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

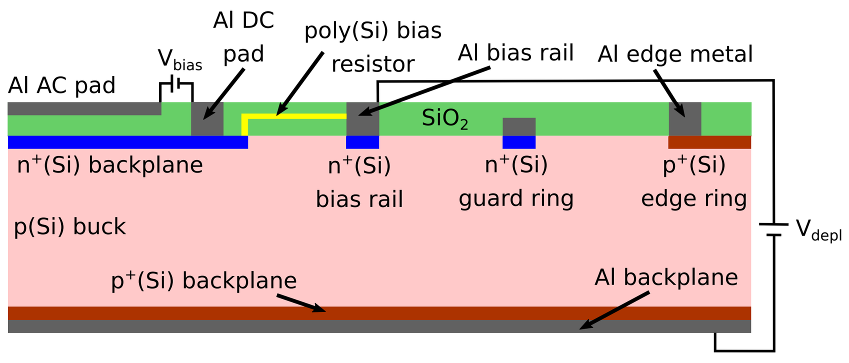
J. Kroll[1,†], P.P. Allport[3], A. Chisholm[3], V. Fadeyev[4], W. George[3], L. Gonella[3], I. Kopsalis[3], J. Kvasnička[1], V. Latoňová[1,2], J. Lomas[3], F. Martinez-Mckinney[4], M. Mikeštíková[1], X. Shi[5], P. Tůma[1], M. Ullan[6] ,Y. Unno[7]

[1]Institute of Physics of the Czech Academy of Sciences, Na Slovance 1999/2, 18221 Prague 8, Czech Republic,
[2]Faculty of Mathematics and Physics, Charles University, V Holešovičkách 2, 18000 Prague 8, Czech Republic
[3]School of Physics and Astronomy, University of Birmingham, Birmingham B152TT, United Kingdom
[4]Santa Cruz Institute for Particle Physics (SCIPP), University of California, Santa Cruz, CA 95064, USA
[5]IHEP, Chinese Academy of Sciences, 19B Yuquan Road, Beijing 100049, China
[6]IMB-CNM, CSIC, Campus UAB-Bellaterra, 08193 Barcelona, Spain
[7]Inst. of Particle and Nuclear Study, KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
†jiri.kroll@cern.ch

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. 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.

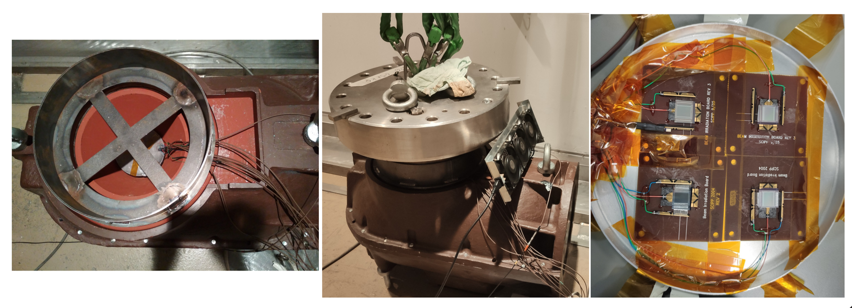
Low voltage offset between AC and DC pads



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 on R_{bias} for irradiated sensor.

