The 38th RD50 Workshop (online Workshop)

Monday, 21 June 2021 - Wednesday, 23 June 2021

Book of Abstracts

Contents

Time resolution of 4H-SiC PIN and simulation of 4H-SiC LGAD 1

AC-LGAD novel geometries exploration by etching of metal on the surface AC-coupled pads 1

DAQ-ROC4Sens Update 2

MPW2 testing in the RBI microbeam 3

Observation of an inactive region in irradiated silicon diodes 3

Time resolution of an irradiated 3D silicon pixel detector 3

Latest Results on charge sharing in AC-LGAD (aka RSD) 4

A table-top Two Photon Absorption –TCT system: experimental results 4

Comparison studies of heavily irradiated dielectrics for AC-coupled pixel detectors on MCz silicon 5

Update on radiation damage investigation of epitaxial p-type Silicon using Schottky / pn junctions 5

Full-size passive CMOS sensors for radiation tolerant hybrid pixel detectors 6

The performance of IHEP-NDL and IHEP-IME LGAD sensors after neutron Irradiation . 7

Study of gain suppression in LGADs using IBIC and TRIBIC 7

Timing measurements on neutron-irradiated LGADs in epitaxial wafers 8

iLGAD Sensor For X-Ray Applications 8

Response of 3D pixel sensors to grazing angle incident particles 9

First results from thin silicon sensors irradiated to extreme fluence 9

Preliminary Test Results of LGADs from Teledyne e2v for the LHC's High-Luminosity Upgrade 10

LGAD Development at Teledyne e2v for the LHC's High-Luminosity (HL) Upgrade . . . 11

Test beam measurements of BNL and HPK AC-LGADs 11

A new testing system for multipad RSD sensors based on a a new FAST ASIC 12

Current Deep Level Transient Spectroscopy (I-DLTS) technique applied to p-type silicon diodes for Acceptor Removal studies 13

A table-top Two Photon Absorption –TCT system: Method and Setup 13

Characterization on the radiation hardness of USTC-1.1 LGADs 14

The boron-oxygen (BiOi) defect complex induced by irradiation with 6 MeV electrons in p-type silicon diodes 14

Characterization of depleted monolithic active pixel sensors in 180 nm TowerJazz technology 15

Radiation hardness and development of a large electrode DMAPS design in a 150 nm CMOS process 15

Systematic study of heavily irradiated LGAD stability using the Fermilab Test Beam Facility 16

Development of large-area LGADs for Space Application 17

Principle of operation of an innovative new sensor for neutron detection based on resistive AC coupled LGAD 17

Performance of Stitched Passive CMOS Strip Sensors 18

3D n-on-n detectors 18

Defects formed in boron-doped Si diodes after high energy electron irradiation 19

A new vision of I-V characteristics in irradiated Si sensors with heavily damaged regions 19

Studies of effective inter-pad distance of different HPK and FBK LGADs 20

Status of the design of RD50-MPW3 ASIC 20

A comprehensive feasibility study on the utilisation of the Ion Beam Induced Charge (IBIC) Nuclear Microprobe Technique at the RBI for the LGAD's Characterization including the Interpad-Gap Measurements 21

The mortality study on irradiated W36 LGADs and PINs for tuning the HV safety parameters and establishing the turning point for the irreversible breakdown (Part I): Using TCT-SPA with 800 nm of fs-laser at ELI 22

The mortality study on irradiated W36 LGADs and PINs for tuning the HV safety parameters and establishing the turning point for the irreversible breakdown (Part II): Using TCT-TPA with 1550 nm of fs-laser at ELI 22

The RD50-MPW2 High Voltage-CMOS sensor chip DAQ and preliminary testbeam results 23

New TPA-TCT system at JSI 24

Readout system and testbeam results of the RD50 MPW2 HV-CMOS pixel chip 24

Gain suppression mechanism observed in Low Gain Avalanche Detectors 24

Investigation of acceptor removal by 4-point probe and LTPL measurements 25

Radiation Tolerance study of AIDA2020v2 LGADs manufactured at IMB-CNM 25

Bistability of the BiOi complex –a reason for the observed large scattering in the determined acceptor removal rates in irradiated p-type silicon 26

LGAD irradiated with 1e19 1MeV n/cm2 - HRTEM annealing studies up to 350 oC 27

Modelling of the Coulombic centres charge emission: electric field approximation comparison in simulating the measured TSC signal 27

Discussion on defects and material characterization 27

Discussion on High Fluences and Detector Characterization 28

New results of edge-on measurements with electron beam on pad diodes 28

Timing resolution simulation of 2D and 3D SiC devices 28

Discussion on LGAD 29

Discussion: LGAD mortality 29

Discussion on Monolithic and Pixel sensors 29

Discussion: TCT techniques and 3D sensors 29

Optical detection of single defects in silicon 29

The Caribou Data Acquisition System 30

EPS-TIG event in Montenegro Invitation 30

SiC, Detector Characterization and Very High Fluence Experiments / 1

Time resolution of 4H-SiC PIN and simulation of 4H-SiC LGAD

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To explore the timing performance of the wide bandgap semiconductor devices, we measured the time resolution of 100 um 4H-SiC PIN device manufactured in China using the beta source and LGAD as reference. A simulation has been carried out to investigate the timing performance. We also reported the prospects of 4H-SiC with gain layer structure (LGAD) using the TCAD simulation.

LGAD - Low Gain Avalanche Detectors / 2

AC-LGAD novel geometries exploration by etching of metal on the surface AC-coupled pads

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Low Gain Avalanche Detectors (LGADs) are thin silicon detectors with moderate internal signal amplification. LGADs can provide time resolution of few 10's of pico-seconds for minimum ionizing particles. In addition, the fast rise time and short full charge collection time (as low as 1 ns) of LGADs

are suitable for high repetition rate measurements in photon science and other fields. However the current major limiting factor in granularity is due to structures preventing breakdown caused by high electric fields in near-by segmented implants. As a result, the granularity of LGAD sensors is currently limited to the mm scale.
In this contribution, we present measurements on AC-LGADs (also named Resistive Silicon Detectors RSD), a version of LGAD which has shown to provide spatial resolution on the few 10‘s of micrometer scale with a sparse readout. This is achieved by an un-segmented (p-type) gain layer and (n-type) N-layer, and a di-electric layer separating the metal readout pads. The high spatial precision is achieved by using the information from multiple pads.
The sensors were produced by FBK (Italy) with square pad of several pitch and pad size, the production is called FBK RSD1. To study and optimize alternative pad configuration the metal layer of the pads was etched to create new geometries such as circles, crosses and micro-strips. The pad metal surface was etched at BNL (US) with laser lithography. Additionally results with AC-LGADs produced at BNL with geometries of pads, strips and hexagons will be shown.
The alternative geometries have been studied using a focused IR-Laser scans directed both at the read-out side on the front and the bias side on the back of the sensor. The etching process and preliminary measurements with the laser will be presented. For the BNL hexagonal and strip sensors a position reconstruction method based on the AC-LGAD master formula will be shown.

