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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Abstract

The powering configuration of the silicon strip modules developed for the new Inner Tracker of the ATLAS experiment includes a voltage of up to 0.5 V across the coupling capacitor of each individual strip. 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 strip sensors in real experimental conditions, four prototype ATLAS17LS miniature sensors were irradiated by ^{60}Co source and annealed, both with and without the bias voltage of 0.5 V applied across the coupling capacitors. The values of interstrip resistance measured on irradiated samples before and after annealing indicate that increase of radiation damage caused by the applied voltage can be compensated by the presence of this voltage during annealing.

Keywords: ATLAS Innter Tracker, silicon strip sensors, gamma irradiation, annealing, interstrip resistance
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1. 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^+-in-p silicon sensors, PCB hybrids accommodating the front-end electronics, and powerboard providing high voltage, low voltage, and monitoring electronics [1, 2].

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 [3, 4]. When the module is powered, the bias voltage of up to 0.5 V is applied across the coupling capacitor of each individual strip. This voltage comes from the sum of (i) 0.25 V offset between the hybrid ground and a potential of input transistor of the readout chip, (ii) -0.115 V offset between the hybrid or powerboard ground and a potential of sensor bias ring, and (iii) 0.4 V voltage drop on bias resistors of individual strips of an irradiated sensor.

To study the effect of irradiation and subsequent annealing on the silicon strip sensor in its real operational conditions, four prototype ATLAS17LS miniature sensors - W213, W214, W215, and W219 - were gamma irradiated by ^{60}Co source (1.17 MeV and 1.33 MeV) to the TID of 57.2 Mrad, with the dose rate of 8.5 krad/min. Samples were positioned in the Charge Particle Equilibrium (CPE) box (ESA/SCC Basic Specification No. 22900, 1.0 mm aluminium + 1.0 mm lead surrounding the samples) 3 cm above the ^{60}Co source. 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 W219. The maximal temperature and relative humidity (RH) measured in the CPE during the irradiation was +28 °C and 25%, respectively.

2. IV and CV characteristics before and after irradiation

The dependence of the leakage current (IV) and bulk capacitance (CV) on the depletion voltage was measured for all tested samples before irradiation at +23.5°C, as well as after irradiation at −20.0°C. For the irradiated samples the measurement was done both before and after standard annealing of the sensors for 80 minutes at +60°C. The benefitial effect of annealing can be clearly observed in the IV characteristics of the tested samples, see Figure 1, while the CV curves measured before and after annealing are practically equivalent.

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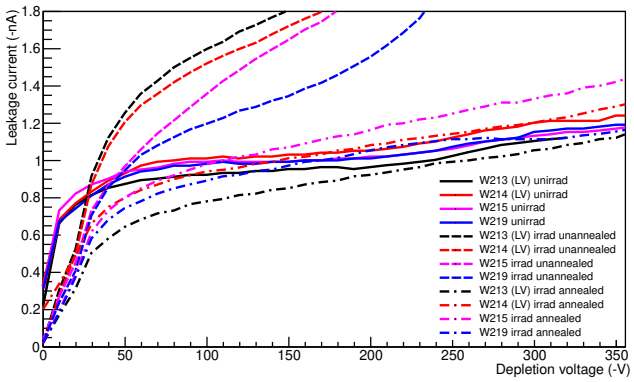

Figure 1: IV characteristics measured for all tested samples before and after their irradiation. Irradiated samples were studied both annealed and unannealed. Significant decrease of the sensor leakage current after annealing can be observed. Label (LV) indicates sensors irradiated with bias voltage of 0.5 V applied across the coupling capacitors.

3. Interstrip resistance of gamma irradiated sensors

The dependence of interstrip resistance R_{int} on the depletion voltage V_{dep} was measured by the 3-probe method on the probe station Tesla 200mm at the temperature of -20.0°C and RH below 1%, both before and after standard annealing. For the selected values of V_{dep} the R_{int} was determined from the slope of the current measured for the testing voltages between -1.0 V and +1.0 V.

During the standard annealing process the V_{bias} of 0.5 V was applied across the coupling capacitors of selected strips of sensors W213 (strips 0-30) and W214 (strips 0-59). Measured data indicates that R_{int} values of samples irradiated with V_{bias} applied over the coupling capacitors are reduced by 25% when compared with samples irradiated without V_{bias}. However, application of V_{bias} during the annealing process seems to compensate this effect, as the ratio between the averaged R_{int} value measured for sensor W213 (W214) and the averaged R_{int} obtained for samples W215 and W219 with no wire bonds is 0.90 (1.07) for strips annealed with V_{bias} applied across the coupling capacitors, and 0.62 (0.87) for strips annealed without any bias voltage, see also Figure 2.

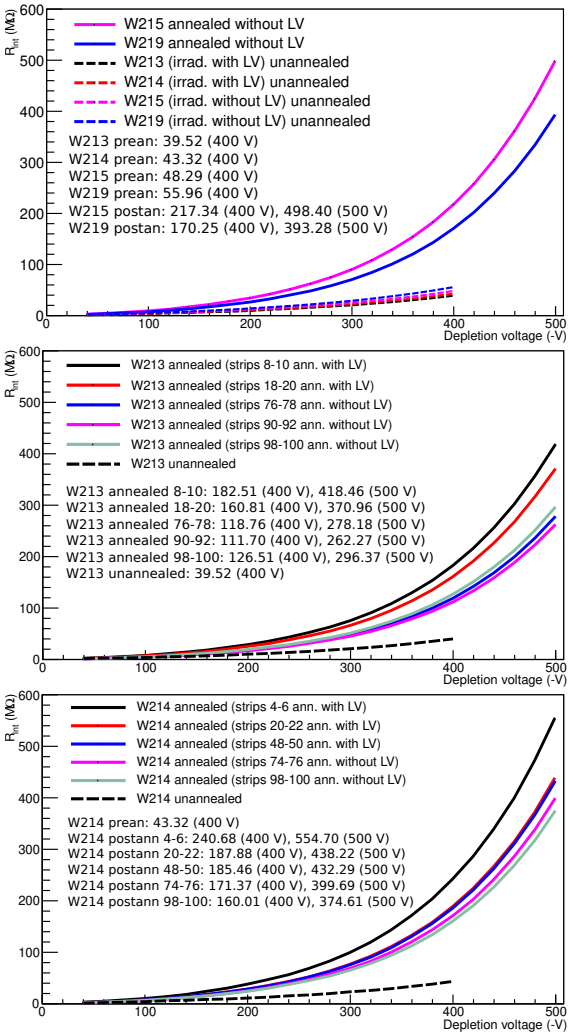

Figure 2: Dependence of R_{int} values on the depletion voltage measured for all irradiated sensors before their annealing, as well as for irradiated and annealed samples W215 and W219, is shown on the top plot. The same characteristics measured for irradiatated and annealed samples W213 and W214 is displayed on the middle and bottom plot, respectively. For samples W213 and W214 the numbers of measured strips are provided, including the information on whether these strips were annealed with or without the applied bias voltage. Values of R_{int} meaured at -400 V and -500 V are explicitly listed in all plots.

4. Conclusions

Difference in performance of ATLAS ITk strip 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 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.

5. Acknowledgement

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