The 40th RD50 Workshop (CERN)

Tuesday 21 June 2022 - Friday 24 June 2022

CERN

Book of Abstracts

Contents

Defect and Material Characterization / **2**

M-center in low-energy electron irradiated n-type 4H-SiC

Authors: Takahiro Makino[1]; Tihomir Knežević[2]; ivana capan[None]; Takeshi Ohshima[1]

[1] *QST*

[2] *Ruđer Bošković Institute*

Corresponding Authors: ivana.capan77@gmail.com, tihomir.knezevic@irb.ht

In this work, we present a study on the low-energy electron irradiated 4H-SiC material studied by means of deep-level transient spectroscopy (DLTS) and Laplace-DLTS. Electron irradiation has introduced the following deep level defects: EH1 and EH3 previously assigned to carbon interstitial-related defects, and M-center, a metastable defect also recently assigned to carbon interstitial defects. We propose that EH1 and EH3 are identical to M1 and M3 and we assign them to C_iˆ(=) (h) and C_iˆ(0) (h), respectively. Additionally, we discuss about the conversion barriers C_iˆ(=) (h) ⊠ C_iˆ(=) (k), which could be lower than previously assumed. Moreover, we provide direct evidence that Laplace-DLTS can be used as an excellent and practical tool to distinguish otherwise identical DLTS signals associated with S1 (VSi) and EH1 (Ci). These signals have caused much confusion in the labeling and identification of irradiation-induced deep level defects located at 0.40 and 0.70 eV below the conduction band.

Facilities / **3**

EURO-LABS

Author: Marko Mikuz[1]

[1] *Jozef Stefan Institute (SI)*

Corresponding Author: marko.mikuz@cern.ch

The Horizon Europe project EURO-LABS will provide Transnational Access to Research Infrastructures (RI) for users from the Nuclear and Particle Physics communities. It comprises three pillars: Nuclear Physics, HEP Accelerators and HEP Detectors.

HEP Detectors RI's should be of vital interest to RD50. The RI's are grouped into 3 tasks dealing with Detector Characterization, Test Beams and Irradiations. The slate of RI's matches that in the TA od AIDA/AIDA2020, with increased budget in terms of Access Units and a few new facilities added.

The project will start on September 1st with a duration of 4 years.

Low Gain Avalanche Detectors / **4**

Measurements on last IMB-CNM LGADs production

Authors: Giulio Pellegrini[1]; Neil Moffat[1]; Salvador Hidalgo[1]; Jairo Antonio Villegas Dominguez[1]; Marcos Fernandez Garcia[2]; Ivan Vila Alvarez[3]; Richard Jaramillo Echeverria[2]; Efren Navarrete[4]; Anup Kumar Sikdar[5]

[1] *IMB-CNM (CSIC)*

[2] *Universidad de Cantabria and CSIC (ES)*

[3] *Instituto de Física de Cantabria (CSIC-UC)*

[4] *IFCA*

[5] *Indian Institute of Technology Madras (IN)*

Corresponding Authors: anup.kumar.sikdar@cern.ch, efren.navarrete@alumnos.unican.es, richard.william.jaramillo.echeverria@ce ivan.vila@cern.ch, mfgarcia@cern.ch, giulio.pellegrini@csic.es, neil.moffat@imb-cnm.csic.es, jairo.villegas@imb-cnm.csic.es, hidalgo.salvador@cern.ch

Abstract: In this contribution we will present the first measurements on LGADs corresponding to our CNM's second engineering run based on 6-inch, 50µm active layer thick, epitaxial wafers (6LG3 technology). Some of the wafers were carbon enriched using two different doses and one implantation energy. For the gain layer, samples were fabricated using different boron doses and diffusion times and one implantation energy. Measurements, simulations and analysis of breakdown and depletion voltages were carried out on these LGADs. The presented results will serve as a stepping stone to select the best technological parameters for the gain and carbon layer definition in the upcoming ATLAS-CMS common run, based on 6-inch Si-Si wafers (6LG2 technology).

