THE ATLAS TRACKER UPGRADE: SHORT STRIPS DETECTORS FOR THE sLHC

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It is foreseen to increase the luminosity of the Large Hadron Collider (LHC) at CERN around 2018 by about an order of magnitude, with the upgraded machine dubbed Super-LHC or sLHC. The ATLAS experiment will require a new tracker for sLHC operation. In order to cope with the order of magnitude increase in pile-up backgrounds at the higher luminosity, an all silicon detector tracker is being designed. As the increased luminosity will mean a corresponding increase in radiation dose, a new generation of extremely radiation hard silicon detectors is required. A massive R&D program is underway to develop silicon sensors with sufficient radiation hardness. New front-end electronics and readout systems are being designed to cope with the higher data rates. The challenges of powering and cooling a very large strip detector will be discussed. Ideas on possible schemes for the layout and support mechanics will be shown. Planar detectors to be made on p-type wafers in a number of different designs have been developed. These prototype detectors were then produced by a leading manufacturers and irradiated to a set of fluences matched to sLHC expectations. The irradiated sensors were subsequently tested with LHC-readout-electronics in order to study the radiation-induced degradation, and determine their performance after serious hadron irradiation of up to 10^{15} $n_{eq}cm^{-2}$. The signal suffers degradation as a function of irradiation. It is however evident that sufficient charge can still be recorded even at the highest fluence. We will give an overview of the ATLAS tracker upgrade, in particular focusing on innermost silicon strip layers. We will draw conclusions on what type and design of strip detectors to employ for the upgrades of the tracking layers in the sLHC upgrades of LHC experiments.

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1. Introduction

An upgrade of the LHC machine towards higher luminosities (10^{35} $cm^{-2}s^{-1}$) has been considered as an extension of its physics program. The upgraded machine is called the Super-LHC (sLHC). The increase in luminosity will pose serious problems as the damage in magnets or detectors caused by radiation or the increase in pile-up of events per beam crossing. The detectors will need to be replaced and technologically improved.

2. ATLAS Upgrade

The most significant upgrade for ATLAS will be the full replacement of the whole Inner Detector (ID). The new ID will consist of a Vertex region with pixel detectors and the Tracker region with short strip (3 inner layers) and long strip detectors (2 outer layers, replacing the TRT)[1]. Table 1 shows the SCT Upgrade parameters.

Table 1. SCT Upgrade parameters.

Layer	Length(cm)	Area(m^2)	Nº channels
Short strips	200	60	28 M
Long strips	380	100	15 M

The radiation environment inside the tracker will increase. The short strip detectors are required to withstand $9x10^{14}$ 1-MeV$n_{eq}cm^{-2}$ while the outer detectors will have to cope with $4x10^{14}$ 1-MeV$n_{eq}cm^{-2}$. A massive R&D program is underway to develop silicon sensors with sufficient radiation hardness[2].

3. Silicon Strip Detectors

The detectors fabricated from high-resistivity p-type float zone (FZ) silicon are the most promising radiation hard sensors[3]. Working towards the sLHC application, R&D programs into n-on-p strip sensors have been carried out with sensors processed at Hamamatsu (HPK), Japan[4]. A new batch of R&D sensors, called ATLAS 07[5], was fabricated in 6-inch (150 mm) 320 µm thick wafers. With these, strip isolation schemes, high-voltage performance, punch-through protection and charge collection as a function of irradiation fluence will be investigated. These devices were fabricated with and without an additional p-spray doping. The ATLAS 07 miniature sensors were irradiated with neutrons at the Reactor Centre at the Jozef Stefan Institute at Ljubljana[6] and with protons at the Cyclotron and Radioisotope Center (CYRIC) at Tohoku University[7].

3.1. *Charge Collection Efficiency (CCE) Measurements*

In figure 1 is shown the collected CCE curves obtained by different sites and systems[8]. Figure 2 depicts a summary of the measurements with neutron irradiation. Figure 3 shows the results after proton irradiation.

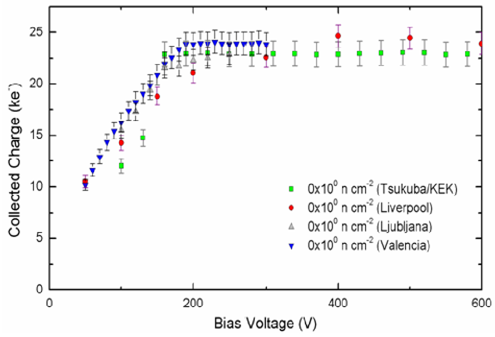

Fig. 1. CCE curves for non-irradiated sensors measured in different sites.

