36th RD50 Workshop (CERN - - online Workshop)

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Book of Abstracts

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CERN EP seminar: Innovative silicon sensors for future trackers

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Abstract:
Future particle trackers require formidable position (˜5 microns) and time (˜ 10 ps) resolutions. In traditional silicon sensors, better position resolution implies smaller pixels and, consequently, much higher channel count and smaller area available for the electronics. This combination is at odd with the requirement of also measuring accurately the timing information, a request that increases considerably the complexity of the readout and its power consumption. In this seminar, we will present a novel design of silicon detectors, the so-called Resistive Silicon Detector (RSD). RSD uses internal gain, a resistive n+ junction contact on a p-bulk, and AC readout to achieve signal sharing among several readout pads (somewhat similar to the RPC concept). This design leads to a drastic reduction of the number of read-out channels for equal spatial resolution while it maintains the excellent time performances of low gain silicon sensors. The RSD design (also called AC-LGAD) has a 100% fill factor and it is easily adapted to any geometry since the segmentation is achieved uniquely by the metal AC pads. In the first part of the seminar, we will present the challenges in the design and production of the first prototypes at FBK, while in the second part we will cover the signal formation, reconstruction techniques, and preliminary laboratory and beam test results. The last part of the seminar will focus on the plans for design optimization and the introduction of machine learning in the reconstruction to exploit the distributed nature of the signal.

Welcome / **2**

Welcome

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Welcome to the first RD50 online Workshop

Defect Characterization / **3**

Discussion Session: Defect Characterization & Acceptor Removal

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Discussion

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Discussion Session: LGAD

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LGAD Discussion

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Acceptor removal and gain Reduction in proton and neutron irradiated LGADs

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Using electrical characterization, acceptor removal coefficients are estimated and compared for Boron, Gallium and Boron with Carbon diffused gain layer LGADs. Effective implant is computed as a function of fluence for up to 6e15 neutron and proton irradiated sensors in different processes. Results are compared to gain reduction calculations aand relent coefficients are derived. The two separate approaches are compared with laboratory charged collection measurements obtained, while a breakdown voltage model is also considered. A direction for further improvement on radiation hardness is presented for discussion.

CMOS / 6

[US] Effects of neutron irradiation on HV-JFETs

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We had p-type HV-silicon JFETs, fabricated at Brookhaven National Laboratory, irradiated with neutrons at the Triga reactor in JSI, up to a fluence of 1.5e15 neq/cm2. Most notably, output characteristics show a dramatic increase of the drain saturation voltage with the irradiation. By means of TCAD simulations, which used the Perugia radiation damage model, we are explaining this effect as due to the charge introduced by the traps, that modifies the electrostatics in sensitive areas of the

JFET and limits the hole current toward the drain. Effects of acceptor removal are also visible in the I-V curves.

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Annealing effects on operation of thin Low Gain Avalanche Detectors

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Several thin Low Gain Avalanche Detectors from Hamamatsu Photonics were irradiated with neutrons to different equivalent fluences up to $\Phi_{eq} = 3 \cdot 10^{15}$ cm^{-2}. After the irradiation they were annealed at 60°C in steps to times > 20000 minutes. Their properties, mainly full depletion voltage, gain layer depletion voltage, generation and leakage current, as well as their performance in terms of collected charge and time resolution, were determined between the steps.

It was found that the effect of annealing on timing resolution and collected charge is not very large and mainly occurs within the first few tens of minutes. It is a consequence of active initial acceptor concentration decrease in the gain layer with time, where changes of around 10\% were observed. For any relevant annealing times for detector operation the changes of effective doping concentration in the bulk negligibly influences the performance of the device, due to their small thickness and required high bias voltage operation. At very long annealing times the increase of the effective doping concentration in the bulk leads to a significant increase of the electric field in the gain layer and,
by that, to the increase of gain at given voltage. The leakage current decreases in accordance with generation current annealing.