Monolithic Sensors / **3**

DAQ-ROC4Sens Update

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The purpose of the proposed acquisition system is to provide a all-in-one solution that be able to capture and process the data generated for up to 4 Roc4Sens readout chips simultaneously. In order to achieve this goal, the system is composed of a FPGA Zynq Ultrascale+, a custom PCB and a management software. Thus, the operator will be able to manage the entire acquisition system from the GUI provided by the developed software, reducing the deployment time of the experiment and minimizing risks using a proven platform.
The FPGA chosen is a Xilinx Zynq UltraScale+ (model XCZU3EG-1SFVA625) that implements a processing system (PS) and a programmable logic (PL). Thus, this architecture makes integrate the acquisition as well as process the experiment possible to data on the same device. The PS is composed of a quad-core ARM Cortex A53, a dual-core ARM Cortex RSF and several peripherals to manage external devices such as NAND flash memories, CAN transceivers, or PCIe connections. This block will be in charge of running the operating system (a custom build based on GNU/Linux) that will execute the manage and control processes. The dual-core ARM will be destinated to run those algorithms in real time, taking advantage of the fact that it can read and write data directly from the programmable logic.
In relation to the PL, this part of the FPGA will implement the digital logic to communicate with the Roc4Sens chips in order to extract and store the relevant information in dynamic memory. Subsequently, this data will be collected and processed by the acquisition software.
The last block corresponds to the acquisition software, which will be the interface between the operator of the telescope and the proposed data acquisition system. It will be based on a client-server arquitecture. This program must meet the following requirements:
• GUI to set the different reference voltages
• Represent the data acquired from each Roc4Sens
• Execute commands directly on the operating system
Lastly, it should be noted that the proposed acquisition system is in an advanced design stage. Specifically, the logical design is in a debugging stage to ensure that every module works properly. Additionally, the custom PCB is under testing to validate its performance. Finally, the acquisition software is under developing, defining a proper API that can be easily integrated with other acquisition frameworks.

Monolithic Sensors / 5

MPW2 testing in the RBI microbeam

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We would present a very recent experiment about the working of the MPW2 monolithic detector chip prototype under proton and ion microbeams at the RBI Pelletron facility. We plan to test the integrity of the memory cells using a proton beam for aiming to the target by looking the Particle X ray emission (PIXE) and then shooting ions in mili broadbeam (around 1 mm2), and microbeam (around 1 um2) in focused and scanning modes. We expect to evaluate the single event sensitivity of the memory cells block.

TPA-TCT / 6

Observation of an inactive region in irradiated silicon diodes

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The Transient Current Technique (TCT) is used to investigate the response of silicon diodes. Electron-hole pairs are generated close to the surface by illuminating the diode with two sources: either a pulsed red-light laser or α-particles. These charge carriers drift in the electric field and induce transient currents on the diodes electrodes. The charge collection of a diode is determined by integrating these transients.

In this work, n^+-p-p^+ diodes irradiated with 23 MeV protons up until a 1 MeV equivalent neutron fluence of $1.2 \times 10^{16}\mathrm{cm}^{-2}$ are examined. The measurements are done at -20 °C up to a bias voltage of 800 V. TCT observations show evidences for a region with zero charge collection at the n^+-p interface. The thickness of this inactive region is determined by comparing charge collection measurements with the two sources. This talk presents the results for three diodes irradiated with varying degrees of fluence.

3D sensors / 7

Time resolution of an irradiated 3D silicon pixel detector

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We report on the measurements of time resolution for double-sided 3D pixel sensors with a single cell of 50 μm $\times$ 50 μm and thickness of 285 μm, fabricated at IMB-CNM and irradiated with reactor neutrons to different radiation doses up to 1e16 MeV n_{eq}/cm^2.

LGAD - Low Gain Avalanche Detectors / 8

Latest Results on charge sharing in AC-LGAD (aka RSD)

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We present measurements on AC-LGADs (also named Resistive Silicon Detectors RSD), a version of LGAD which has shown to provide spatial resolution on the few 10‘s of micrometer scale based on charge sharing among neighboring pads.
Using focused IR-Laser scans directed alternatively at the read-out side on the front and the bias side on the back of the AC-LGAD, RSD produced by FBK have been investigated to understand the charge sharing properties as a function of process parameters, and where available, compared with beam tests and detailed TCAD simulation of the charge collection process.

TPA-TCT / 9

A table-top Two Photon Absorption –TCT system: experimental results

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The Transient Current Technique (TCT) has become a very important tool for characterization of unirradiated and irradiated silicon detectors. In recent years a novel method, the Two Photon Absorption - Transient Current Technique (TPA-TCT), based on the charge carrier generation by absorption of two photons, was developed. TPA-TCT proved to be very useful in 3D characterization of silicon devices with unprecedented spatial resolution. Currently the first compact TPA-TCT setup is under development at CERN. The results obtained on non-irradiated silicon strip and LGAD sensors as well as irradiated LGAD sensors will be covered in this talk.

SiC, Detector Characterization and Very High Fluence Experiments / 10

Comparison studies of heavily irradiated dielectrics for AC-coupled pixel detectors on MCz silicon

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The motivation of this study is the development of next generation capacitively coupled (AC-coupled) pixel sensors with coupling insulators having good dielectric strength and radiation hardness simultaneously. The AC-coupling insulator thin films were aluminum oxide (Al_2O_3) and hafnium oxide (HfO_2) grown by Atomic Layer Deposition (ALD) method. The Al_2O_3 thin films were patterned for finely segmented structures by traditional wet etching, whilst HfO_2 was patterned by Chemical Mechanical Polishing (CMP) into structures defined by Reactive Ion Etching (RIE).

We will be presenting results based on the comparison study of the dielectric material used in MOS, MOSFET and AC-pixel sensors processed on high resistivity p-type Magnetic Czochralski silicon (MCz-Si) substrates. These devices were irradiated with 10˜MeV protons up to a fluence of 5e15 p/cm^2. Capacitance-voltage measurements of MOS and MOSFET test structures indicate negative oxide charge accumulation induced by proton irradiation. These studies are coherent to numerical simulations. Furthermore, current-voltage (I-V) measurements indicate very good dielectric strength performance in both the materials, even after proton irradiation. Electrical characterization to study the impact of different dielectric-silicon interfaces on the functionality of the AC-pixel sensors was further investigated by edge-TCT (Transient Current Technique) method. The negative oxide charge during the irradiation is an essential prerequisite of radiation hardness resiliency of $n^+/p^-/p^+$ (n on p) particle detectors widely intended to be used in future high-luminosity experiments.

Defect and Material Characterization - Acceptor removal studies / 11

Update on radiation damage investigation of epitaxial p-type Silicon using Schottky / pn junctions

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This project focuses on the investigation of radiation damage of epitaxial p-type silicon.

Various test structures consisting of Schottky diodes and pn-junctions of different size and flavors have been fabricated at different facilities, including RAL and Carleton University. The structures are fabricated on a 6-inch wafer of various doping (1e13, 1e14, 1e15, 1e16, and 1e17 B cm-3) and 50 µm thick epitaxial layer.

Updates and details on the first batch of fabricated devices on high and medium resistivity wafers will be given. Test results obtained so far - and cross-checked between institutes - will be shown. Some initial approaches on how to reduce the surface component of the leakage current that could potentially be applicable to the foreseen irradiated sample measurements will also be discussed. Furthermore, details of the ongoing Synopsys TCAD simulation will be provided.

Finally, the progressing activities for the next round of wafer processing and proposed plans for irradiation with protons/neutrons in the coming months, will be reviewed.

