14th RD50 Workshop

Wednesday, 3 June 2009 - Friday, 5 June 2009

Freiburg, Germany

Book of Abstracts

Contents

Pixel sensors, 3D and SOI detectors, Radiation Monitoring / **0**

Evaluation of novel pixel sensors for future tracking detectors

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An upgrade of the LHC towards a 10 times higher luminosity will require tracking detectors with unprecedented radiation tolerance. Furthermore, the high track density will call for fast and high granularity detectors, which also fulfill the boundary conditions of low radiation length and low costs. Over the last years several promising material developments and design concepts for the next generation of silicon pixel detectors have been brought forward.
In the framework of Pixel Sensors R&D at CERN the noise and signal behavior for different sensor types has been studied with the goal of optimizing detector layout for their signal-to-threshold performance. The study included planar silicon sensors, 3D silicon sensors of different layout and manufactured by different producers as well as CVD diamond sensors. Details about the test results including for example comparative noise studies for different sensor types will be presented. Particular emphasis will be put on testing novel 3D-DDTC (Double side Double Type Columns) sensors produced by FBK/irst.

1

Simulation study for improving the breakdown voltage of Si sensors for use in High Energy Physics (HEP) Experiments

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To ensure a reliable long term performance in the harsh radiation environment of present and future high energy experiments, silicon detectors are required to be operated at voltages beyond, sometimes quite far from, the full depletion voltages. It is, thus desirable to improve breakdown voltage characteristics of silicon sensors, and floating guard rings are generally employed to perform this task. However, it is important to understand the application of guard rings under the influence of various physical and geometrical parameters, both for its optimal design and to gain physical insight. In this work, a TCAD based simulation is performed for the detailed study of the silicon sensors equipped with floating guard rings. The results also establish the criteria for optimizing guard ring spacing under various conditions.

Summary:

To improve the breakdown voltage characteristics,floating guard rings study is been performed under the influence of various Physical and geometrical parameters,both for its optimal design and to gain physical insight.

Pad Detector Characterization and Defect Engineering / **2**

Contributions of Electrons and Holes to Total Collected Charge in Heavily Irradiated Si Pad and Strip/Pixel Detectors: A Comparison Simulation Study

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A simplified approach to compare quantitatively the contributions of electrons and holes to the total collected charge in heavily irradiated Si pad detectors and strip/pixel detectors has been developed in this study. By applying a step function to approximate the weighting field and a step function to approximate the linear- and/or double junction- electric field, in the detector, one can obtain analytical solutions of total collected charge and contributions from electrons and hole for irradiated Si detectors with various electric field and weighting field profiles combinations. Although the results do not exactly replicate the situation in a real detector, they qualitatively and quantitatively explain the contributions of electrons and holes in various detectors with different segmentation- and field-profiles.

Summary:

A simple model has been developed utilizing step functions for both the weighting field and electric field, to calculate the contributions of electrons and holes to the total collected charge by MIP in strip- (or pixel) and pad- detectors at various radiation fluences. With this model, I obtained analytical solutions for the collected charge, together with much simplified forms for approximating various special situations, thereby gaining much better insight on the underling physics of charge collection in strip/pixel and pad detectors, especially at high fluences.
1. At low radiation fluences (< 2x1015 neq/cm2), the contribution of electron drift (for n+ collection electrodes; holes for p+ collection electrodes) dominates the total collected charge in a segmented detector, especially for ones with small pitches (P«d). For partially depleted detectors, the total collected charge in segmented detectors is zero provided that the junction is on the opposite side to the collection electrodes (Strip-Front-Junction-Back (SFJB)). In all other cases (segmented detectors: SFJF (Strip-Front-Junction-Front); pad detectors: PFJF (Pad-Front-Junction-Front), and PFJB), the total collected charge is proportional to the detector's depletion depth w (L (JF) or d-L (JB) in this paper): . For fully depleted detectors, the total collected charge is proportional to the detector's thickness d: . The relative loss in charge due to trapping in partially depleted pad detectors is or , where are the carrier drift velocities and the trapping time. 2 At high radiation fluences (> 4x1015 neq/cm2), the contribution of hole drift (for n+ collection electrodes; electrons for p+ collection electrodes) to the total collected charge in segmented detector increases to the same level of that of electrons because the charge-collection distances of both carriers are less than the pitch P. At extremely high fluences, about 1x1016 neq/cm2 (the maximum SLHC fluence), the total collected charge in any detector (pad and segmented detectors) is independent of both the detector's thickness and depletion depth: it exhibits a little dependence for bias voltage V > 1000 volts. For pad and segmented detectors, this takes the analytical form of , and it is around 2000 to 3000 es, where are the charge collection distances for electrons and holes.
3 The total collected charge in a segmented (strip or pixel detector) Si detector is dominated by carriers the collecting electrodes (strips or pixels) collect (in our cases, electrons for n+ collecting electrodes) at low fluences. However, at high fluences, the contribution by the other carriers will increase and becomes comparable, especially at the SLHC fluence of 1x1016 neq/cm2, as shown in Fig. 1a). In other words, for electron collecting n+ electrodes in typical n on n and n on p detector configurations, although the electron contribution is the main part of total collected charge, the contribution by holes at very high fluence can be significant as well.
4 The best detector configuration is to have the detector junction (high electric field) on the same side of the collecting electrodes (Fig. 1a), as otherwise the total collected charge can be significantly reduced after irradiation Fig. 1b), and may be diminished in a partial depletion condition.