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[US] Deep Junction LGAD: a new approach to high granularity LGAD

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Low Gain Avalanche Detectors (LGADs) are silicon detectors with modest internal gain (up to ˜50) that allows the sensor to be very thin (20-50 um). LGADs are characterized by an extremely good time resolution (down to 17ps), a fast rise time (˜500ps) and a very high repetition rate (˜1ns full charge collection). In a broad array of fields, including particle physics (4-D tracking) and photon science (X-ray imaging), LGADs are a promising R&D path. However, due to structures required to provide electrostatic isolation between LGAD pixels, the granularity of production-level devices is limited to the 1x1 mmˆ2 scale. However applications in particle physics and photon science demand granularity scales of 100x100 umˆ2 or better. Several promising approaches to improve this

current limitation of LGADs are currently in R&D status. In this talk, we'll report an updated on a completely new idea involving a buried gain layer to overcome the current granularity limit: the DJ-LGAD.

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Latest results on RSD spatial and timing resolution

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In this contribution we present the latest results on spatial and timing resolution of Resistive AC-Coupled Silicon Detectors (RSD), produced by FBK in 2019. RSD are a new type of silicon detectors specifically designed for high precision 4D tracking. They are based on the LGAD technology, benefiting from its excellent timing performances, and can achieve a spatial resolution a factor 10 better than the one estimated in binary read-out (pixel size/$\sqrt{12}$), thanks to charge sharing maximization among pads. The results we will present have been obtained for the first time with a combined analysis of data coming from both extensive laser measurements performed in the Torino Innovative Silicon Detectors Laboratory and the last beam test performed at Fermilab with a 120 GeV/c proton beam.

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[US] Energy dependence of the acceptor removal by protons for several UFSD types

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The performance of Ultra-Fast Silicon Detectors (UFSD) is compromised by hadronic irradiation which removes the acceptors in the thin layer below the junction responsible for the gain. This

effect is measured in several different UFSD after irradiation with protons with energy of 70 MeV (CYRIC), 800 MeV (LANL) and 24 GeV (CERN) and compared to the same sensors irradiated with neutrons at IJS. The fluence dependence were determined with capacitance –voltage, C-V, measurements of the doping concentration and with measurements of charge collection, CC, using charged particles. We find that the simplified assumption of NIEL scaling does not apply to the acceptor removal mechanism which exhibits a larger effect for protons than predicted by NIEL

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Investigation of LGAD performance dependence on neutron flux

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A set of LGADs from HPK was irradiated with different neutron fluxes to the equivalent fluence of $4 \cdot 10^{14}$ cm^{-2} . The fluxes covered range from 10^{10} cm^{-2} s^{-1} to close to 10^{13} cm-2 s^{-1}. The gain layer and bulk depletion voltage as well as charge collection and timing performance were measured after 80 min at 60°C annealing point. No dependence of the damage on neutron flux was observed.

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Position reconstruction using machine learning algorithms applied to Resistive Silicon Detectors (RSD)

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RSDs (Resistive AC-Coupled Silicon Detectors) are n-in-p silicon sensors based on LGAD (Low-Gain Avalanche Diode) technology, featuring a continuous gain layer over the whole sensor area. The innovative feature of these sensors is that the signal induced by an ionizing particle spreads among several pixels, allowing position reconstruction techniques that combine the information of many read-out channels.
In this contribution, the first application of a machine learning technique to RSD devices is presented: using inputs from 3 or 4 pads, a Multi-Output regressor algorithm is trained and validated using laboratory data taken with a Transient Current Technique (TCT) setup; then it is applied to beam test data. RSD matrices having different pitch and pixel sizes have been tested, in order to assess the algorithm performances with different geometries.
As an example, an RSD with 200 µm pixel provided 5 µm position resolution, 10 times better than what is achievable with binary read-out (200µm / sqrt(12) ~ 55µm).