SiC, Detector Characterization and Very High Fluence Experiments / 13

Full-size passive CMOS sensors for radiation tolerant hybrid pixel detectors

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CMOS process lines are an attractive option for the fabrication of hybrid pixel sensors for large-scale detectors like the ATLAS and CMS detectors. Besides the cost-effectiveness and high throughput of

commercial CMOS lines, multiple features like poly-silicon layers, metal-insulator-metal capacitors and several metal layers are available to enhance the sensor design.

After an extensive R&D programme with several prototype sensors using the 150 nm LFoundry technology, passive CMOS pixel sensors have been manufactured for the first time as full-size sensors compatible with the RD53 readout chips.

This presentation will focus on IV-curve measurements and the characterization of the full-size sensors, before and after irradiation to fluences of 2×10^{15} neq/cm² and 5×10^{15} neq/cm², using a minimum ionising electron beam. The measured hit-detection efficiency after a fluence of 5×10^{15} neq/cm² is larger than 99 %.

LGAD - Low Gain Avalanche Detectors / 14

The performance of IHEP-NDL and IHEP-IME LGAD sensors after neutron Irradiation

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The Institute of High Energy Physics, Chinese Academy of Sciences (IHEP, CAS) has designed two types of LGAD sensors, which are produced in the Novel Device Laboratory (NDL) and Institute of Microelectronics (IME) respectively. The sensors of the two foundries were irradiated with neutrons to fluences of 0.8e15, 1.5e15 and 2.5e15 neq/cm2 in Institut Jozef Stefan (JSI). The timing resolution and collected charge of LGAD sensors were measured with electrons from a beta source. After irradiation with a fluence of 2.5e15 neq/cm2, the collected charge of the IHEP-NDL (IHEP-IME) sensor can be greater than 7 (9) fC, and the time resolution is better than 39 (50) ps.

LGAD - Low Gain Avalanche Detectors / 15

Study of gain suppression in LGADs using IBIC and TRIBIC

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The study of a Low Gain Avalanche Detector (LGAD) has been carried out by Ion Beam Induced Charge (IBIC) and Time Resolved Ion Beam Induced Charge (TRIBIC) using the nuclear microbeam line of the Centro Nacional de Aceleradores (CNA). For that purpose, a 3 MeV H ion beam was employed, and the results were compared to that obtained by the Transition Current Technique (TCT) using an infrared laser at the SSD laboratory at CERN and at the Clean Room of the Physics Institute of CAntabria (IFCA). Although the charge collection time is the same for both techniques, near the onset voltage the shape of the induced current pulses is significatively different. Moreover, the values of the absolute gain curve are considerably higher when measured by TCT. This gain suppression is related to the shielding effects of the electric field in the multiplication layer, which depend on the generated carrier density. Therefore, in order to study how the plasma effects change with the generated carrier density, experiments have been carried out by varying the proton incidence angle from 0° to 85°.
In this talk, the gain curves for all angles will be shown. The results indicate that when mean ionization density projected on the multiplication layer is minimum (50°) the measured gain is maximum. Also, at very large angles (> 70°) the electron path in the multiplication layer is the dominant factor for the gain suppression. TRIBIC results will also be shown, from which some conclusions can be drawn about the decrease in the hole gain and plasma effects outside the multiplication layer when the Bragg peak falls inside the detector.

LGAD - Low Gain Avalanche Detectors / 16

Timing measurements on neutron-irradiated LGADs in epitaxial wafers

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In this contribution we will present the first measurements on neutron-irradiated LGADs corresponding to our 6-inch, 50µm active layer thick, epitaxial wafers run (6LG3). Samples were fabricated using three boron implantation doses, and one energy, for the gain layer definition. Gain, collected charge, acceptor removal constant and timing measurements were carried out on these LGADs irradiated with neutrons at equivalent fluencies ranging from 1e14 to 1e16 atm/cm2. The presented results will serve as a stepping stone to select the best technological parameters for the gain layer definition in the upcoming ATLAS-CMS common runs, based on 6-inch epitaxial and Si-Si wafers (6LG3 and 6LG2 technologies, respectively).

LGAD - Low Gain Avalanche Detectors / 17

iLGAD Sensor For X-Ray Applications

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In this work, we have optimized an Inverted Low Gain Avalanche Detector (iLGAD) for X-Ray irradiations. The first iLGAD generation was fabricated at IMB-CNM as a tracking sensor for high-energy physics (HEP) experiments. Based on this device, we have designed a new periphery using TCAD simulations, which can cope with up to a dose of 10 Mrad. The breakdown voltage of the sensor has been increased by four times in a harsh radiation environment. The second generation of iLGADs has been fabricated at IMB-CNM. We present in this contribution the electrical characterization of the sensors, as well as gain measurements. Moreover, the detectors have been irradiated at 10 Mrad, showing promising results.

3D sensors / 18

Response of 3D pixel sensors to grazing angle incident particles

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Finely segmented 3D pixel sensors are being considered for the innermost layer of the Phase-2 Tracker upgrade of CMS due to their intrinsic radiation tolerance and low demanding power consumption. No significant degradation of performance is observed up to fluences of 1e16 neq/cm2.

The innermost layer of the Phase-2 Tracker will be placed as close as 3 cm from the beam and will extend 20 cm in both directions from the center of the detector along the beam direction. Ionizing particles originating at vertices near the center of the detector will
therefore traverse the modules at the edges of the innermost barrel layer at essentially grazing angles of incidence which could be as large as 87 degrees. Pixel sensors in this region will have particles traversing a long distance inside the sensors and deposit charge in a large number of pixels, resulting in pixel "clusters" of extremely large size. Apart from the reduced resolution along the beam direction, these tracks create a potential "cluster breaking" problem: if the generated charge of any pixel along the particle trajectory fluctuates low and remains under the detection threshold of the front-end readout electronics, this pixel is lost, and the cluster breaks into several sub-clusters.

In this presentation, test beam data obtained with 3D sensors tilted almost horizontally with respect to the beam, are analyzed to quantify and study the potential cluster breaking in 3D sensors. The results show that fresh 3D sensors are not affected by cluster breaking. Even unbiased, the cluster breaking rate never exceeds 3%. This is a direct consequence of the homogeneity of charge collection independently of the depth of the track, as is also shown.

SiC, Detector Characterization and Very High Fluence Experiments / 19

First results from thin silicon sensors irradiated to extreme fluence

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The first 25 and 35 mμ thick LGAD sensors produced at FBK have been irradiated with neutrons up to 1·10^{17} n$_{eq}$/cm^2.
The preliminary electrical characterisation of the irradiated sensors will be presented.
The plans towards the next production of thin sensors optimised for extreme fluences will be discussed.

LGAD - Low Gain Avalanche Detectors / 20

Preliminary Test Results of LGADs from Teledyne e2v for the LHC's High-Luminosity Upgrade

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The need for 4D (fast timing in addition to 3D resolution in space) silicon particle detectors has become very apparent with the introduction of the High-Luminosity (HL) upgrade at the LHC. Timings on the order of tens of picoseconds will allow better reconstruction of the ~200 primary vertices along the beam line in every bunch crossing. Correct association of tracks with primary vertices is particularly difficult closer to the beam axis where the track density is greatest and reconstruction with 3D detectors alone is insufficient.
The University of Birmingham, University of Oxford, the Rutherford Appleton Laboratory and the Open University are developing and testing new LGAD sensors. This project, aimed at developing Ultra-Fast Silicon Detectors (UFSD) of characteristics and performances suitable for use at HL-LHC High Granularity Timing Detector (HGTD) is being developed in collaboration with Teledyne e2v.
The first fabricated batch of 22 six-inch wafers, featuring 50 µm thick high resistivity epi layer with different gain layer implants was completed successfully.

