Design and Evaluation of Large Area Strip Sensor Prototypes for the ATLAS Inner Tracker Detector

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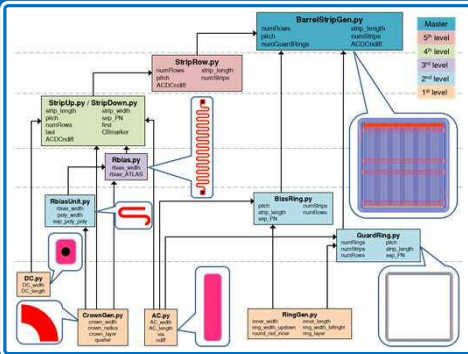
Abstract

The ATLAS community is facing the last stages prior to the production of the upgraded silicon strip Inner Tracker (ITk) for the High Luminosity Large Hadron Collider (HL-LHC). An extensive Market Survey was carried out in order to evaluate the capability of different foundries to fabricate large area silicon strip sensors, satisfying ATLAS ITk specifications. The semiconductor manufacturing company Infineon Technologies AG was one of the two foundries, along with Hamamatsu Photonics KK, evaluated for the production of the new barrel silicon strip sensors for the ITk. This work presents the complete tests carried out on the sensors designed and fabricated in 6-inch wafers in the framework of the Market Survey.

The full prototype wafer layout was designed using a Python-based Automatic Layout Generation Tool, able to rapidly design sensors with different characteristics and dimensions based on a few geometrical and technological input parameters. A complete characterization of the large area strip sensors fabricated is presented, including the results of proton and neutron irradiations, and their compliance with the specifications of the ITk strip tracker.

Layout of Large Area Strip Sensor Prototype

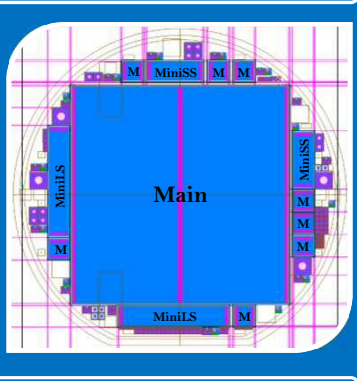


Automatic Layout Generation Tool (ALGT):

- New Python-based layout tool developed to address the need to fabricate prototypes with different characteristics and dimensions.
- Programmable-Cell (PCell) scripts compiled in layout software GLADE[1], and arranged in different hierarchy levels to generate more complex structures.

Large Area Strip Sensor (ATLAS17LS-IFX) Prototype:

- Layout design of a full-sized barrel long-strip sensor in 6-inch wafer for the participation of Infineon[2] in the ATLAS ITk strip sensor Market Survey.
- Main sensor, Miniature sensors and monitor diodes generated using the ALGT.
- Manual positioning of the different devices in the final wafer layout.



ITk Strip Sensors Market Survey

Selection and Evaluation of foundries for the ATLAS ITk Strip Sensor production, divided in three steps:

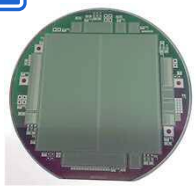
STEP-1 Selection of Candidate Vendors → **STEP-2** Evaluation of Fabrication Capability → **STEP-3** Evaluation of Real Full-size Prototype

This work presents the prototype layout design and evaluation of Infineon Main sensor for the Market Survey Step-3[3].

Experimental Description

Fabrication of 6 wafers, each one containing:

- 1 x Barrel Long-strip Sensor (Main)
- 8 x Mini Sensors (M)
- 2 x Mini Short-strip Sensors (MiniSS)
- 2 x Mini Long-strip Sensors (MiniLS)
- Several Monitor Diodes (from 8x8 mm² to 1x1 mm²) and Test Structures



Samples and Irradiations

Proton irradiation:

- Irradiation with 70 MeV protons at CYRIC (Japan) up to 1-MeV equivalent neutron fluence of $5 \cdot 10^{15}$ n_{eq}/cm^2.

Neutron irradiation:

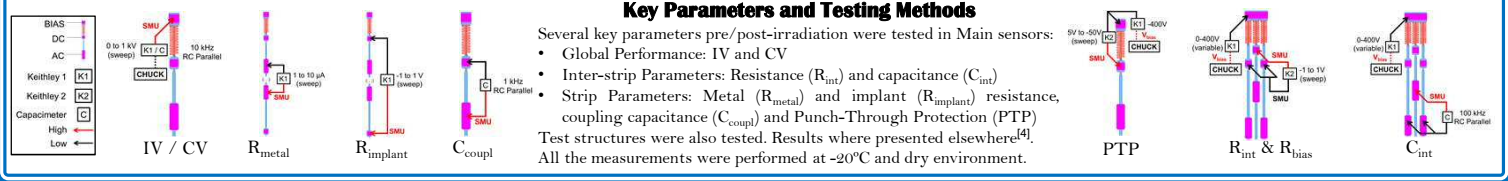
- Irradiation with neutrons at IJS (Slovenia) up to $5 \cdot 10^{15}$ n_{eq}/cm^2.