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Radiation tolerant small-pixel passive CMOS sensors with RD53A readout

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With the HL-LHC upgrade of the ATLAS detector, the surface of the ATLAS pixel detector will increase from 2 m² to approximately 13 m² . Therefore, commercial CMOS processing lines offering high production throughput at comparatively low costs represent an attractive option for such large-area detectors. Further benefits originate from multiple metal layers, metal–insulator–metal capacitors, and polysilicon layers which can be used to enhance the sensor design.

Thinned, small-pixel passive CMOS sensors in 150 nm technology offered by LFoundry were manufactured and assembled into hybrid pixel modules using the RD53A readout chip.

The sensors were characterized, before and after irradiation to a fluence of 5×10^{15} $\mathrm{n_{eq}}$/cm², in the laboratory and also using a minimum ionising electron beam. Their performance in terms of noise and hit-detection efficiency equals that of conventional planar pixel sensors. In particular, a hit-detection efficiency of 99 % is measured after irradiation to 5×10^{15} $\mathrm{n_{eq}}$/cm².

Detector Characterization, NIEL and Irradiation Facilities / 14

Measurement of the charge collection for the irradiated n^+pp^+ pad diode in the region of the n^+p interface

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The charge collection of two $\mathrm{n^+pp^+}$ pad diodes for light with a wavelength of 660 nm from a sub-nanosecond laser and α-particles with energies, E_α, between 1.5 and 2.8 MeV injected from the $\mathrm{n^+p}$ side, has been measured. The diodes had an area of 25 mm^2, a thickness of 150 μm and a doping concentration of $4.5 \times 10^{12}\mathrm{cm}^{-3}$ in the bulk region. The measurements were performed at -20 °C for bias voltages up to $V_{bias} = 800$ V. One diode had been irradiated by 23 MeV protons to a 1 MeV equivalent fluence of $\Phi_{eq} = 2 \times 10^{15}$ cm^{-2}, the other one had not been irradiated. As expected, above the depletion voltage the charge measured for the non-irradiated diode, Q_0, is independent of the bias voltage. The Charge Collection Efficiency (CCE) for the irradiated diode is obtained from $\mathrm{CCE}_\Phi(V_{bias}) = Q_\Phi(V_{bias})/Q_0$, where $Q_\Phi(V_{bias})$ is the charge measured for the irradiated diode. As expected, $\mathrm{CCE}_\Phi(V_{bias})$ increases with bias voltage because the higher electric field increases the drift velocity of the holes, which dominate the signal. In addition, it is observed that $\mathrm{CCE}_\Phi(V_{bias})$ for α-particles increases with increasing E_α, and at $E_\alpha \approx 1.5$ MeV the $\mathrm{CCE}_\Phi(V_{bias})$ for α-particles (with ≈ 5 μm range in silicon) is the same as for the laser light of 660 nm (with 4.5 μm attenuation length at -20 °C).

The data can be described assuming a V_{bias}-independent layer with zero charge collection of thickness d_0, followed by an active region with the V_{bias}-dependent mean charge collection $\mathrm{CCE}_\Phi(V_{bias})$ for the remaining range of the α-particles. It is found that $d_0 = 1.15 \pm 0.10$ μm and $\mathrm{CCE}_\Phi = 55 \pm 1$ % at $V_{bias} = 300$ V increasing to 78 ± 1 % at $V_{bias} = 800$ V. The presence of an inactive layer is relevant for the determination of charge-carrier lifetimes using light with a short attenuation length or low energy α-particles: Not taking into account d_0 underestimates the values for the lifetime.

Defect Characterization / 15

Update on Radiation damage investigation of epitaxial P type Silicon using Schottky / pn junctions and LGAD - GaN activities at RAL

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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 p junctions of different size and flavors are being fabricated at different facilities, including RAL, Carleton University and CNM.

The structures are fabricated on a 6 inch wafer of various doping (1e13, 1e14, 1e15, 1e16, and 1e17 B cm-3) and 50 um thick epitaxial layer.