a) SFJF b) SFJB

Fig. 1 Collected charges for a strip or pixel detector with a) junction on the strip side (SFJF), and, b) junction on the backside (SFJB). The high-weighting field is 100 times more than the low one (⊠ = 0.01), and the high-electric field is 30 times more than the low one (⊠ = 0.03 for JF, and 33.33 for JB).

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Commissioning the CMS pixel detector with cosmic ray data

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The CMS Pixel detector, consisting of three barrel layers and two endcap disks at each barrel end, was installed in the CMS experiment in summer 2008. After a preliminary commissioning phase with pulse injections the detector participated in data taking with cosmic ray triggers and 3.8T field. We report on the first running experience with CMS and present preliminary results on detector performance. In addition, we discuss the detector performance after irradiation obtained from beam test measurements at CERN.

Defect and Material Characterization / 4

Annealing induced evolution of defect centers in epitaxial silicon irradiated with high proton fluences

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High-resolution photoinduced transient spectroscopy (HRPITS) has been used to studying the effect of isochronal annealing temperature on the properties defect centers in epitaxial silicon exposed to irradiation of 24 GeV/c protons with fluences ranging from 5x10ˆ15 to 1.6x10ˆ16cmˆ-2. The defect levels for standard and oxygenated epilayers have been compared. The main decrease in the concentrations of the defect centers in the both kinds of layers is observed after annealing at 160 oC. After annealing at 240 oC, the concentrations of midgap centers with activation energies of 420 meV and 535 meV, attributed to divacancies and higher order vacancies aggregates, are found to be approximately two times lower in the oxygenated epilayers than those in the standard epilayers.

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Determination of strip detector properties by using Edge-TCT

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Transient Current Technique (TCT) was used to evaluate p-type silicon micro-strip detectors. A pulsed IR laser focused to a spot of to 6 μm illuminated the detector edge so that the beam was parallel with the surface and perpendicular to the strips. In that way electron hole pairs were created at known depth in the detector. Scans over the entire detector thickness with 0.5 μm resolution were performed. For each laser beam position the induced current shape is measured for one of the

strips. The charge collection efficiency was studied as a function of laser position (depth of carrier generation), voltage, integration time. Determination of electric field profiles without relying on precise values of effective trapping times will be discussed.

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Comparison of the CCE properties of microstrip detectors made with different substrates and irradiated with protons and neutrons at different temperature

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The comparison of the charge collection properties of microstrip detectors made with FZ and MCz substrates are compared after irradiation with 26MeV and 24GeV/c protons and reactor neutrons. The lower energy proton irradiations took place at low temperature. The irradiations with the higher energy protons in the PS have been performed at room (>30oC) and cooled (about 0oC) T conditions. Their CCE performances are compared also with similar sensors irradiated at RT (˜22oC, but shorter irradiation times) conditions in the nuclear reactor.