In this talk, we will discuss preliminary I-V and C-V measurements across wafers for device sizes of 1 mm and 4 mm, and comparisons to PiN diodes where the gain layer is not present. Initial gain measurement using TCT laser injection on both PiN and LGAD diced devices will be shown. Some preliminary test results of diced structures before and after proton irradiation will also be provided.

LGAD - Low Gain Avalanche Detectors / 21

LGAD Development at Teledyne e2v for the LHC's High-Luminosity (HL) Upgrade

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The need for 4D (fast timing) silicon particle detectors has become very apparent with the introduction of the High-Luminosity upgrade at the LHC. Timings on the order of 10's picoseconds will be required in order to fully reconstruct trajectories along the beam line where the intensity is largest and post-collision reconstruction with 3D detectors is insufficient.
The University of Oxford, University of Birmingham, the Rutherford Appleton Laboratory and the Open University are developing and testing new LGAD sensors. This project, aimed at developing UFD of characteristics and performances suitable for use at HL-LHC High Granularity Timing Detector (HGTD) is being developed in collaboration with Teledyne e2v.
The first fabricated batch of 22 six inch wafers, featuring 50 um thick high resistivity epi layer with a range of gain layer implants (dose and energy) was completed successfully.

In this talk, we'll concentrate on the LGAD design process and first IC-CV measurements carried out on wafers. Comparisons with Synopsys TCAD simulations will be shown.
Details of the wafer laser dicing along with initial measurements on individually diced LGAD and PiN devices will then be provided. Plans for next tests will also be discussed

LGAD - Low Gain Avalanche Detectors / 22

Test beam measurements of BNL and HPK AC-LGADs

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We present measurements of AC-LGADs performed at Fermilab test beam facility. We also present first test beam results of sensors which utilize a buried gain layer. The buried layer is formed by patterned implantation of a 50-micron thick float zone substrate wafer-bonded to a low resistivity carrier, followed by epitaxial deposition of the amplification region. We studied strip and pixel sensors produced by BNL and HPK. Measurements are performed at our upgraded setup that utilizes high precision telescope tracker, and simultaneous readout of up 7 channels per sensor, which allows detailed studies of charge sharing characteristics. We study several reconstruction algorithms to optimize position and time resolution. These measurements allows us to assess the differences in designs between different manufacturers and optimize them, based on experimental performance in test-beams.

LGAD - Low Gain Avalanche Detectors / 23

A new testing system for multipad RSD sensors based on a a new FAST ASIC

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The development of next-generation silicon sensors is directed towards improving the spatial and temporal resolution of today's particle trackers. To this end, our group in Turin recently developed a solution that features the combination of silicon LGAD (Low Gain Avalanche Detector) sensors with FAST, an integrated device responsible for both amplification and basic processing of the signal. The sensors used in these studies are of the RSD (Resistive Silicon Detector) type, designed in Turin and manufactured by Fondazione Bruno Kessler. Fabricated using 110 nm CMOS technology, the FAST ASIC designed in Torino has temporal resolutions as low as a few tens of picoseconds, all while operating on up to 20 independent channels.

The performance of this detection chain, composed of RSD sensors coupled with FAST, was evaluated using a custom, programmable testing environment developed in the past months. The apparatus

uses a short-pulsed laser to generate a signal in the sensor similar to the one released by a particle, as well as a micrometrical x-y stage for sensor positioning and a multichannel data acquisition system based on a high performance digitizer to read the front-end output signals. Thanks to this innovative system both the sensor's and amplifier's behavior can be characterized as a whole, providing useful data for later calibration.

Instrumentation and hardware choices will be presented, as well as the software techniques and workflows that have been developed. Finally, some results obtained from the analysis of data collected using the system will be reported.

Defect and Material Characterization - Acceptor removal studies / **24**

Current Deep Level Transient Spectroscopy (I-DLTS) technique applied to p-type silicon diodes for Acceptor Removal studies

Authors: Anja Himmerlich[1]; Michael Moll[1]; Yana Gurimskaya[2]; Chuan Liao[3]; Eckhart Fretwurst[3]; Ioana Pintilie[4]; Isidre Mateu[5]; Joern Schwandt[3]; Leonid Makarenko[6]; Vendula Maulerova[3]

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Two current-based microscopic analysis methods - TSC and I-DLTS - with current injection and/or optical filling (in development) were recently and effectively used by CERN RD50 Acceptor Removal project group as reciprocal tools in the investigation of highly irradiated p-type silicon sensors and their related radiation hardness study aiming to understand and parametrise the existing acceptor removal problem. For such devices, defect filling has become a major issue in the defect identification, for which the contest between filling and emission processes, but also - competition and interaction among various defect levels have been carefully examined and taken into account. For several detected defect levels including the two of the main interest - BiOi and CiOi, the clear dependence between the filling conditions (Tfill, tfill, UP), but also Vbias and Nt concentration was ascertained, which makes the problem of acceptor removal parameterisation extremely difficult to solve. The optimised protocol in defect filling conditions as well as a quantitative analysis of the I-DLTS, C-DLTS and TSC results on electron irradiated PiN diode as an example will be discussed.

TPA-TCT / **25**

A table-top Two Photon Absorption –TCT system: Method and Setup

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The Transient Current Technique (TCT) has become a very important tool for characterization of unirradiated and irradiated silicon detectors. In recent years a novel method, the Two Photon Absorption - Transient Current Technique (TPA-TCT), based on the charge carrier generation by absorption of two photons, was developed. TPA-TCT proved to be very useful in 3D characterization of silicon devices with unprecedented spatial resolution. The first compact TPA-TCT setup was developed at CERN. In this talk the TPA-TCT method and the CERN setup will be presented.

LGAD - Low Gain Avalanche Detectors / 26

Characterization on the radiation hardness of USTC-1.1 LGADs

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A High-Granularity Timing Detector (HGTD), based on low gain avalanche detector (LGAD) technology, is proposed for ATLAS Phase-II upgrade. The USTC Group is involved in this project and has been developing the LGAD sensor technology. In this talk, we will report the recent results of USTC-1.1 LGAD sensors, which are designed by USTC and fabricated at IME (Institute of Microelectronics ,CAS). Various designs with different peripheral structures and gain layer implantation are realized in the production. The electrical IV/CV characterization and timing measurements with Sr-90 beta source are performed on the single-pad test structures and 5x5 arrays, both before and after neutron irradiation at JSI. The best c-factor of USTC-1.1 sensors extracted from standard CV results is 1.85E-16 cm^2. The preliminary results show that the time resolution is better than 35 ps before irradiation and better than 70 ps with the collected charge larger than 4 fC when the radiation fluence reaches 2.5E15 cm^-2 1MeV neutron equivalent, which means the radiation hardness of USTC-1.1 LGAD sensors can potentially satisfy the specification of HGTD.