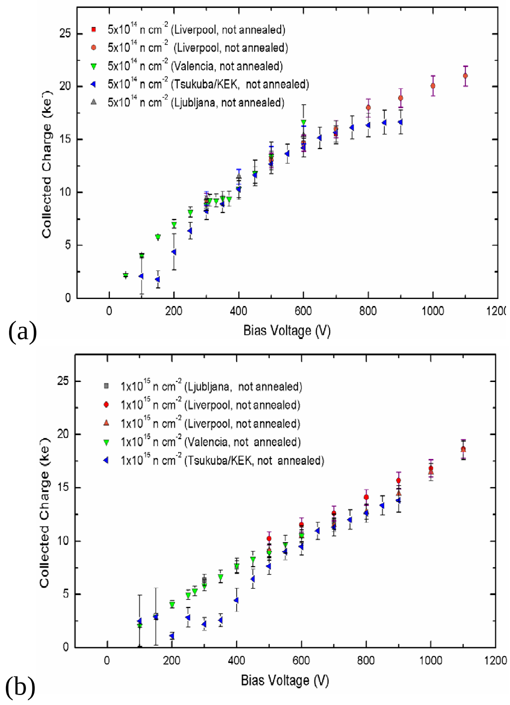

Fig. 2. Collected charge as function of bias voltages for neutron irradiated samples at (a) $5x10^{14}$ n/cm^2 and (b) 10^{15} n/cm^2.

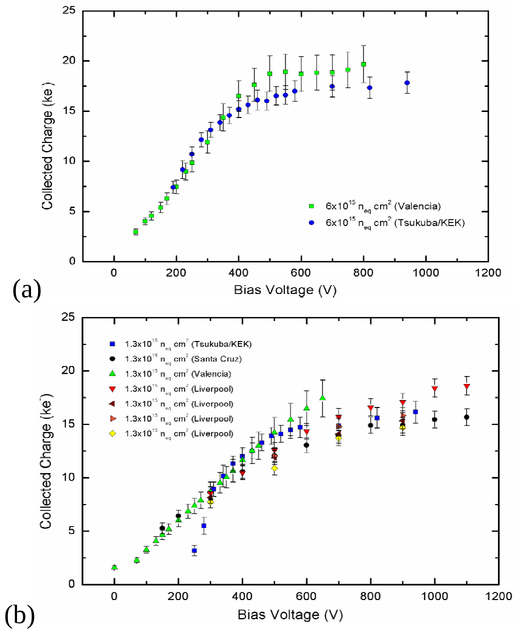

Fig. 3. Collected charge as function of bias voltages for proton irradiated samples at (a) $6x10^{14}$ n_{eq} cm^{-2} and (b) $13x10^{14}$ n_{eq} cm^{-2}.

There is good agreement between the measurements performed at different sites. The ATLAS 07 performance is as expected. Later, the comparison between Hamamatsu (ATLAS07) and Micron sensors was done. Micron sensors were used to study damage caused by pions, neutrons and protons. Figure 4 depicts the results for the CCE as function of the fluence for both types of sensors, which shows that the performance of the sensors produced at Micron and Hamamatsu are the same after all measured irradiation sources.

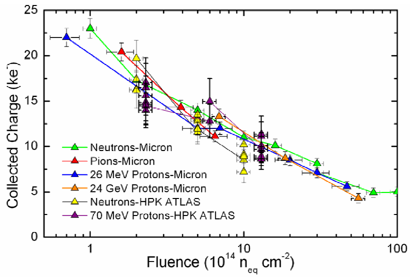

Fig. 4. Collected Charge Eficiency as a function of the fluence for Micron and HPK sensors.

3.2. *Full Size Sensor Testing*

Five non-irradiated Hamamatsu large sensors have been tested. Their dimensions are 97.5x97.5 mm^2, and they are 320 µm thick. The sensors are made of p-type FZ silicon, n+ strips and p-stop isolation. Several groups were involved in the evaluation. They tested a total of 19 sensors from different wafers (full depletion voltage, strip current, strip test…). Figure 5 shows the results.