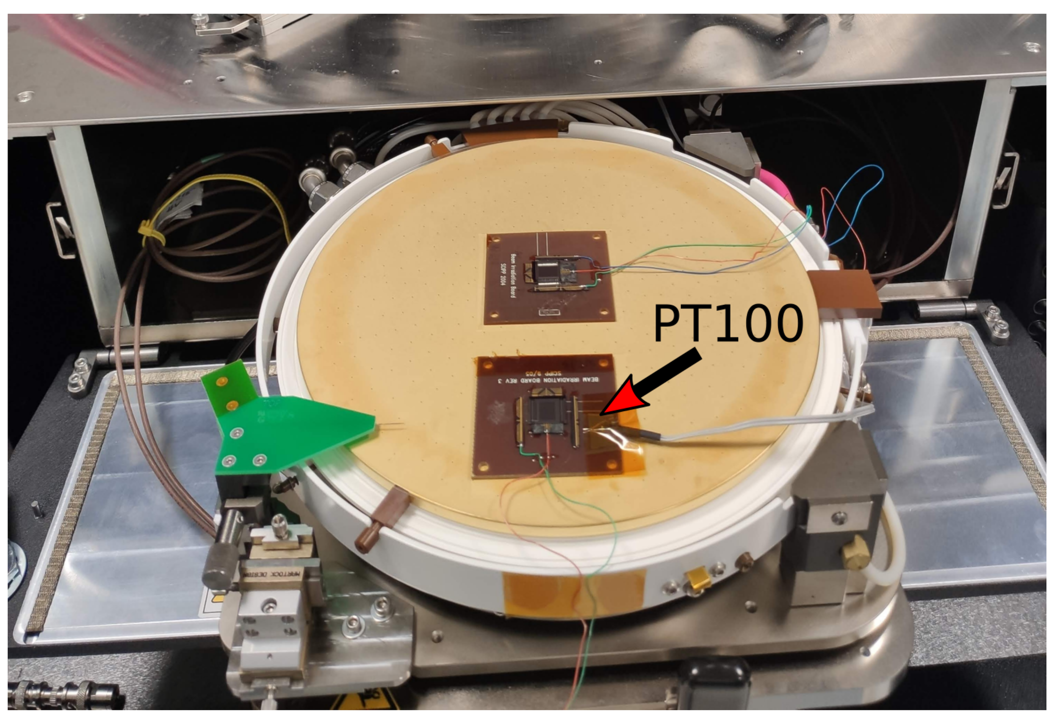
Gamma irradiation at UJP Praha, a.s.

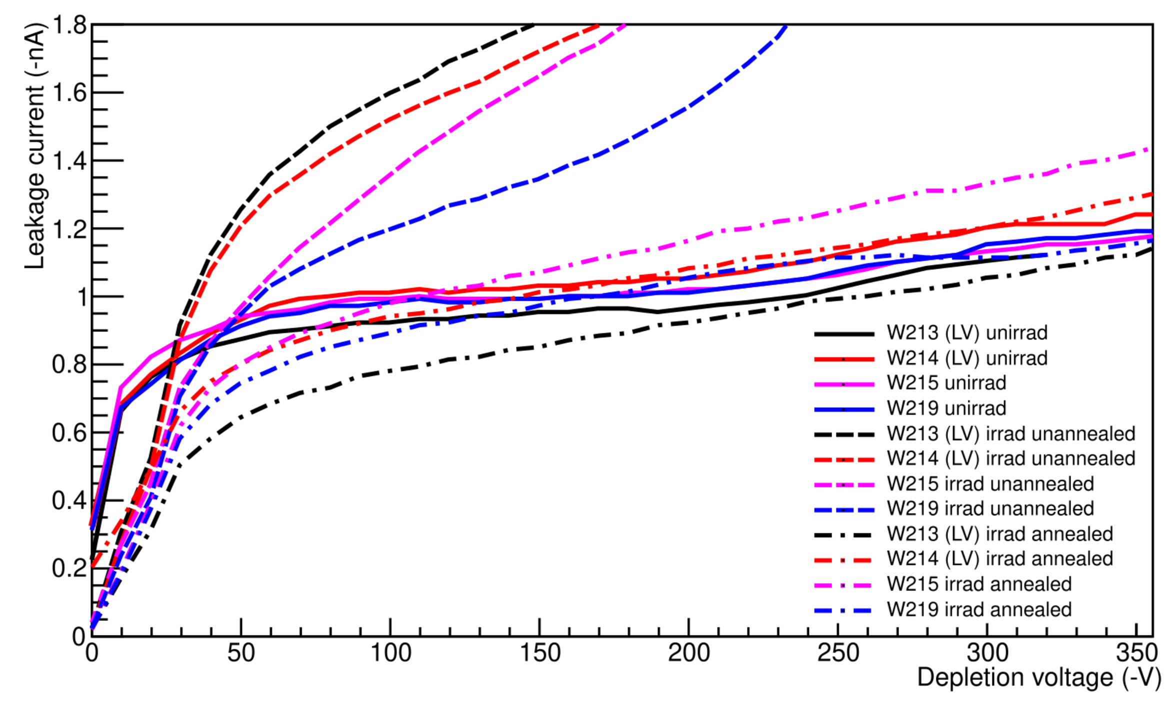
Samples were positioned in the Charge Particle Equilibrium box (ESA/SCC Basic Specification No. 22900, 1.0 mm aluminium + 1.0 mm lead surrounding the samples) 3 cm above the ^{60}Co source (1.17 MeV and 1.33 MeV). Irradiation with the dose rate of 8.5 krad/min reached the TID of 57.2 Mrad. The maximal 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.