Defect and Material Characterization - Acceptor removal studies / 27

The boron-oxygen (BiOi) defect complex induced by irradiation with 6 MeV electrons in p-type silicon diodes

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Abstract: The radiation induced BiOi defect complex by 6 MeV electrons in low resistivity (10 Wcm) p-type epitaxial silicon diodes has been studied using the Thermally Stimulated Current (TSC) and the Thermally Stimulated Capacitance (TS-Cap) technique. The fluence values were in the range between 1 × 1015 e/cm2 and 6 × 1015 e/cm2. The extracted results on the activation energy, defect concentration as well as the isothermal annealing behavior at 80 oC will be presented and discussed in comparison with data from TSC and DLTS(Deep Level Transient Spectroscopy) measurements achieved by the team of the CERN-RD50 "Acceptor removal project". In addition, the extracted microscopic data are compared with results from capacitance-voltage (C-V) characteristics.

Monolithic Sensors / **28**

Characterization of depleted monolithic active pixel sensors in 180 nm TowerJazz technology

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The high-luminosity upgrade of the LHC (HL-LHC) leads to new requirements on the detectors. With the availability of highly resistive silicon from commercial CMOS vendors, there are ongoing efforts to build depleted monolithic active pixel sensors (DMAPS) for high energy particle detectors. TJ-Monopix is a family of such a pixel sensor in 180 nm TowerJazz technology implementing a small collection electrode design. It is designed for usage in high-radiation environments such as the HL-LHC. The pixels with a size in the order of 30 um to 40 um are read out using a column-drain readout architecture.
In this talk, results from the first iteration, TJ-Monopix1, will be shown as well as an overview of the design and first measurements with TJ-Monopix2.

Monolithic Sensors / **29**

Radiation hardness and development of a large electrode DMAPS design in a 150 nm CMOS process

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Monolithic CMOS active pixel sensors in depleted substrates (DMAPS) are an attractive development for pixel tracker systems in high-rate collider experiments. The radiation tolerance of these devices is enhanced through technology add-ons and careful design, which allow them to be biased with large voltages and collect charge through drift in highly resistive silicon bulks. In addition, the use of commercial CMOS technology would reduce the current production complexity and costs of large module areas.

LF-Monopix1 is the first fully functional large-scale DMAPS demonstrator chip with a column drain readout architecture. It was designed in a 150 nm CMOS process that made it possible to place and isolate each pixel's front-end circuitry within a charge collection electrode of a size comparable to the pixel area. This presentation will give an overview of the chip performance and focus on its radiation hardness. Measurements on neutron irradiated samples showed an in-time detection efficiency of $\sim 97\%$ after a NIEL dose of $1 \times 10^{15} n_{eq}/cm^2$. Moreover, gain did not degrade and noise increased by 25% after a X-ray TID dose of 100 MRad.

The presentation will end with a design overview and results from initial observations on the new functional LF-Monopix2 chip. This prototype reimplemented and improved successful front-end designs from LF-Monopix1 in a column length of 2 centimeters and a reduced pixel pitch of 150 x $50\ \mu m^2$.

LGAD Mortality Studies / 30

Systematic study of heavily irradiated LGAD stability using the Fermilab Test Beam Facility

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LGAD sensors will be employed in the CMS MTD and ATLAS HGTD upgrades to mitigate the high levels of pileup expected in the High Luminosity phase of the LHC. Over the last several years, much attention has focused on designing radiation tolerant gain implants to ensure these sensors survive the fluences expected, in excess of 1-2 x 10ˆ15 neq/cmˆ2. As verified with beta source measurements, the latest sensor prototypes are able to provide adequate gain for precision timing even at the end of life. However, in test beams, highly irradiated LGADs operated at high voltage have been seen to exhibit violent burn-out events that render the sensors non-operational. We present the results of the first systematic study of heavily irradiated LGAD mortality using data collected at the Fermilab Test Beam Facility. For this campaign, 30 sensors were exposed to the 120 GeV proton beam in a highly controlled environment. We demonstrate that rare, highly-ionizing proton interactions can lead to single-event burnout. Sensors with diverse characteristics and treatments are included to study which properties affect the mortality risk and understand potential mitigation strategies. With proper operational mitigation, we expect sensor mortality can be avoided with minimal impact on the performance of the CMS MTD.

LGAD - Low Gain Avalanche Detectors / 31

Development of large-area LGADs for Space Application

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Recently, Low Gain Avalanche Detectors (LGADs) has emerged as a technological solution for precise timing measurements in the tens of ps range. They have led to a range of developments in High Energy Physics and other applications. In space application, the timing of particles is one of the crucial observable that has a direct implication on particle identification. However, to distinguish particles with similar mass an absolute timing resolution is required in the order of O (10 ps). In space the rate of particles is not as high as HEP and power consumption is an issue, ultimately reducing the number of channels. The typical size of silicon sensor for strip geometry in space application is 100 μm pitch and 50-60 cm long resulting in a channel area of about 1 cm2 whereas, the typical LGAD channel size is O (1 mm2
). This work was motivated by
the requirement of a O (1 cm2
) sized LGAD detector. In this work, we investigated the jitter of the sensor as a function of different sensor thickness and gain values. In addition, we measured some big area sensors using the transient current technique (TCT) to study the signal shape and gain uniformity. We discuss the measurements performed with pad sensors of dimensions 5 mm × 5 mm (with and without gain), and strip sensors with pitch 192 μm and 3.5 cm long stips. These pad sensors with gain layer, are the biggest single channel LGADs ever fabricated in Fondazione Bruno Kessler (FBK) with standard LGAD technology. After successful measurements with TCT, we discuss the gain, gain uniformity, signal shape, signal propagation, and issues that need to be addressed while making large-area sensors.

LGAD - Low Gain Avalanche Detectors / 32

Principle of operation of an innovative new sensor for neutron detection based on resistive AC coupled LGAD

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In this work, we present the principle of operation of an innovative sensor for neutron detection obtained by depositing a thin layer of converter, about 35 microns of 6LiF, on a multi-pad AC-LGAD. When the neutrons are captured in the converter, the ensuing emission of alpha particles and/or

tritium nucleuses is recorded by the silicon sensor. In this study, the AC-LGAD is first glued on a 16-ch read-out board, then, a well to contain the converter is positioned around the sensor, and, lastly, the converter is deposited by means of an evaporative technique. The good timing performances and excellent position resolution of such detector are ideal for applications in neutron imaging.

SiC, Detector Characterization and Very High Fluence Experiments / 33

Performance of Stitched Passive CMOS Strip Sensors

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The vast majority of foreseen upgrades to existing particle physics detectors, as well as future Linear Collider experiments will continue to be based on silicon sensors as main tracking device. This means sensors will become even more of a cost driver than they already are today. In addition, sensors in the Float-Zone technology currently used in the LHC experiments are available from only a very small number of manufacturers in the large quantities required. Therefore, alternative detector technologies and designs that are cost-effective and that can be realised through widely established commercial industrial production processes are becoming more and more relevant.

One important group of candidates are sensors realised in CMOS technology. Typically, industrial CMOS foundries are equipped for high volume production but fabricating chips that are much smaller in area than in particular the full size strip sensors in production for e.g. LHC Phase-II experiment upgrades today.
In order to obtain sensors in the large dimensions required, several neighbouring reticles have to be connected in a process known as stitching.

The passive strip sensors presented in this contribution were designed and developed in a p-CMOS technology and produced by a European manufacturer. Stitching of up to six different reticles was used on the strip sensors to obtain detectors with strip lengths of up to 4 cm. Sensors in our study comprise three different flavours of strip sensors fabricated on a 150 m thick wafer made with the passive p-CMOS 150 nm process.