Updates and details on the initial fabrication phase of devices on high resistivity wafer will be given. Plans for the testing of the devices will also be discussed.

Initial design and simulations of LGAD structures, currently being developed at RAL-Oxford-Birmingham in collaboration with T2eV semiconductor foundry, will also be presented.

Finally, some initial plans for GaN radiation hardness investigation using custom devices from NRC in collaoration with Carleton University will be presented

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First tests and characterization of the RD50-MPW2 active pixel matrix, bandgap voltage reference and SEU tolerant memory

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This contribution will be focused on the lab performance evaluation of the electrical parameters before irradiation of three different blocks of the RD50-MPW2 device, the 8 by 8 matrix of depleted monolithic active pixel sensors, the bandgap voltage reference and the SEU (Single Event Upset) tolerant memory array. The RD50-MPW2 was developed in the framework of the RD50 collaboration and implemented in the 150 nm HV-CMOS process of LFoundry. The device was submitted for

fabrication in January of 2019 and the first samples received in February of 2020. In first place, a reminder of the main characteristics of the aforementioned RD50-MPW2 circuits will be carried out. Secondly, the different tests performed in order to verify and characterize the pixel analog readout electronics, the configuration and bias registers as well as the analog multiplexer will be described. Measured results corresponding to input charge generated both with the pixel injection circuit and radioactive sources will be displayed. In third place, the measurements to assess the bandgap output voltage stability against the input voltage will be presented. Finally, preliminary lab measurements of the Single-Event tolerant memory array of the chip will be also showed.

LGAD / 17

AC-LGAD strip sensor measurements with 120 GeV protons

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This contribution describes the first measurements of a resistive AC-coupled Low Gain Avalanche Diode (AC-LGAD) strip detector using 120 GeV protons. AC-LGADs combine the precise time resolution of standard LGAD silicon sensors with precise spatial resolution, and make excellent candidates for future 4-dimensional tracking detectors. The sensor studied in this result has a strip pitch of 100 μm, and was produced at Brookhaven National Laboratory. Measurements were performed at the Fermilab Test Beam facility. In this result, we characterize the sensor signal properties, compare the experimental results with TCAD simulations, and demonstrate sensor efficiency $> 99\%$.

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[AS] Radiation performance of the Low Gain Avalanche Diodes developed by NDL and IHEP in China

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This paper studies the radiation hardness of low gain avalanche detector(LGAD) developed by the Novel Device Laboratory (NDL) in Beijing and the Institute of High Energy Physics (IHEP) of Chinese Academy of Sciences, in the context of an upgrade project of the ATLAS detector for the high luminosity phase of LHC. NDL LGAD sensors with different layouts, epitaxial resistivity and doping profile were irradiated up to 1.02 ×1015 neq /cm2 by
70MeV protons at Cyclotron and Radioisotope Center (CYRIC). The timing resolution of NDL LGAD sensors reached 50 ps and the collected charge reached 3 - 4 fC after irradiation.

Simulations / 19

[AS] TCAD Simulation of Radiation Damage for LGAD Sensor

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A TCAD simulation of radiation damage for Low Gain Avalanche Detector (LGAD) by using various deep energy level models and acceptor removal has been performed. The simulation illustrates the influence of initial gain layer acceptor density and sensor structure. Other radiation damage characteristics could also be reproduced qualitatively: gain reduction, electric field distribution, and leakage current.

Simulations / 20

[AS] TRACS development for LGAD sensor

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The High Luminosity of the Large Hadron Collider (HL-LHC) is scheduled to be in operation around 2027, where the instantaneous luminosity will reach up to 7.5e34cm-2s-1. To mitigate the high luminosity induced pile-up, both ATLAS and CMS has proposed to use LGAD as the key sensor for timing measurement in the irradiation region. On the other hand, radiation hardness study on detectors will help investigate the stability and radiation endurance. TRACS is a multi-threading fast simulator tool of transient currents mainly for silicon strip detectors before and after irradiation. Development on TRACS has been extended to simulate the LGAD sensor with avalanche region, and preliminary results to compare the simulation with HPK LGAD sensors will be presented.