Key Parameters and Testing Methods

Several key parameters pre/post-irradiation were tested in Main sensors:

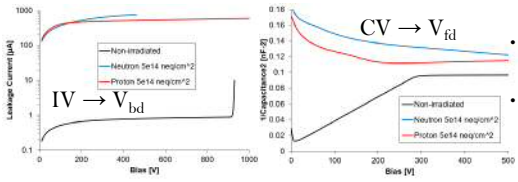
- Global Performance: IV and CV
- Inter-strip Parameters: Resistance (R_{int}) and capacitance (C_{int})
- Strip Parameters: Metal (R_{metal}) and implant ($R_{implant}$) resistance, coupling capacitance (C_{coupl}) and Punch-Through Protection (PTP)

Test structures were also tested. Results where presented elsewhere[4].
All the measurements were performed at -20ºC and dry environment.

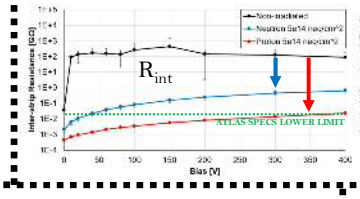


Results

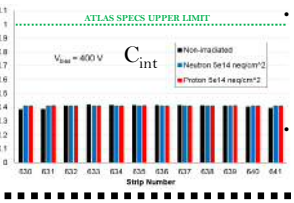
Global Performance



- Expected increase in current after irradiation
- Breakdown voltage fulfilling the ATLAS Specs (>500 V) pre- and post-irradiation

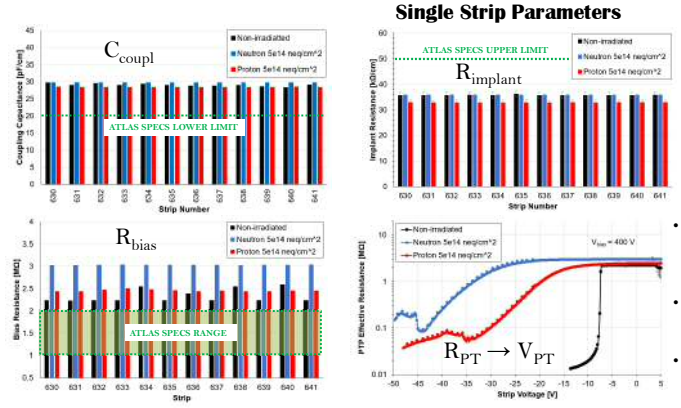


Inter-strip Parameters



- Decrease of several orders of magnitude in inter-strip resistance after irradiation, but within the ATLAS Specs.
- No influence of irradiation in inter-strip capacitance.

Single Strip Parameters



- No remarkable influence of irradiation in coupling capacitance and implant/metal resistance, showing values within the ATLAS Specs.
- Bias resistance values higher than the range established by ATLAS, with an increase after irradiation.
- Increase of PTP effective resistance and PTP voltage after proton and neutron irradiations.

Market Survey Evaluation

Parameter	ATLAS Specs	Non-irradiated	Neutron 5e14 n_{eq}/cm^2	Proton 5e14 n_{eq}/cm^2
Breakdown Voltage (V_{bd})	> 500 V	~ 950 V	> 500 V	> 1000 V
Full Depletion Voltage (V_{fd})	< 300 V	~ 280 V	?	?
Inter-strip Resistance (R_{int})	> 15 MΩ	122,204.54 ± 128,254.42 MΩ	447.81 ± 147.10 MΩ	14.36 ± 0.48 MΩ
Inter-strip Capacitance (C_{int})	< 1 pF/cm	0.41 ± 0.01 pF/cm	0.41 ± 0.01 pF/cm	0.41 ± 0.01 pF/cm
Coupling Capacitance (C_{coupl})	≥ 20 pF/cm	29.09 ± 0.41 pF/cm	29.82 ± 0.01 pF/cm	28.50 ± 0.02 pF/cm
Bias Resistance (R_{bias})	1.5 ± 0.5 MΩ	2.26 ± 0.05 MΩ	3.03 ± 0.01 MΩ	2.46 ± 0.02 MΩ
Metal Resistance (R_{metal})	< 30 Ω/cm	11.81 ± 3.35 Ω/cm	17.97 ± 1.09 Ω/cm	8.07 ± 1.76 Ω/cm
Implant Resistance ($R_{implant}$)	< 50 kΩ/cm	35.77 ± 0.14 kΩ/cm	35.85 ± 0.02 kΩ/cm	32.90 ± 0.05 Ω/cm
PTP Voltage (V_{PT})	Non Defined	~ 7 V	~ 33 V	~ 18 V

- Main sensor shows most of the key parameter values, pre/post-irradiation, within the ATLAS Specifications, only showing slight deviation in R_{bias}.

Conclusions

- Layout of ATLAS barrel long-strip prototype sensor and test structures, generated using a new Automatic Layout Generation Tool, for the participation of Infineon in the ITk Strip Sensor Market Survey for production
- Extensive evaluation of key parameters pre/post-irradiation, with protons and neutrons, up to HL-LHC fluences.
- Large area strip sensor prototype presents good agreement with the limits established in the ATLAS Specifications, showing only small deviations in bias resistance.
- In July 2018 Infineon management decided to discontinue the development of strip sensors based on the business case.

References

[1] Peardrop Design Systems; www.peardrop.co.uk
[2] Infineon Technologies AG; www.infineon.com
[3] ATLAS Collaboration; *Technical Design Report*, CERN-LHCC-2017-005, 2017.
[4] J. Fernández-Tejero, et al.; https://indi.to/BcThk, TREDI2019, 2019.

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