Following initial electrical characterisation on a probe station, the sensors were tested in the laboratory with Sr-90 sources and IR-lasers. Results from two batches of sensors are presented in this study, with an improved backside processing on the second batch of sensors to enhance the HV performance of the initial batch. Our results include TCAD simulations of those sensors as also a preliminary analysis of a testbeam data. The detectors are recently irrradiated with 23MeV protons and first elecectrical characterization will be shown in this presentation. In this context, we also evaluate the impact of stitching on the sensor functionality. Based on our results, we are able to demonstrate that stitching does not show any negative effect on the sensor performance, and, hence, the stitching of CMOS strip sensors can be considered successful.

3D sensors / 34

3D n-on-n detectors

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In my talk I will present the results of the first fabrication of n-on-n 3D detectors. The sensors have been irradiated with neutrons at fluences up to 1E17n/cm 1 M-ev/equivalent. Using the TCT set up available at CNM we have been able to do the measurements before irradiation both of the charge collection efficiency and the timing performance using a 50x50 pixel array with a pitch of 50um. Using a CFD of 50% we can get a timing resolution of 83ps before irradiation at room temperature. Reuslts on the irradiated detectors will also be presented.

Defect and Material Characterization - Acceptor removal studies / **37**

Defects formed in boron-doped Si diodes after high energy electron irradiation

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The performance and lifetime of silicon-based sensor devices operated in high radiation environment are essentially determined by the defects formed during the interaction of the high energy particles with the sensors. In p-type Si, for example, a significant deactivation of active boron is observed accompanied by the formation of boron-interstitial oxygen-interstitial (BiOi) defects.
In this talk we present defect studies using deep-level-transient-spectroscopy (DLTS) as well as thermally stimulated current technique (TSC) on electron irradiated p-type Si diodes of different resistivity (50 to 1000 Ωcm). The diodes were characterized directly after irradiation as well as after annealing. Changes in the defect concentrations will be presented and an overview of the introduction rates after electron irradiation compared to proton and neutron irradiation will be given.

SiC, Detector Characterization and Very High Fluence Experiments / **38**

A new vision of I-V characteristics in irradiated Si sensors with heavily damaged regions

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The study is focused on the impact of heavily damaged Bragg peak region (BPR), which arises in Si p+-n-n+ diodes at the end of 15 um track of 53.4 MeV 40Ar ions on the degradation of the bulk current The method of the study included simulation of ion collisions with the silicon atoms, the measurements of I-V and C-V characteristics of irradiated diodes and their treatment using a specially built algorithm. It was revealed that the profiles of the current density gradient dJ/dx (the current generation rate) demonstrated nontrivial shapes with two features: the maxima shift from the BPR, and a plateau with a reduced dJ/dx inside the BPR. These features are related, respectively, to the contribution of the diffusion current of holes outflowing from the nondepleted BPR to the total current, and an exhaustion of hole current from the depleted BPR. The main result important for practice is that suppression of the current is a common effect for Si sensors with regions enriched with defect clusters, such as track ends of short-range ions, or uniformly damaged regions in sensors irradiated with hadrons at fluences beyond 10ˆ16 neq/cm2.

LGAD - Low Gain Avalanche Detectors / 39

Studies of effective inter-pad distance of different HPK and FBK LGADs

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Effective interpad distance of non-irradiated and irradiated LGAD prototypes from HPK and FBK was measured and compared to simulations. The effective interpad distance is substantially larger than nominal before irradiations and becomes nominal after irradiations. The measurements were compared with simulations which showed that the field lines from a sizeable region at the edge of the pad end on JTE, hence the carriers generated there don't undergo multiplication.

Monolithic Sensors / 40

Status of the design of RD50-MPW3 ASIC

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RD50-MPW3 is a new prototype HV-CMOS ASIC, developed by the CERN-RD50 CMOS Working Group, whose submission for fabrication is planned for Q4 2021. It is the most advanced prototype of the RD50-MPWx series. RD50-MPW1 includes a fully monolithic matrix of 40 x 78 pixels, with a very small 50 µm x 50 µm pixel area that integrates both analog and FE-I3 style digital readout electronics inside the collecting electrode. In this prototype, however, the diodes exhibit high leakage currents and the readout electronics show IR drops and crosstalk. To fix these issues, we took a staged approach. RD50-MPW2 minimizes the sensor leakage currents, in more than four orders of magnitude compared to its predecessor, with novel methodologies and includes simplified yet improved pixels. The pixel size is 60 µm x 60 µm to increase the spacing between the HV ring and the collecting deep n-well to achieve higher breakdown voltages of 120 V before irradiation. The pixels include analog front-end electronics only to simplify the design and are arranged in an 8 x 8 matrix.
RD50-MPW3 will incorporate all the lessons learnt so far and fix the IR drops and crosstalk. This ASIC will include a fully monolithic matrix of 64 x 64 pixels with a 60 µm x 60 µm pixel area and both analog and FE-I3 style digital readout electronics. To reduce the number of routing lines and minimize the crosstalk, the pixels will be arranged in a double column scheme and will be configured through serial circuitry. Other improvements will focus on increasing the readout speed of the peripheral electronics by means of more efficient End Of Column (EOC) blocks and an I2C link to read/write the control status registers. The data will be packed into frames, zero-suppressed and serialized at 640 Mbps. A transmission protocol will be implemented to facilitate data transmission and resynchronization. The design will follow a digital-on-top flow to guarantee the timing and power performance. Figure 1 shows a block diagram of RD50-MPW3.
In this talk, the authors will present the status of the design of RD50-MPW3.

LGAD - Low Gain Avalanche Detectors / 41

A comprehensive feasibility study on the utilisation of the Ion Beam Induced Charge (IBIC) Nuclear Microprobe Technique at the RBI for the LGAD's Characterization including the Interpad-Gap Measurements

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Techniques for silicon detector characterization have predominantly relied on the laser methods such as TCT and quite recently TPA-TCT. We show that the Ion Beam Induced Charge (IBIC) technique has great potential in future LGAD characterizations. The LGAD sensors, 200 um thick and arranged in a 2x2 array configuration with a nominal interpad distance of 50 um were tested. The microprobe system at the Rudjer Boskovic Institute delivered different energies for the proton and carbon ion beams so that the 2D charge collection efficiency maps were obtained for shallow and deep probing. In the vicinity of the interpad region, the two different doses of irradiation were performed with the carbon ions so that a damage of 3.1x1011 ions/cm2 and 6.3x1011 ions/cm2 was introduced. As a consequence of the induced damage, the charge collection efficiency degradation was studied and some regions with extremely high electric fields were notified. The dependence of the interpad measurements on the penetration depths was demonstrated using proton beams with various energies. It was observed that the interpad distance increases with the penetration depth of ions. This result confirms the previously established hypotheses regarding the bending the el. field towards JTE. The results presented here are part of the joint research of the University of Montenegro

(UoM), the Jozef Stefan Institute (JSI) and the Rudjer Boskovic Institute (RBI) where the experiment was carried out. This research may also have a significant impact on the future development of the IBIC technique hence it was shown that LGAD is a good tool for further exploitation of the IBIC. Thus, this research also is a good example of how both, the sensor device (LGAD) and the tool used for its characterisation (IBIC technique) can benefit from each other through further improvements of its own imperfections in a well-designed research approach. This will be the subject of the next research.