Detector Characterization, NIEL and Irradiation Facilities / 21

Fluence profiling at JSI TRIGA reactor irradiation facility

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In this contribution, we present an analysis of the flunece profile at the JSI TRIGA neutron reactor facility in Ljubljana.
For the study, 5×5 array LGAD sensors are used, with 1.3×1.3 mm^2 pad area. The gain layer active doping has been extracted via C-V measurements for each pad before and after irradiation at $1.5\cdot10^{15}$ n_{eq}/cm^2, providing a precise measurement of fluence distribution.

Experimental results are compared to neutron fluence expectations calculated with Monte Carlo techniques.

Defect Characterization / 22

Defect characterization in boron doped silicon sensors after exposure to protons, neutrons and electrons

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The radiation tolerance of 50 µm thin p-type Si epitaxial (EPI) devices differing in resistivity (initial Boron concentration) has been studied for 24 GeV/ c protons, reactor neutrons and 5.5 MeV electrons in the fluence range between 1E+10 cmˆ−2 and 1E+15 cmˆ−2 . The talk will summarize an update on characterisation and identification of the radiation-induced defects with a special focus to Boron-related ones responsible for deterioration of sensor properties. The data have been achieved with the TSC and DLTS techniques in the framework of the RD50 Acceptor Removal Project.

LGAD / 23

First LGAD timing/jitter measurement at ELI with fs-lasers of 800 nm and 1450 nm

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The results presented in this contribution are the results of the joint research of the Extreme Light Infrastructure (ELI) –Beamline The first measurements were devoted to understanding the potential of ELI ultrafast spectroscopy for LGAD studies (timing with SPA/TPA) and building up an infrastructure for future LGAD tests. As it will be shown, the preliminary results opened new possibilities for research on LGAD such as study of mortality of the irradiated sensors at very high pulses.

Detector Characterization, NIEL and Irradiation Facilities / 24

Timing resolution on a 3D silicon pixel detector

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We report the measurements of time resolution for double-sided 3D pixel sensor with a single cell of 50 μm x 50 μm fabricated at IMB-CNM. Measurements were conducted using a radioactive source at -20 and 20 degrees ℃ in a bias voltage range of 50-200 V.

Temporal resolution measurements are reported before and after irradiation of 8x10^{14} N$_{eq}$/cm^2 (1 Mev equivalent neutrons).

The reference time was provided from an LGAD detector produced by Hamamatsu. Results are compared to previous measurements on identical type sensors.

CMOS / 25

A reconfigurable HR-CMOS sensor for Tracking, Pre-Shower and Digital Electromagnetic Calorimetry

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Digital calorimetry relies on a highly granular detector where the cell size is sufficiently small so that only a single particle in a shower enters each cell within a single readout cycle. The DECAL sensor, a depleted monolithic active pixel sensor (DMAPS), has been proposed as a possible technology for future digital calorimeters. A DECAL sensor prototype has been designed and fabricated in the standard TowerJazz 180 nm CMOS imaging process, using high resistivity 18 µm epitaxial layer. The prototype has a pixel matrix of 64x64 pixels with a pitch of 55x55 µm, and reads out using fast logic