Full detector systems / **7**

Can we claim multiplication effects in irradiated silicon?

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New measurements to very high voltage are here shown that can give more support to the appearence of charge carrier multiplication effects in irradiated Micron silicon microstrip detectors

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Anneling of Charge Collection in Strip sensors and the Depletion Voltage

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we have irradiated n-type and p-type magnetic Czochralski and Float Zone silicon detector to proton, pion and neutron fluences up to 1.3*1015 neq/cm2. The data are collected right after irradiation and

after elevated temperature annealing at 60oC, corresponding to several years of annealing at room temperature. As a function of bias voltage V, the following electrical parameters were measured: C-V at room temperature to extract the depletion voltage Vdep, and the charge collection efficiency in a beta source at lowered temperature to determine the "efficiency voltage", i.e. the voltage at which the sensor becomes efficient at a threshold of 1 fC.

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Sensor R&D for an upgrade of the CMS pixel barrel

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Measurements of lorentzangle in highly irradiated silicon-strip-detectors

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The planned SLHC-Upgrade will result in a 10 times higher luminosity and therefore higher radiation-damage to the silicon-detectors in the tracker-subsystem of CMS. The magnetic field inside the tracker causes a shift of chargecarriers inside the detector-silicon resulting in a displacement of the measured position to the real position of the particles track. The angle the carriers are shifted by is called the lorentzangle.
In my diploma-thesis I measured lorentzangles in 3 materials: FZ-p-in-n, FZ-n-in-p and MCz p-in-n. The latter 2 were irradiated up to 10E16 neq/cm². Also, extensive measurements of non-irradiated sensors were done to compare the results with data from modells and simulations.
The results of my work will be presented at this workshop.

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Predictions on charge collection efficiency in heavily irradiated Si detectors basing on the approach of active base region

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The approach of an active base with a non-zero electric field in heavily irradiated Si detectors is further developed for estimations of the collected charge up to the fluences of super-LHC range (10ˆ16 cmˆ-2). The steady-state electric field in heavily irradiated detector has double peak shape with two maxima and the base region in between, in which the electric field is about few kV/cm. Using this approach, the collected charge vs. fluence dependence is calculated and compared to that in the detector with a standard linear electric field. The study is carried out for pad detectors and strip detectors typical for ATLAS topology. Fitting of the calculated charge collection efficiency vs. fluence dependence to the experimental curves allowed definition of the main base parameters. It is shown that the electric field in the active base depends on the irradiation fluence and stimulates an essential increase of the collected charge.

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The avalanche effect in operation of heavily irradiated silicon p-i-n detectors

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The recent study of silicon detectors irradiated up to fluences beyond 10ˆ15 neutron/cmˆ2 demonstrated an increase of the collected charge up to the value that is even higher than the charge initially generated by the detected particles. In the present investigation this effect is analyzed in terms of avalanche process in the abrupt p-n junctions. On the basis of double peak electric field distribution model developed earlier in the Ioffe institute, the dependence of the detector signal is calculated for different fluences and the detector operational bias. It is shown that the electric field distribution in heavy irradiated detectors is close or corresponds to the requirements for the avalanche process. In the case of short range particles the effect is more pronounced and can be observed. For MIPs detection it is suppressed by the spreading of generated pairs along the detector thickness ant therefore it requires higher bias voltage. The detector parameters which allow reaching an evident avalanche effect are defined and discussed in terms of detector operational environment and biasing conditions.

Defect and Material Characterization / **13**

Comparative study of the electric field dependent variations of carrier recombination and drift parameters in MCZ Si detectors irradiated by different fluences of neutrons