LGAD Mortality Studies / 42

The mortality study on irradiated W36 LGADs and PINs for tuning the HV safety parameters and establishing the turning point for the irreversible breakdown (Part I): Using TCT-SPA with 800 nm of fs-laser at ELI

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The HL-LHC presents unprecedented challenges and timing information is expected to play a key role in mitigating the impact of pile-up in both ATLAS (HGTD) and CMS (MTD-ETL). However, yield and stability after heavy irradiation remain a concern. The presented results are the results of the main part of the second big experimental campaign on LGAD fatalities and its irreversible breakdown after being irradiated to the fluences of the LHC-HL interest; the study lasted almost one month at ELI Beamlines since very dedicated and systematic approach was applied. Only part based on TCT-SPA with 800 nm of fs-laser beam is shown here. Results from TCT-TPA with 1550 nm of fs-laser beam are shown in a separate talk. The first mortality campaign at ELI was performed and completed successfully in February and the results have been shown at the TREDI2021 Workshop. This is the second campaign dedicated to tuning the HV safety parameters. This time, starting with a low pulse energy of 1 pJ the bias was increased from 100 V to 650 V (later this limit was extended to 670 V) whereas the signal was observed on the oscilloscope (waveforms were recorded) and the leak current was monitored. This procedure was repeated for increasing pulse energies with a 5 pJ step until 50 pJ. For every scan we searched for the first symptoms of instability in the signal. When the signal started slightly "jumping"the values of laser energy and HV bias was noted as the "stability threshold". After reaching the threshold the bias was further increased (to 670 V) in order to explore the "unstable region"; this was possible as long as the signal was safely measured by the scope. When the signal was high and significantly deformed the scope was disconnected and only the leakage current was observed with increasing bias. In the end the energy was set at 50 pJ and the bias was increased until the breakdown of the sensor was achieved. The damaged sensors were finally inspected by optical and electronic microscopes. The fatality signatures and the HV threshold values for LGAD's irreversible breakdown will be shown and discussed.

LGAD Mortality Studies / 43

The mortality study on irradiated W36 LGADs and PINs for tuning the HV safety parameters and establishing the turning point for the irreversible breakdown (Part II): Using TCT-TPA with 1550 nm of fs-laser at ELI

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Aside from the SPA mortality studies, the first attempts with the TPA mechanism have been performed. In particular, the stability and mortality of the system were monitored with well localized TPA generation of charge in different depths of the device (Z −direction). The first results suggest that the stability of the devices varies rather weakly as long as the charge is generated inside the device. In addition, the location and character of damage features observed by electron microscopy are similar to those obtained by SPA damage.

Monolithic Sensors / **44**

The RD50-MPW2 High Voltage-CMOS sensor chip DAQ and preliminary testbeam results

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The CERN-RD50 collaboration aims to develop and study High Voltage-CMOS (HV-CMOS) sensors for use in very high luminosity colliders. Measurements will be presented for the RD50-MPW2 chip, a prototype HV-CMOS pixel detector with an active matrix of 8 x 8 pixels. The active matrix is tested with injection pulses, a radioactive source and a proton beam. The talk will cover the FPGA based DAQ system, the software and firmware developed to take and analyse data. Preliminary results from a Proton test-beam will also be presented.

SUMMARY

An overview of the DAQ system to measure RD50-MPW2 will be presented. The DAQ is composed of a Xilinx ZC706 FPGA board, a Caribou data acquisition board and the dedicated chip board. The Zynq-7000 XC7Z045 SoC on the ZC706 is programmed with a custom version of the Peary Caribou firmware, a processor side coded in C and logic side coded in VHDL.

A custom C++ GUI has been developed to communicate with the firmware to configure and readout the chip. This allows a simple interface to be used to select a pixel for injection, perform a hit

map scan, generate a response curve to calculate the gain, generate s-curve data to calculate the noise, modify the internal DACs of RD50-MPW2, adjust the internal DC baseline level, set thresholds and control the analogue multiplexer. An overview of the entire DAQ chains hardware and firmware/software will be presented.

Preliminary results of a recent test-beam at the Northumbria Rutherford Cancer Centre in the UK will be presented, including initial plots of ToT and Analogue amplitude data. Measurements were taken using an IBA Proteus One –S2C2 Synchrocyclotron proton beam, using a range of energies from 70.2 to 200 MeV.

TPA-TCT / 45

New TPA-TCT system at JSI

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A new TPA-TCT system based on FYLA fs laser has been assembled at JSI. The setup and first measurements will be presented in this talk.

Monolithic Sensors / 46

Readout system and testbeam results of the RD50 MPW2 HV-CMOS pixel chip

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The RD50-CMOS group aims to design and study High Voltage CMOS (HV-CMOS) chips for use in a high radiation environment. Currently, measurements are performed on RD50-MPW2 chip, the second prototype developed by this group.
The active matrix of the prototype consists of 8x8 pixels with analog frontend. Details of the analog frontend and simulations have been already published earlier. Standard tests on passive test-structures have been performed as well and will be briefly mentioned.
This talk focusses on the digital, Caribou based readout system of the active matrix and results of the first small testbeams. Relevant aspects of hardware, firmware and software are introduced, always focusing on the operation of the chip in combination with a tracking telescope to measure hit efficiency.

LGAD - Low Gain Avalanche Detectors / 47

Gain suppression mechanism observed in Low Gain Avalanche Detectors

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Low Gain Avalanche Detectors (LGADs) is one of the most promising sensing technologies for future 4D-tracking applications and recently it has been qualified to be used in the ATLAS and CMS timing detectors for the HL-LCH upgrade. LGADs are able to achieve an excellent timing performance by the presence of an internal gain that improves the signal-to-noise ratio leading to a better time resolution.

These detectors are designed to exhibit a moderate gain with an increase of the reverse voltage. Also, the value of the gain strongly depends on the temperature. Thus, these two values must be kept under control in the experiments to maintain the gain within the required values. A reduction in the reverse bias or an increase in the temperature will reduce the gain significantly.

In this talk, we present a new mechanism of gain suppression observed in LGADs. It was observed that the gain measured in these devices highly depends on the charge density generated by a laser or particle in the bulk. Measurements performed with different detectors under different conditions showed that ionizing processes that induce less charger density in the detector bulk lead to an increase in the detector's measured gain.
Therefore, measurements conducted with IR-laser and Sr-90 in the lab confirm this mechanism and will be presented in this talk.

Defect and Material Characterization - Acceptor removal studies / 49

Investigation of acceptor removal by 4-point probe and LTPL measurements

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To investigate the acceptor removal by irradiation, high resistivity FZ silicon samples are implanted by boron, gallium and indium. A co-implantation with oxygen, carbon, nitrogen and fluor is done as well. After Implantation the samples are annealed in an RTP furnace. The sheet resistance and low temperature photoluminescence (LTPL) spectra are measured. Then the samples are irradiated by 1MeV electrons and 23MeV protons. Subsequently, the sheet resistance and the LTPL spectra are measured again.
In the pre-irradiated state the implanted boron atoms are only affected by the high dose carbon co-implantation. This co-implantation increases the sheet resistance of the sample. In case of the indium doping the co-implantation affects the sheet resistance strongly. After irradiation a strong scattering in the 4-point probe measurement occurs making the interpretation of the results difficult. Nevertheless it has been found by LTPL measurements that the acceptors are to the most part removed by the irradiation.

