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Evaluation of Total Ionising Dose effects on HV-CMOS pixel sensors in 150 nm technology

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This work presents the Total Ionising Dose (TID) radiation assessment of HV-CMOS pixel sensors fabricated in the LFoundry 150 nm process. Two prototypes, UKRI-MPW1 and RD50-MPW4, were irradiated with X-rays up to 100 Mrad while biased and operated under designed conditions. Post-irradiation measurements on UKRI-MPW1 revealed increased leakage current, reduced breakdown voltage, and parasitic inter-pixel resistive channels due to Si-SiO₂ interface charge accumulation. RD50-MPW4 was operated throughout irradiation to monitor real-time power consumption and evaluate pixel performance at different dose intervals. These results complement existing Non-Ionising Energy Loss (NIEL) radiation studies, supporting the deployment of HV-CMOS sensors in high-radiation environments.

Summary (500 words)

High-Voltage CMOS (HV-CMOS) pixel sensors have gained growing attention in the particle detector community for their low material budget, excellent radiation tolerance, and cost-effective production. Their monolithic structure, integrating both sensing and readout electronics in a single layer, makes them ideal for experiments requiring large areas of thin pixel detectors, such as the Mu3e experiment, the LHCb Mighty Tracker upgrade, and the proposed Circular Electron Positron Collider (CEPC). The use of a high voltage to bias a high-resistivity substrate enables fast charge collection in a wide depletion region, maintaining high detection efficiency even after substantial radiation exposure.

Two HV-CMOS prototypes, UKRI-MPW1 and RD50-MPW4, have been developed using the LFoundry 150 nm process. Both share similar pixel diode structures and guard rings around the chip edge. UKRI-MPW1 mainly explores sensor structure optimisation, while RD50-MPW4 focuses more on developing readout electronics. Neutron irradiation tests have demonstrated that both sensors withstand Non-Ionising Energy Loss (NIEL) fluences up to several $10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$, and depletion of 50 μm was achieved after $10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$ for test structures in UKRI-MPW1 [1,2]. However, their tolerance to Total Ionising Dose (TID) effects, which primarily impact oxide layers and transistor operation, has not been investigated.

This work presents the first TID evaluation of these two HV-CMOS sensors. Several UKRI-MPW1 samples were irradiated with X-rays at a rate of 2 Mrad/h to reach doses up to 100 Mrad, while biased at 200 V. Post-irradiation characterisation involved I-V measurements and inter-pixel resistance tests to evaluate charge buildup at the Si-SiO₂ interface. Preliminary results indicate increased leakage currents, reduced breakdown voltages, and the formation of parasitic resistive paths between pixels. follow-up measurements after room-temperature annealing will also be presented.

RD50-MPW4, which includes a 64×64 pixel matrix with integrated analogue and digital in-pixel electronics and a digital periphery based on the I2C protocol and one 640 Mbits/s serial link, was irradiated under designed operating conditions to assess the impact of TID radiation on active electronics. The sensor was connected to its DAQ system during irradiation, with real-time monitoring of leakage current and current consumption in analogue and digital power domains. X-ray shielding with aluminium was applied to the entire setup except the sensor, which was exposed to X-rays through a window in the shield. S-curve scans were performed on pixels to monitor their gain, noise, and threshold at different dose intervals. Although an initial irradiation campaign was interrupted by the failure of voltage regulators on the Caribou board at ~ 1.5 Mrad due to insufficient shielding (5 mm aluminium), a second campaign using a reinforced 15 mm aluminium shielding is underway. Updated results will be included in the presentation.

These results complement existing NIEL radiation studies, and provide information for understanding and mitigating TID damage in HV-CMOS sensors, supporting their deployment in high-radiation environments.

[1] C. Zhang et al., Design and evaluation of UKRI-MPW1: a monolithic HV-CMOS pixel sensor with high radiation tolerance, *Journal of Instrumentation*, 2025, 20(01): C01008-C01008

[2] B. Pils et al., Characterization of the RD50-MPW4 HV-CMOS pixel sensor, *NIMA*, 2024, 1069: 169839

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