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Simultaneous measurements of the characteristics of photoconductivity transients, TOF, SCD (TCT) and SCLC by using various regimes of the surface and bulk excitation as well as current transient differential and integral registration regimes have been performed to clarify the electric field and

neutron fluence dependent variations of carrier recombination and drift parameters in pad-detectors fabricated on MCZ Si. Significant changes of carrier drift time and of recombination with increase of fluence from 1012 to 1016 n/cm2 of the reactor neutrons have been obtained. However, carrier recombination lifetime is independent of the applied electric field at fixed irradiation fluence. It has been unveiled that current transients are determined by diffusion of light induced carrier domain at lowest values of applied voltage while these transients evolve via SCLC and SMD regimes to TOF transient with increase of electric field strength for low and moderate irradiation fluences. Changes of current transients due to variation of the carrier drift regimes are always observed within time scale of excess carrier density decay controlled by microwave probed photoconductivity transients. Peculiarities of extraction of material parameters at different regimes are discussed. Enhancement of excess carrier density with intensity of excitation tends to dominance of the diffusion of carrier domain and of the SCLC regimes at applied voltages up to full depletion of pin diode for fluences of <1015 n/cm2. Crucial shortening of carrier diffusion length at fluences > 1015 n/cm2 determines current transients which weakly depend on applied field.
Analyze of the linear dependence of free carrier lifetime on fluence performed by modelling of clusters using the density functional theory. The calculated decrease of bandgap at the ring shape clusters (V6) demonstrate the importance of the local field for both carriers drift to the cluster and it causes the near to the linear decrease of the lifetime dependence on hadron fluence.

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Capacitance Measurements and Depletion Voltage for Annealed Fz and MCz Diodes

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We irradiated n and p-type Float Zone (FZ) and magnetic Czochralski (MCz) silicon diodes with protons up to 1.4 x 10^15 neq/cm2. The devices were annealed at 60 ℃ and measured after 10, 80, 1,000 and 10,000 minutes. Capacitance and leakage current measurements were performed at room temperature and the depletion voltage extracted. A comparison of the different device types will be presented.

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TCT-Measurements of mixed irradiated Magentic Czochralski Diodes in the SLHC-Scenario

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Magnetic Czochralski Diodes both n-type and p-type of 300um thickness were irradiated with protons and neutrons to fluences corresponding to different Radii in the CMS-Tracker. IV- and CV-Measurements were performed to study the depletion behaviour of diodes with increasing current. Measurements with a TCT-Setup with red and infrared laser light are in progress to extract trapping times and charge collection efficiency.

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Electrical Characterization of Irradiated Silicon Diodes at Different Temperature

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For CV/IV characterization of irradiated silicon detectors a standard temperature of 20℃ and frequency of 10 kHz are adopted. However, at high irradiation level it is necessary to perform measurements at lower temperature. The obtained values Vfd and Id depend on the temperature and frequency, as well as on material and radiation type and the fluence.
To study this dependence CV/IV measurements in the temperature range from -10℃ to 20℃ and in the frequency range from 100 Hz to 100 kHz, as well as charge collection measurements were performed for epitaxial and MCz silicon diodes after irradiation with 24 GeV/c protons and reactor neutrons of different fluences.

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Effect of microscopic defects in n-type irradiated MCz silicon detectors: Impact on macroscopic parameters

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In order to study the effect of microscopic defects on macroscopic detector parameters, we have used synopsis T-CAD device simulator for four-level numerical modeling of radiation induced deep level traps using parameters obtained from experimental measurements.
The resulting analysis techniques has been validated and calibrated by means of detailed comparison of the simulation with experimental measurements carried out on irradiated samples.

Summary:

In order to study the effect of microscopic defects on macroscopic detector parameters, we have used synopsis T-CAD device simulator for four-level numerical modeling of radiation induced deep level traps using parameters obtained from experimental measurements.
The resulting analysis techniques has been validated and calibrated by means of detailed comparison of the simulation with experimental measurements carried out on irradiated samples.

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Test Beam Measurements with 3D-ddtc Silicon Strip Detectors

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3D double-sided double type column (ddtc) detectors were measured in a test beam at the CERN SPS in 2008. It was performed in the framework of RD50 and CMS and was provided by the University of Helsinki. The CMS silicon beam telescope and CMS tracker readout electronics were utilised. This talk focuses on a device under test produced by FBK-IRST (Trento). The current status of the analysis, which is done in collaboration with groups from Glasgow and Helsinki, is presented. The results comprise studies on spatially resolved charge collection and efficiency. A comparison with results obtained for 3D-stc (single type column) strip detectors shows the differences of the properties of the two designs.