at 40 MHz. Each pixel contains four collection electrodes, trimming logic, pre-amplifier, shaper, comparator and discriminator with digital output. The pixel configuration logic provides a five bit calibration DAC and a mask flag. It can be reconfigured to function as either a strip sensor for particle tracking or a pad sensor, counting the number of pixels above threshold for digital calorimetry.
The talk will present results of chip characterisation, including digital summing logic, analogue pixel performance and threshold scans under laser illumination. The summing logic is tested using a test data shift register at the top of the pixel matrix that allows to inject a five bit number at the top of each column. The analogue pixel performance is validated illuminating a test pixel in the top left corner of the matrix with a laser with wavelength of 1064 nm. The performance of the digital pixels is less straight forward to evaluate as there is no direct readout available for individual discriminator output. Performing a threshold scan in columns and rows using trimming logic, the rate of hits in each pixel allows to test the full chain from analogue to digital. Laser illuminations in the digital pixel area and the response measured using a threshold scan confirm successful digital functionality in strip and pad operation mode. A new version of the DECAL sensor, has been designed and submitted for fabrication in the TowerJazz modified process with the aim to improve the Si sensor radiation hardness performance and the charge collection at the pixel edges. The variant chosen with a gap in the additional n- layer design for each pixel and expected to shape the electric field so the charge carriers produced are steered more directly towards the collection electrode in the pixel centre. In addition, the logic has been modified to have the pixel trim range extended from five to six bits, where the sixth bit will be for pixel mask flag which de-activates the in-pixel comparator.

Detector Characterization, NIEL and Irradiation Facilities / 26

Investigation on the effects of trapped charge on the signal from subsequent laser pulses in irradiated p-type sensors

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During edge-TCT studies on irradiated p-type sensors, a significant change on signal amplitude and shape from subsequent laser pulses has been observed, even with pulse repetition time of several microseconds.
We observed in particular a strong reduction of the collected signal, which can be due to a recombination with the previously trapped charge or to a significant change of the electric configuration due to the trapped charge.
By means of edge- and top- TCT measurements, we investigated the dependence on generation depth, temperature, pulse repetition time, intensity and voltage. Results indicate that the latter phenomena, also known as polarization, gives main contribution to the signal change. This is well known in larger band-gap materials like diamond, but usually negligible in silicon at the relative high measurement temperature of about -25℃.
A mathematical analysis of the results and simulations performed with kDetSim confirm the formulated description on the trapping effect

Detector Characterization, NIEL and Irradiation Facilities / 27

[US] Measurement of the silicon effective band gap energy with the ATLAS pixel detector

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Silicon sensor leakage currents are often used as a diagnostic tool for monitoring the bulk damage caused by non-ionizing energy loss. One of the key inputs to interpreting leakage current data is the effective band gap energy, which is used to correct for temperature variations in the current. Using dedicated temperature scans in 2017 and 2018, the effective band gap energy is measured for the silicon sensors in the ATLAS pixel detector. This talk will report the results of the measurement and discuss implications for fluence monitoring and predictions.

CMOS / 28

Data acquisition system for the characterization of the RD50 HV-CMOS active pixel matrix prototypes

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The data acquisition (DAQ) system used to read out and characterize the two versions of RD50 HV-CMOS prototype chips (MPW1 and MPW2) is based on the CaRIBOu (Control and Readout Inner tracking Board) system. CaRIBOu is a widely used versatile DAQ platform to characterize pixel detectors and ASICs, such as CLICpix2, C3PD and others. It consists of a system-on-chip board (e.g. Xilinx ZC706), a control and readout (CaR) interface board and an application specific detector carrier board. In a first approach chip boards and firmware for the chip specific functionality of both MPW1 and MPW2, respectively, were developed. Moreover, a custom software was implemented and executed in the embedded CPU of the SoC board to configure and read out the chips. For future integration into data acquisition frameworks like EUDAQ, chip specific device modules for the CaRIBOu DAQ software framework Peary are being developed and operated for the two RD50 chips.
In this contribution, we will describe the hardware of the DAQ system as well as first experience of the integration into the Peary software framework. Moreover, the latest developments of an alternative DAQ hardware, currently being developed at IFIC Valencia, will be presented.

CMOS / 29

Initial I-V and e-TCT measurements of a depleted CMOS sensor within the CERN-RD50 collaboration

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Future high energy particle physics experiments, such as the High Luminosity Large Hadron Collider (HL-LHC) and the proposed Future Circular Collider (FCC), will reach unprecedented energies and produce many billions of particles per second to probe into physics beyond the standard model. As part of these experiments, detectors will need to be capable of recording this incredibly large number of particles, and withstand damage sustained after prolonged use in these harsh environments.