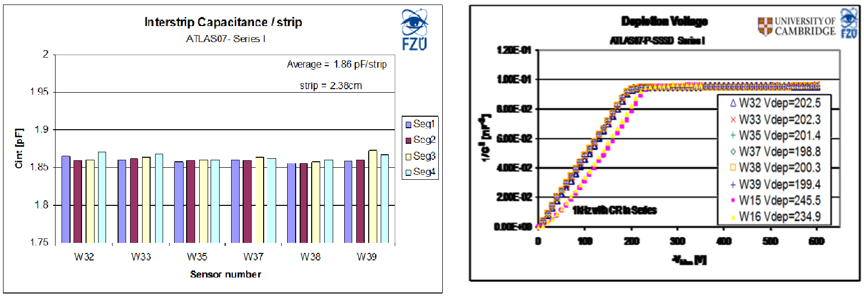

Fig. 5. Interstrip capacitance (every line corresponds to different segments) and $1/C^2$ as function of bias voltages for the Hamamatsu large sensors.

In terms of the full depletion voltage, the curves look very uniform for all the sensors. The mean coupling capacitance is 67 pF/strip and the bias resistor is approximately 1.4 MΩ along all the strips. The strip integrity is completely correct. An average value of 1.86 pF/strip (0.75 pF/cm) is obtained for the interstrip capacitance measurements which is a 10-15% higher when including next neighbours.

4. Alternative module integration concepts

The concept being developed is that of a super-module, self-contained in terms of services and suitable for use in the extreme radiation and detector occupancy environment of the sLHC. As well as the increased radiation levels, the much greater number of channels would add further to the challenges in designing adequate services and read-out. Integrated cooling would be required as part of the super-module to handle the lower temperatures now needed for radiation survival, coupled with increased electronics channel density and higher power dissipation in the irradiated detectors. A light structure, easy to integrate will have to be designed to house the sensors, readout electronics, power distribution and cooling. Recently the ATLAS collaboration proposed the stave concept[9] (straight stave for the barrel SCT and petal stave for the End-cap SCT).

4.1. *The stave concept*

It is a carbon honeycomb structure with embedded cooling pipes (CO_2) and bus cable and silicon sensors directly glued onto the structure. The baseline has hybrids glued directly on the sensors. The baseline integrated stave concept consists of: a mechanical support with an integrated cooling (mechanical core), a bus cable laminated to the mechanical core, mechanics to hold the stave to the support structure and connectors. The silicon detector modules (hybrid with readout electronics and silicon sensor) will be glued to the bus cables. A stave with petal shape, called petal, will be used for the End-cap. Every disk will be divided into 32 petals, with 4 different petal types depending on the inner radius chosen (38<R<95 cm). There will be 6 different detector types mounted on petals.

4.2. *Thermal management*

The designs need to be evaluated to find the optimal thermal performance and to avoid the thermal runaway. Thermal simulations of end-cap modules are being carried out at IFIC-Valencia[10]. Figure 6 shows the highest temperature on sensor as a function of the sensor power with a fixed chip power. It is assumed to have -30 ºC coolant temperature and -27 ºC on the return pipe. The applied voltage on the sensor is 500V[11].

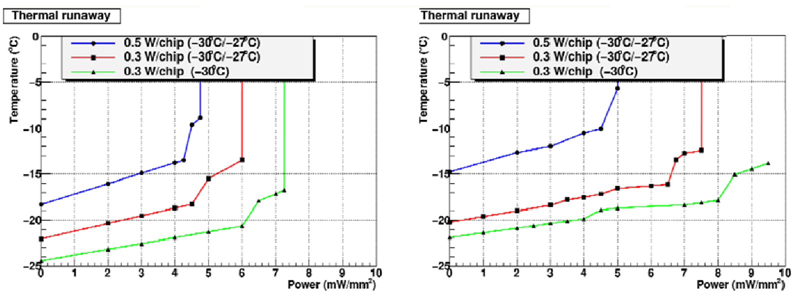

Fig. 6. Temperature on sensor as function of the power for an end-cap module with 8 chips (left) and an end-cap module with 4 rows x 8 chips (right). Every colored line corresponds to a different chip power.

The expected operation condition is about 1 mW/mm^2 for the tracker modules and we require that thermal run-away does not occur within a factor 2 of the operation conditions. As can be seen in Figure 6 this is comfortably fulfilled by the simulated modules.

5. Summary

A massive R&D program, involving many particle physics groups and several leading manufacturers of silicon detectors for particle physics, is underway to develop silicon sensors with sufficient radiation hardness. The most suitable candidates are n-on-p microstrip sensors as many studies are demonstrating. In parallel, the SCT commissioning experience has taught us to look into alternative module concepts, in which higher levels of integration are combined with the modularity of the SCT approach. New module integration concepts - Stave/Petal designs - have arisen from it.

References

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