LGAD - Low Gain Avalanche Detectors / 50

Radiation Tolerance study of AIDA2020v2 LGADs manufactured at IMB-CNM

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A comprehensive review of the characterization results of neutron-irradiated (up to a fluence of $2.5 \times 10^{15} n_{eq}/cm^2$) LGADs manufactured at IMB-CNM in the context of the AIDA-2020 project will be given. The single-diode LGADs studied have an architecture that corresponds to that envisaged for the high-luminosity LHC MIP timing detectors.

Defect and Material Characterization - Acceptor removal studies / 51

Bistability of the BiOi complex –a reason for the observed large scattering in the determined acceptor removal rates in irradiated p-type silicon

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Our study focused on the BiOi defect, as determined from DLTS and TSC experiments, in connection with the acceptor removal rates in B-doped silicon PAD and LGAD diodes irradiated with 23 GeV protons and 1 MeV neutrons. We followed the dependencies on doping, irradiation fluence and particle type in a try of understanding the large scattering in the results reported previously for acceptor removal rates in p type Si. We show that the main reason behind is the metastable behavior of the BiOi defect which can exists in at least two configurations (labelled as A and B). The switch between the different BiOi defect configurations was observed for defect concentrations exceeding 1012 cm-3 in both, high resistivity and medium doped silicon and only through variations detected in the A configuration of the defect, characterized by a donor energy level at ˜0.25 eV from the conduction band. The defect reversibly passes from one configuration to another after exposing the samples to an excess of carriers, achieved by thermal treatments at moderate temperatures or by the inherent exposure to the ambient light when manipulating the samples prior to the electrical measurements performed in dark, indicating thus a bistable character of the center. It also change its electrical activity causing not only significant long time variations in both, the effective doping concentration - Neff and the concentration of BiOi defect, as determined from the emission of electrons by the donor level of the A configuration, but also an underestimation of the true introduction rate of the BiOi defect and of the "acceptor removal"rate. Any electrical measurement performed before the BiOiA(0/+) configuration is stabilized will give a different result. Thus, we conclude that such procedural reasons are contributing significantly to the large scattering in both, the reported values concerning the "acceptor removal"as determined from C-V/I-V measurements and the BiOi introduction rate as detected in DLTS and TSC measurements.

Defect and Material Characterization - Acceptor removal studies / 52

LGAD irradiated with 1e19 1MeV n/cm2 - HRTEM annealing studies up to 350 oC

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High Resolution Transmission Electron Microscopy (HRTEM) is a milestone in the imaging of structural defects. A LGAD sample irradiates at a fluence of 1e19 1MeV neutrons/cm2 has been investigated with a JEOL 2100 system, equipped with high resolution polar piece. Structural changes subsequent to a 30 min isochronous thermal treatment @150C, 200C, 250C, 200C and 350C respectively have been followed via HRTEM.
Point defects (vacancies and/or interstitials) or very small clusters of point defects have been observed to organize along well defined tracks. From a qualitative perspective, this aspect was found to be common along the whole series. However, starting from 250C, significantly larger clusters of defects started to be randomly observed.

Heading

Defect and Material Characterization - Acceptor removal studies / 53

Modelling of the Coulombic centres charge emission: electric field approximation comparison in simulating the measured TSC signal

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Three-dimensional Poole-Frenkel emission from BiOi was studied using three different approximations of the electric field inside the active p-type region. All three approaches for obtaining the TSC spectrum rely on the same assumption that every emitted charge is captured by the electrode without the possibility for recombination or re-trapping. With this common approximation the electric field was calculated using three different approaches: 1) the electric field in the active region is calculated for a uniform charge distribution with no temperature dependence, 2) the charge distribution is calculated at each temperature step which introduces a temperature dependence in the electric field and 3) a finite element approach is used to calculate the electric field in the active region as a function of position and temperature. This study reveals the importance of the modelling approach to characterize Coulombic centres in the active region of detectors. It will be shown how the electric field is influenced for different device parameters and consequently the changes that are translated to the TSC spectrum.

Defect and Material Characterization - Acceptor removal studies / 54

Discussion on defects and material characterization

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SiC, Detector Characterization and Very High Fluence Experiments / 55

Discussion on High Fluences and Detector Characterization

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TPA-TCT / 56

New results of edge-on measurements with electron beam on pad diodes

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The previously introduced technique of edge-on measurement using an electron beam for pad diodes has been studied further. The method has been
improved in several aspects: the spatial resolution (by a factor of 2), the precision of the in-situ alignment (by a factor of 2.5), and the statistical errors (by
a factor of 2.0).
In this study, the pad diodes have areas of 25 mm2 and 12.5 mm2
, a thickness
of 150 µm and a p-doping concentration of 4 × 1012 cm−3
. For irradiation
study, four diodes were irradiated with 23 MeV protons up to a 1 MeV neutron
equivalent fluence of Φeq = 1.2×1016 cm−2
. The measurements were performed
at −20 ◦C for bias voltages up to 800 V. In addition, a non-irradiated diode
was measured for bias voltages in the range of 10 to 120 V.
This work presents the new results. Using these results, one can develop

SiC, Detector Characterization and Very High Fluence Experiments / 57

Timing resolution simulation of 2D and 3D SiC devices

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SiC devices can work at high irradiation fluence and temperature environment, and 3D-SiC devices can achieve good time resolution and high charge collection, which makes it have broad application prospects. This report contains the time resolution simulation of 2D SiC devices and the comparison between measurement data and 2D simulation. The understanding of time resolution simulation of SiC devices is deepened through comparing. Based on 2D simulation, we simulate the 3D SiC

devices and predict the time resolution of 3D-SiC devices in a certain structure. This can be used as a reference to the tape out of our future 3D SiC devices.

LGAD - Low Gain Avalanche Detectors / 58

Discussion on LGAD

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LGAD Mortality Studies / 59

Discussion: LGAD mortality

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Monolithic Sensors / 60

Discussion on Monolithic and Pixel sensors

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TPA-TCT / 61

Discussion: TCT techniques and 3D sensors

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Defect and Material Characterization - Acceptor removal studies / 62

Optical detection of single defects in silicon

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The boom of silicon in semiconductor technologies was closely tied to the ability to control its density of lattice defects. After being regarded as detrimental to the crystal quality in the first half of the 20th century, point defects have become an essential tool to tune the electrical properties of this semiconductor, leading to the development of a flourishing silicon industry. At the turn of the 21st century, progress in Si-fabrication and implantation processes has triggered a radical change by enabling the control of these defects at the single level. This paradigm shift has brought silicon into the quantum age, where individual dopants are nowadays used as robust quantum bits to encode and process quantum information. These individual qubits can be efficiently controlled and detected

by all-electrical means, but do not feature an optical interface adapted to long-distance propagation in optical fibers. In order to develop applications for quantum communications, we have started investigating defects in silicon that are optically-active in the near-infrared telecom bands.

Recently, we have demonstrated that this semiconductor hosts a large variety of point defects that can be detected at single scale by using optical confocal microscopy operating at 10K [1,2]. These fluorescent individual defects are either carbon-related complexes, such as the so-called G-center, or radiation damage centers made of interstials. Besides opening new perspectives for Si-based quantum technologies, these results could also benefit to other research fields. The optical characterization of Si-based devices at single-defect scale could enable early-stage detection of their degradation in environments with strong radiations such as particle-physics detectors.

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Monolithic Sensors / 63

The Caribou Data Acquisition System

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LGAD - Low Gain Avalanche Detectors / 64

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