In this work we present initial I-V and Edge Transient Current Technique (e-TCT) measurements of a Depleted Monolithic Active Pixel Sensor (DMAPS) prototype, "RD50-MPW2". This prototype is being developed by the CERN-RD50 collaboration to study these sensors for future particle physics experiments and has been recently fabricated in the 150 nm High-Voltage CMOS (HV-CMOS) process from LFoundry.

Defect Characterization / 30

Electron mobility dependence on neutron and electron irradiation fluence in Si

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There are presented the simulation of electron mobility dependence on concentration of different defects (ionized and neutral impurities, dipoles, clusters) according the known models and by TCAD Synopsys program (in the neutron irradiated Si).
The known and new experimental data compared with the simulation results.

Defect Characterization / 31

Quantum characteristics of electron and hole quasiparticles in silicon defects

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Charge recombination lifetime in a silicon wafer is directly proportional to the high energy particle (HEP) irradiation dose of a device. It is widely recognized that the dose of irradiation can be directly related to the density of defects. However, the microscopic picture of defects is highly inhomogeneous with several kinds of defects clustered along the path of HEPs. Electron and hole motion via defect sites thus define the observed recombination process. For this purpose, we perform quantum chemistry calculations for a small cluster of silicon and study the electron density distribution for electron and hole type electronic configurations in for four types of Si defects. In the optimized geometry we study electron and hole wavefunctions, what allows to determine electron and hole hopping amplitudes as well as electron-hole recombination rates. We find that optimized defect geometries show existence of local minima with reduced symmetry. It shows for instance for a vacancy defect, not only a position of vacancy in the lattice but also the displacement of the surrounding atoms determines the charge density distribution. Comparing electron and hole charge densities only few types of defects demonstrate close overlap of the electron and hole densities. Hence, we identify the types of defects responsible for recombination. We can thus conclude that is not the total concentration of whatever defects in the crystal define the electron lifetime, but the concentration of specific recombination centers.

Simulations / 32

Simulation of thickness dependence of time resolution for simple planar devices.

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The parameter space of silicon detectors can be large. For this reason, simulations can be useful tool to simplify the system to get a better understanding of the impact of different parameters .
The study to be presented aims to build a fundamental understanding of what affects time resolution of a detector. The focus of the presentation will be on how thickness influences time resolution. Simulations of simple planar pad and pixel devices without gain will be discussed. The simulations are performed with Garfield++.

Detector Characterization, NIEL and Irradiation Facilities / 33

Determination of the proton related damage on commercial and high-ohmic silicon pad diodes

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Radiation hardness of detector sensors and components is a major challenge for the success of the scheduled High Luminosity upgrade of the CERN Large Hadron Collider, and a world-wide campaign for sensor characterisation and qualification has been undertaken. By convention, effects of irradiation with beams of different particle species and energy, aiming to assess displacement damage in semiconductor devices, are communicated in terms of the equivalent 1 MeV neutron fluence, using the hardness factor for the conversion. These hardness factors are subject to significant uncertainties, that complicate interfacility comparison.
Recently, the hardness factors for protons at three different kinetic energies have been estimated by analysing the I-V and C-V characteristics of reverse biased BPW34F photodiodes, pre- and post-irradiation [1]. The sensors were irradiated at the MC40 Cyclotron of the University of Birmingham, the cyclotron at the Karlsruhe Institute of Technology, and the IRRAD proton facility at CERN, with the respective measured proton hardness factors being: 2.1±0.5 for 24 MeV, 2.2±0.4 for 23 MeV, and 0.62±0.04 for 23 GeV. The hardness factors used in these facilities are in agreement with the measurements.
Following a brief recap of the earlier measurements, the improved set-up for precision electrical measurements at the University of Birmingham will be presented, along with an investigation of the behaviour following irradiation of Hamamatsu high-ohmic silicon pad diodes will be presented. The I–V and C–V characteristics of the diodes are investigated under different biasing schemes, and the active volume of the depleted bulk silicon that contributes in the change of the leakage current between pre- and post-irradiation can be determined with accuracy. Investigations for improved dosimetry in the Birmingham MC40 cyclotron will be also discussed. These studies may open a window for higher precision determination of the hardness factors.