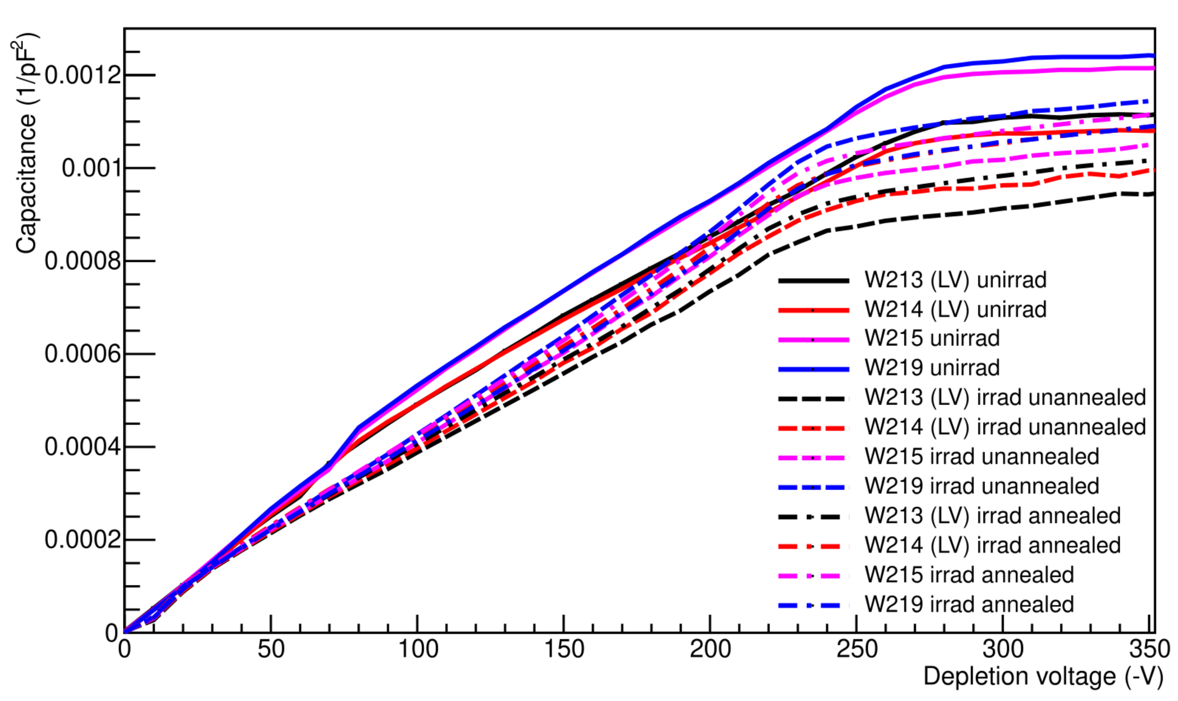


IV and CV characteristics before and after irradiation

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.