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Carrier lifetime variations in MCZ Si during irradiation by 3 - 8 MeV protons at temperatures in the range of 40 -300 K

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Variations of carrier recombination lifetime, linearly dependent on radiation induced defects density, have been in situ examined during irradiations by stopped and penetrative protons in MCZ Si wafers of 350 ⊠m thickness. Irradiations and in situ lifetime measurements were performed at different stabilized temperatures in the range of 40 -300 K. Registration of the averaged carrier decay transients were carried out every second during exposure of a proton beam in remote mode over 15 m distant from vacuumated irradiation chamber by examination of microwave probed photoconductivity transients. Adjustments of the intersection at a boundary of wafer for the laser excitation beam transferred to a fiber spot and of the needle-tip microwave antenna have been performed by 3D stepper connected to irradiation chamber by flexible bellow system with lateral movement precision of ˜ 2 ⊠m. Precision of adjustments were controlled remotely by using LAN interface and PC in safe area for measurements. Visual control of a location of probes within wafer thickness was also arranged by using optical fiberscope combined with VC. Probes were located at half-thickness of wafer under irradiation by penetrative protons, while these were positioned within stopping range for 3 MeV protons. Irradiation was kept for ˜52000 counts or 15 –20 min at 2 - 9 nA beam current. Carrier lifetime varied from 500 ⊠s to 0.5 ns over a complete exposure for initially non-irradiated material, while it changed from 1 ⊠s to 0.2 ns for 1012 p/cm2 pre-irradiated samples. Cross-sectional scans of carrier lifetime were performed just after irradiation. A lifetime reduction has been revealed within stopping range of 3 MeV protons. Carrier lifetime temperature variations in the range of 30 –300 K had been examined before and after irradiations. Carrier decay transients appeared to contain several components caused by growth and radiation induced defects, which can be separated to recombination and carrier trapping centres. Spectrum of temperature variations of different carrier decay components enabled us to identify different defects. Rate of introduction of the radiation defects under proton beam exposure has been unveiled to be dependent on initial state and sample temperature during irradiation. More detailed analysis of evolution of radiation defects during irradiation by penetrative and stopped protons will be discussed.

Defect and Material Characterization / **20**

TSC studies on MCz silicon pad detectors irradiated with neutrons

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We report on the investigation of the radiation damage induced by neutron irradiation on MCz silicon pad detectors by TSC technique.

Pixel sensors, 3D and SOI detectors, Radiation Monitoring / **21**

Status of the Planar Pixel Production at CiS

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A production of Planar Pixel Sensors in the framework of the RD50 Collaboration is ongoing at CiS (Erfurt, Germany) in view of the pixel system upgrade of the ATLAS and CMS detectors for Super-LHC. The production is divided in two batches to investigate both the n-in-n and the n-in-p technologies. The sensors will be realized on Fz and MCz material.
The designs for the two batches are completed and have been submitted to the producer. The layout of the wafers and the R&D plans to be carried out with these structures will be presented.

Full detector systems / **22**

Performance of irradiated MCz detectors in a test beam environment

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The Silicon Beam Telescope (SiBT07) is a reference tracker used to characterize position sensitive detectors. I present selected testbeam results from irradiated MCz strip detector studies and discuss analysis methods associated with those results.

Pixel sensors, 3D and SOI detectors, Radiation Monitoring / **23**

First characterizations of thin SOI and epitaxial n-in-p sensors

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We will present the results of first leakage-current and capacitance measurements of our 75 and 150 micron thin SOI production of n-in-p sensors before irradiation. They exhibit low dark currents and depletion voltages.
A comparison between the performance of the standard and a reduced guard ring structure will be shown.
Furthermore, the RD50 production of thin epitaxial n-in-p sensors, made by CIS, was characterized. Infrared pictures reveal signs of break downs in the inner guard rings as well as in the active area close to the bias ring.