[1] P. Allport et al., “Experimental Determination of Proton Hardness Factors at Several Irradiation Facilities,” JINST 14 (2019) P12004 (arXiv:1908.03049).

Defect Characterization / **34**

DLTS studies on as irradiated PiN diodes of different resistivity

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We will report on the electrically active defects induced by hadron irradiation in p-type diodes processed on different materials (EPI and CZ) and of different resistivities. The generation of the defects and their electrical parameters (activation energy and capture cross sections) have been investigated by DLTS technique, in the framework of the RD50- Acceptor removal project. The defects' generation rate in different materials after irradiation (with 1MeV neutrons or 23 GeV protons) will be discussed in connection with the Boron content in the samples.

CMOS / **35**

Discussion on CMOS devices

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Simulations / **36**

Discussion: Simulations

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Defect Characterization / **37**

Break

Defect Characterization / 38

DLTS and TSC techniques: A brief introduction

Authors: Anja Himmerlich[1]; Yana Gurimskaya[1]; Isidre Mateu[1]; Michael Moll[1]

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Deep Level Transient Spectroscopy (DLTS) as well as Thermally Stimulated Current (TSC) technique are powerful tools for the characterisation of e.g. radiation induced deep level defects in silicon detectors. These techniques, that are based on the analysis of relaxation as well as emission processes after carrier injection, provide information about defect concentrations, thermal activation energies and capture cross sections. This talk will give a short introduction into the fundamentals of both characterization techniques

Detector Characterization, NIEL and Irradiation Facilities / 39

TPA-TCT – Two Photon Absorption - Transient Current Technique

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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 current status of the setup and methods for characterizing the spatial beam profile are presented.

Detector Characterization, NIEL and Irradiation Facilities / 40

1550 nm Femtosecond Fiber Laser System for the Two-Photon Excitation of Transient Currents in Semiconductor Detectors

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The Two Photon Absorption - Transient Current Technique, TPA-TCT is a powerful tool for spatially resolved inspection of semiconductor detectors. The nonlinear absorption of light is excited by femtosecond lasers that deliver photons of energy lower than the band-gap energy of the semiconductor material. Simultaneous absorption of 2 photons (the sum of their energies being higher than the band-gap energy of the semiconductor) occurring only at the focal point of the laser, allows localized generation of transient current. For silicon, emission wavelengths longer than 1150 nm are required to fully avoid Single Photon Absorption, SPA.

The mode-locked Ti:Sa solid state laser is the current standard optical source of femtosecond pulses, but it operates with emission wavelengths in the 700 - 900 nm range. While complex, expensive and inefficient nonlinear frequency conversion techniques are used to extend Ti:Sa emission wavelengths to the near-infrared region, the natural emission wavelength of the erbium doped fiber laser is in the 1550 nm region, thus being an excellent candidate as exciting source of the TPA-TCT.

We have developed a femtosecond fiber laser system, of properties and functionalities particularly designed for the TPA-TCT. Based in an all-fiber Chirped Pulsed Amplification (CPA) architecture and seeded by a solitonic passively mode-locked erbium doped fiber oscillator, the system provides at its output femtosecond pulses at 1550 nm wavelength with configurable properties: pulse energy from <10 pJ to > 10 nJ, pulse repetition rate from single shot to 8 MHz and pulse duration from 200 fs to 500 fs. Standard deviation of the average output power in environmental conditions is below 1% (24 hours operation). Besides, the system offers the functionalities of emission-to-detection synchronization and of pulse properties characterization. Further work is envisaged to decrease the minimum pulse duration below 100 fs.