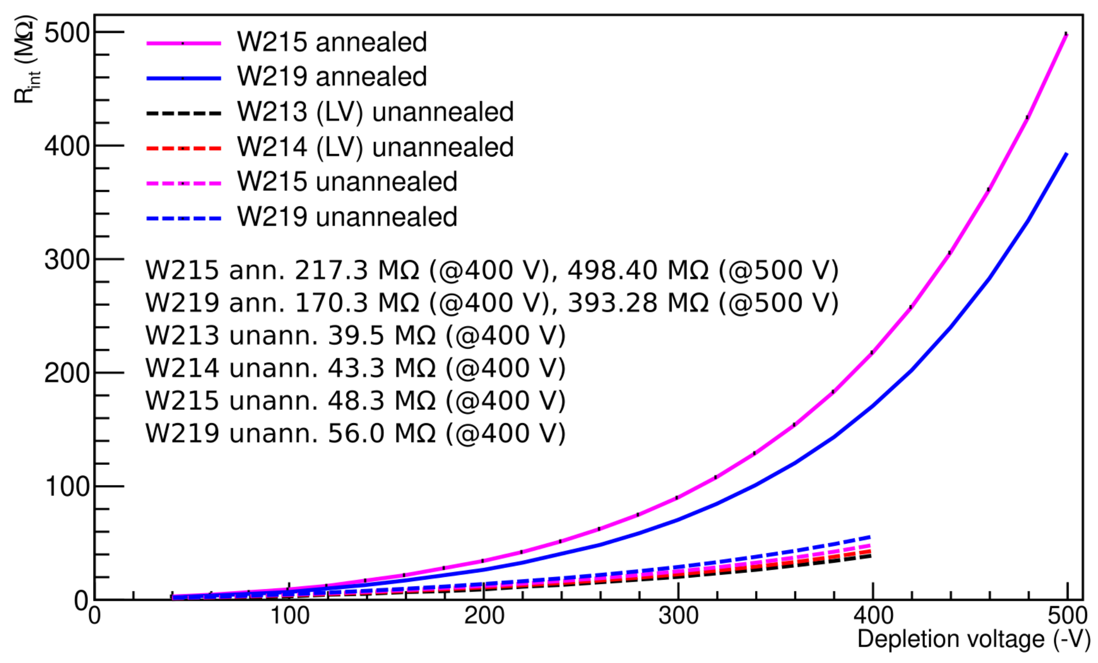


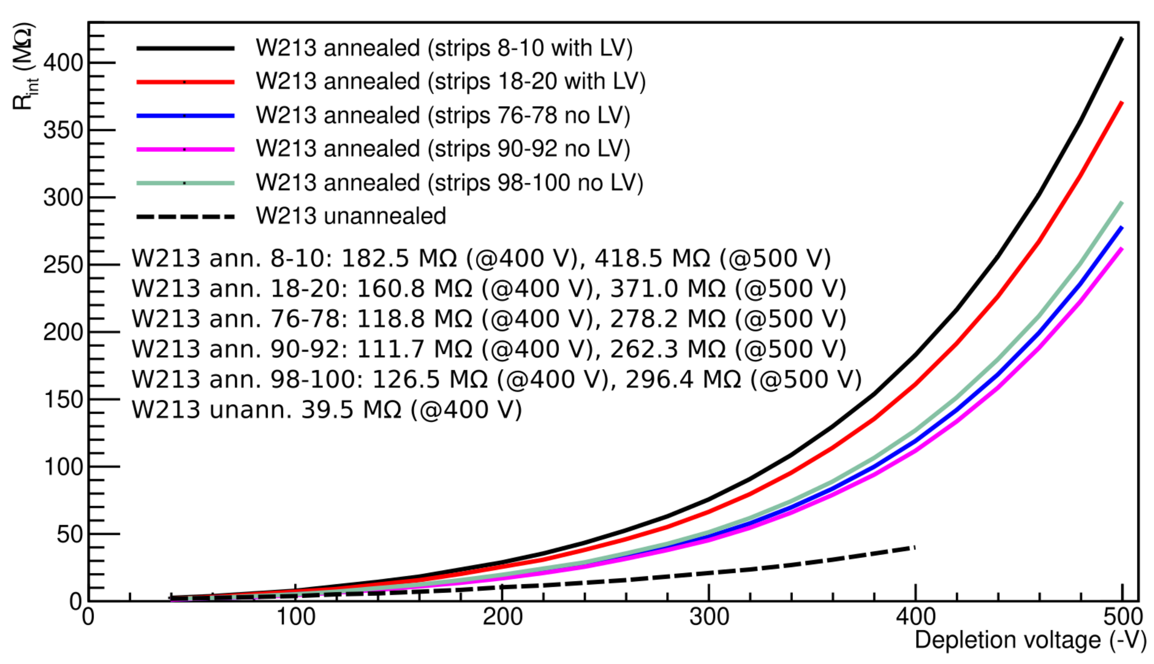


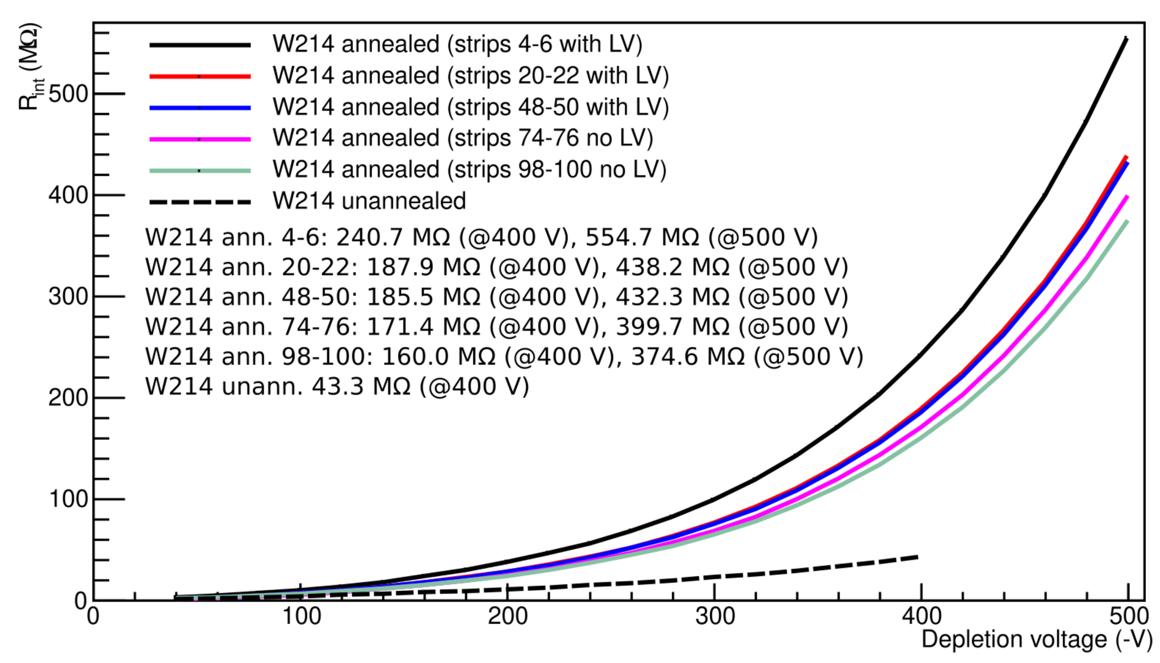


Interstrip resistance R_{int} of gamma irradiated sensors measured before and after annealing

The dependence of 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 relative humidity below 1%, both before and after 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 annealing process (80 min at +60°C) the $V_{bias} = 0.5$ V was applied across the coupling capacitors of selected strips - 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 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) and 0.62 (0.87) for strips annealed with and without the V_{bias} applied across the coupling capacitors, respectively.







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

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