Monolithic devices / 5

RD50-MPW3: General details and pixel matrix

Author: Chenfan Zhang[1]

Co-author: Eva Vilella Figueras [1]

[1] *University of Liverpool (GB)*

Corresponding Authors: vilella@hep.ph.liv.ac.uk, chenfan.zhang@cern.ch

The CMOS Working Group of CERN-RD50 has designed and submitted RD50-MPW3, which is the third High Voltage CMOS (HV-CMOS) pixel chip developed by the collaboration to further study these sensors for future physics experiments. The design of RD50-MPW3 incorporates the lessons learnt from the previous two chips, RD50-MPW1 and RD50-MPW2. It inherits the structures for high breakdown voltage and low leakage current, the fast analog readout circuits and the well-performing bias block and analog buffer from its two predecessors.

RD50-MPW3 is a more advanced prototype with a matrix of 64 × 64 pixels which integrate both analogue and digital readout electronics inside the sensing diodes. To alleviate routing congestion and minimise crosstalk noise, the pixels are serially configured and organised in a double-column architecture. This prototype has optimised digital peripheral readout electronics for effective chip configuration, based on the I2C protocol with internal Wishbone bus, and fast data transmission.

This contribution gives an overview of the general details of RD50-MPW3 and focusses on the design aspects of the pixel matrix. The design of the digital periphery of the chip, and of the electronics beyond the chip, will be presented in a separate contribution to this workshop.

Monolithic devices / 6

Data Readout for Advanced Designs (DRAD), an update

Authors: Pedro Blanco[1]; Jose María Hinojo Montero[2]; Jorge Jiménez[2]; Rafael Millan[2]; Fernando Muñoz[2]; Francisco Rogelio Palomo Pinto[3]

[1] *pblanco@us.es*

[2] *ETSI-University of Sevilla*

[3] *Universidad de Sevilla (ES)*

Corresponding Authors: jjsanchez@us.es, rmillan@us.es, jhinojo@us.es, francisco.rogelio.palomo.pinto@cern.ch

Particle detectors systems need state of the art Data Acquisition Systems as backend. DRAD (Data Readout for Advanced Designs) is a a new DAQ with a client-server data architecture able to handle up to 4 Hybrid Pixel Detectors simultaneusly. At the present, DRAD operates with the OC4SENS read-out chip but is easily adaptable to other pixel detectors. The DAQ is based on a System-on-Module (SoM) that includes FPGA logic fabric and microprocessors. The client-server architecture is enabled by a Linux operating system. The full DAQ is very compact, reducing the hardware load typically needed in particle tracking experiment, specifically during the compulsory particle telescope characterization.

Monolithic devices / 7

QFG transistors radiation damage effects

Authors: Clara Luján[1]; Francisco Rogelio Palomo Pinto[2]; Fernando Muñoz[1]; Jose María Hinojo[1]

[1] *ETSI-University of Sevilla*

[2] *Universidad de Sevilla (ES)*

Corresponding Authors: jhinojo@us.es, fmunoz@us.es, clujan@us.es, francisco.rogelio.palomo.pinto@cern.ch

Highly integrated and very low power microelectronics, as required by Read Out Chips, represents a challenge because maximum performance and minimum power consumption are opposite design requirements. Quasi Floating Gate transistors are a solution because they allow independent control of transistor static and dynamic operation: AC and DC input terminals are different. The DC input terminal has a big equivalent resistor, implemented as a mos reverse biased diode. Radiation displacement damage in mosfet electronics is not tipically an issue because Total Ionization Dose (and Single Event) effects are more relevant due to the shallowness of the active structures in the devices. But body diodes used in the QFG transistors are sensitive to radiation damage. In this work we analyze from first principles the radiation damage sensitivity of QFG transistors, we present experimental results after irradiation with gamma rays and discuss consequences for microelectronic designs.

IRRAD / 8

Influence of radiation damage on the absorption of near-infrared light in silicon

Authors: Annika Vauth[1]; Eckhart Fretwurst[2]; Joern Schwandt[2]; Robert Klanner[2]; Stephan Martens[1]

[1] *Universität Hamburg*

[2] *Hamburg University (DE)*

Corresponding Authors: eckhart.fretwurst@desy.de, robert.klanner@cern.ch, joern.schwandt@cern.ch, annika.vauth@uni-hamburg.de

To study the charge collection efficiency of radiation-damaged silicon sensors, frequently red and near-infrared light is used to generate electron-hole pairs . In order to determine the absolute number of produced charge carriers, the light absorption coefficient, α, has to be known.