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Charge collection and trapping effects in n-type and p-type epitaxial silicon diodes after proton irradiation

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Epitaxial silicon pad diodes of p-type (150 µm, ST material) and n-type (75 µm, 100 µm, 150 µm, both ST and DO) material have been investigated after 24 GeV/c proton irradiation at CERN PS. Time-resolved TCT measurements with 670 nm laser light (front injection) were performed for 150 µm thick diodes and thus the effective trapping time constants for electrons (n-type) and holes (p-type) could be obtained. CCE measurements with 5.8 MeV alpha particles and 670 nm and 1060 nm laser light showed an anomalously high charge collection.

Defect and Material Characterization / 25

Prediction of the macroscopic ”reverse annealing” using microscopic defect concentrations

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Isothermal annealing studies were carried out at 80 ℃ on 75 um thick standard and oxygen enriched Epitaxial (EPI) material, irradiated with 1 MeV neutron fluences of 2E14 n/cm2 and 1E15 n/cm2. Depletion voltage and leakage current were obtained by CV and IV measurements while defect concentrations were measured by means of Thermally Stimulated Current technique (TSC). The microscopic results were used to predict the so called “reverse annealing”. Our findings are in good agreement with the macroscopic sensor properties.

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Online Radiation Dose Measurement System for ATLAS experiment

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In LHC experiments it will be important to continuously monitor the radiation doses to follow the level of degradation of detectors and electronics and to correctly predict future radiation damage. A system for online radiation monitoring using semiconductor radiation sensors was installed in the ATLAS experiment. Ionizing dose in SiO2 will be measured from increase of threshold voltage in p-MOS FET transistors (RadFETs). The 1 MeV neutron equivalent fluences will be monitored from increase of forward voltage at given forward current in two types of p-i-n diodes and from measurements of increase of reverse current in 25 μm thick epitaxial pad diode. From measurements of degradation of current gain in dedicated transistors fluence of thermal neutrons will be estimated. In this contribution the system will be described and the results from long irradiation test in IRRAD6 at CERN will be shown.

Welcome / **27**

Welcome to the 14th RD50 Workshop

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Pad Detector Characterization and Defect Engineering / **28**

Determination of depletion voltage from CV, IV and CCE measurements on Pad Detectors

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New TCT setups at CERN and Louvain

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New strip sensitive TCT & CCE setups are under construction in colaboration between CERN and Louvain. Mechanics and electronics are realized in a twin solution in both test stations. Focused red laser beam will be used for standard and strip sensitive TCT. Sr 90 source and IR laser will be used for calibration and fast CCE. A fix optical fiber setup with splitters and shutters avoids maladjustement and thus allows reliable measurements with laser as well. Cooling is done with vacuum and silicon

oil (CERN) and cold nitrogen vapour (Louvain). Usage of Alibava within the cooled setup is in preparation.

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Discussion Session

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Bias on-off proton irradiation results on MCz-Si and Fz-si detectors

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Full detector systems / 40

Neutron irradiation for p-type sensors. Detector characterization with ALIBAVA system

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This work describes the characterization of p-type microstrip detectors from two different manufacturers, Hamamatsu and CNM carried out at IFIC-Valencia. The sensors have been irradiated with neutrons at several fluences. In order to evaluate the macroscopic radiation damage, IV and charge collection measurements have been carried out by means of a radioactive source setup as well as by an infrared laser illumination. The sensors have been readout with the ALIBAVA system. It is a compact and a portable system which contains two front-end readout chips (Beetle chip) to acquire the detector signals. One of the advantages of the ALIBAVA system is that it uses LHC speed electronics. Another advantage is that it allows performing a pulse by pulse and strip by strip analysis.

Full detector systems / **41**

Electrical characteristics of ATLAS07 Series I large detectors.

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Electrical characteristics of ATLAS07 Series I large detectors in Prague as step before irradiation was done.

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Irradiation program in Prague - status.

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Irradiation program in Prague is preparing on 2 possible way: on Cyclotron-based fast neutron facility at NPI Rez and in Experimental reactor at NRI, Rez. Basic conditions of this and plan for irradiation of ATLAS07 Series I large detectors will be presented .

Pixel sensors, 3D and SOI detectors, Radiation Monitoring / **43**

ALIBAVA - Status of distribution and Discussion on further activities

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CNM status report

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Pixel sensors, 3D and SOI detectors, Radiation Monitoring / 45

3D testbeam at the Diamond light source

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