Effect of irradiation and annealing performed with bias voltage applied across the coupling capacitors on the interstrip resistance of ATLAS ITk silicon strip sensors


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Introduction

In order to cope with the occupancy and radiation doses expected at the High-Luminosity LHC, the ATLAS experiment will replace its Inner Detector with an all-silicon Inner Tracker (ITk), containing pixel and strip subsystems. The strip detector will be built from modules, consisting of one or two n-type silicon sensors, PCB hybrids accommodating the front-end electronics, and powerboard providing high voltage, low voltage, and monitoring electronics. The aluminium strips of the silicon sensors developed for the ITk project are AC-coupled with n-type implants in a p-type float-zone silicon bulk. The module powering configuration includes a voltage of up to 0.5 V across the sensor coupling capacitor. However, this voltage is usually not applied in the sensor irradiation studies due to the significant technical and logistical complications. To study the effect of an irradiation and a subsequent beneficial annealing on the ITk strip sensors in real experimental conditions, four prototype ATLAS17LS miniature sensors - W213, W214, W215 and W219 - were irradiated by $^{60}$Co source to the TID of 57.2 Mrad and annealed for 80 minutes at 60°C, both with and without the bias voltage of 0.5 V applied across the coupling capacitors.

Low voltage $V_{bias} = 0.5$ V applied across the coupling capacitors of individual strips (between AC and DC pads) of sensors W213 and W214 was calculated based on the design of ITk strip modules as a sum of (i) $V(\text{FE}) = 0.25$ V: offset between the hybrid ground and the potential of ABCStar input transistor, (ii) $V(\text{AMAC}) = -0.115$ V: voltage offset between AMAC controlling the sensor bias ring potential and hybrid or power board ground, and (iii) $V(R_{bias}) = 0.4$ V: voltage drop across $R_{bias}$ for irradiated sensor.

Gamma irradiation at UJP Praha, a.s.

Samples were positioned in the Charge Particle Equilibrium box (ES/SCC Basic Specification No. 22900, 1.0 mm aluminium + 1.0 mm lead surrounding the samples) $3$ cm above the $^{60}$Co source (1.17 MeV and 1.33 MeV). Irradiation with the dose rate of $8.5$ krad/min reached the TID of 57.2 Mrad. The maximal temperature and RH measured in the CPE during the irradiation was $+28$ °C and $25\%$, respectively. Samples W213 and W214 were irradiated with voltage $0.5$ V applied across the coupling capacitors of individual strips, while there was no voltage on W215 and W216.

Interstrip resistance $R_{int}$ of gamma irradiated sensors measured before and after annealing

The dependence of leakage current and bulk capacitance on depletion voltage was measured for all tested samples before irradiation (at +23.5°C), as well as after irradiation (at -20.0°C) - both before and after annealing (80 min at +60°C). All characteristics were measured at relative humidity below 1% on the Tesla 200mm probe station, which enables cooling of samples sitting on its chuck. Label (LV) used in the graphs indicates sensors irradiated with the low voltage $V_{bias} = 0.5$ V applied across the coupling capacitors of all their strips. Temperature of tested samples was measured by the PT100 sensor glued close to one of the samples.

Conclusions

Difference in performance of sensors gamma irradiated with and without the $V_{bias}$ of 0.5 V applied across their coupling capacitors is relatively small - within 25% in values of interstrip resistance $R_{int}$. Application of $V_{bias}$ during the standard annealing cycle seems to be beneficial. The presented findings confirm our planning and viability of the sensor technology developed for the ATLAS ITk strip project.

Acknowledgement

This study has received financial support from the Ministry of Education, Youth and Sports of the Czech Republic via the projects LTT17018, Inter-Excellence and LM2018104 CE0N-CZ, Charles University grant GAČR 942119, and Spanish R&D grant PID2019-110189RB-C22, funded by MCIN/AEI/10.13039/501100011033. Preparation of sensors was significantly supported by Department of Energy via the grant DE-SC0010107.