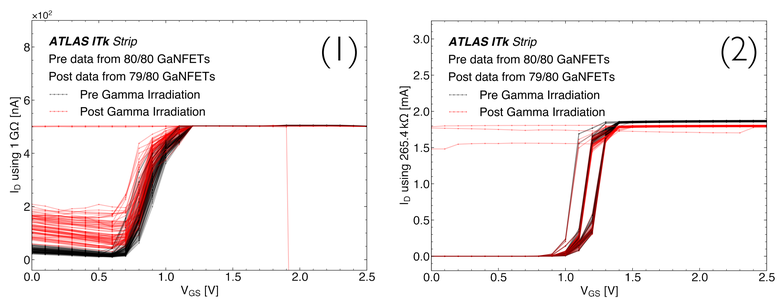

Fig. 8: GaNFET performance for (1) new and (2) fully radiated detector. [ITK-2022-003]

Off-state current increased post-irradiation. 4 off-state GaNFETs effectively always in the on-state due to significant increase.

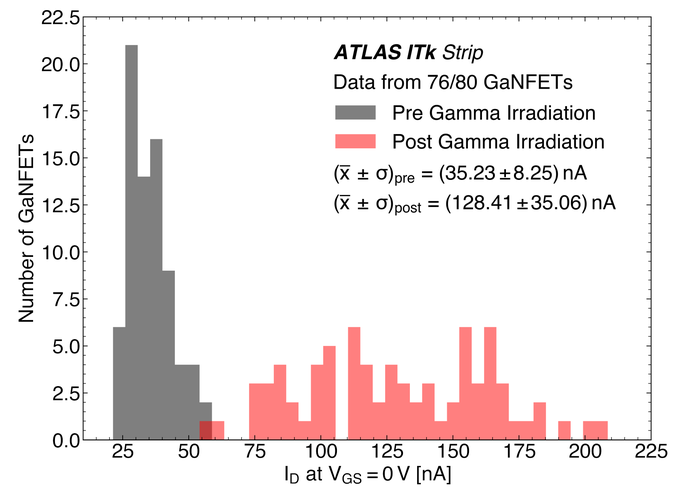

Fig. 9: GaNFET drain current for a gate-source voltage of 0 V assuming a new detector. [ITK-2022-003]

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