To study the change of α due to radiation-induced defects, we have measured the transmission of light with wavelengths between 1-2\,μm through silicon samples irradiated to 1 MeV-neutron-equivalent fluences between 0 and 1×10^{17} cm^{-2}.

In this contribution, the results of these measurements will be presented: the contribution of the irradiation to α was found to scale with fluence for the entire fluence range investigated. In the wavelength region around 1.8\,μm, evidence for the production of the radiation-induced divacancy defect V_{2i}^{0} with a density approximately proportional to the fluence was found. For the band-gap energy, no fluence dependence was found within the experimental uncertainties.

Low Gain Avalanche Detectors / 9

High temperature annealing of irradiated LGADs

Authors: Alissa Shirley-Ann Howard[1]; Bojan Hiti[2]; Gregor Kramberger[1]; Igor Mandic[1]; Brigita Novak[3]; Marko Mikuz[1]; Vladimir Cindro[1]; Žan Kljun[3]

[1] *Jozef Stefan Institute (SI)*

[2] *C*

[3] *Jožef Stefan Institute*

Corresponding Authors: bojan.hiti@student.fmf.uni-lj.si, marko.mikuz@cern.ch, alissa.howard@ijs.si, gregor.kramberger@ijs.si, vladimir.cindro@ijs.si, igor.mandic@ijs.si

LGADs irradiated up to 6e15 n/cm2 with reactor neutrons were annealed at high temperatures between 300C and 450C. Annealing was for 30 minutes in steps of 50C. CV measurements were made after each annealing step and a significant increase of gain layer depletion voltage was observed. Charge collection and timing resolution were measured with electrons from Sr-90 showing beneficial effect of short term high temperature annealing of irradiated LGADs.

Monolithic devices / 10

Timing properties of the RD50-MPW2 HVCMOS chip

Authors: Bojan Hiti[1]; Jernej Debevc[1]; Christina Tsolanta[None]; Igor Mandic[1]; Jory Sonneveld[2]

[1] *Jozef Stefan Institute (SI)*

[2] *Nikhef National institute for subatomic physics (NL)*

Corresponding Authors: bojan.hiti@cern.ch, jory.sonneveld@cern.ch, jernej.debevc@cern.ch, ctsolant@nikhef.nl, igor.mandic@ijs.si

The CERN-RD50 collaboration has been developing radiation hard High Voltage CMOS detector prototypes based on high resistivity substrate and large collection electrode, manufactured in LFoundry 150 nm process. In this contribution we will present measurements of timing properties of the RD50-MPW2 chip, which features an 8 x 8 matrix of active pixels with integrated analog front end and discriminator circuits that can be monitored by a fast oscilloscope.
Charge in the sensor was generated by short laser pulses and by beta electrons from Sr-90 source. In measurements with Sr-90, the timing response of the DUT was evaluated relative to a fast reference signal from an LGAD. Time walk and time resolution of the system were measured from the recorded waveforms and compared to detector response to charge injection with a pulse generator. Measurements were made with detectors before and after neutron irradiation.

Wide Band Gap Materials / 11

Deveopment of 3D SiC radiation detector

Authors: Hongwei Liang[1]; Xiaochuan Xia[1]; Xin Shi[2]

[1] *Dalian University of Technology*

[2] *Chinese Academy of Sciences (CN)*

Corresponding Authors: xin.shi@cern.ch, xiaochuan@dlut.edu.cn, hwliang@dlut.edu.cn

A prototype of 360 um thick single crystal SiC has been fabricated with holes of 100um using laser drilling method. Form scanning electron microscope (SEM) images, there is no crack extending to the single crystal, and no residue on the side wall. It is found that the SiC sidewall is carbon-riched after laser and chemical treatment. The electrodes of 3D 4H-SiC device are formed by extruding the molten indium metal. The ohmic contact characteristic is formed. When 100 V voltage is applied, the current value are 6 pA and 10 nA under dark and 405 nm illumination conditions.

Wide Band Gap Materials / **12**

SiC Neutron Irradiaion Study at CSNS

Authors: Rui Fan[1]; Xinbo Zou[2]

[1] *Institute of High Energy Physics, CAS*

[2] *Shanghai Tech University*

Corresponding Authors: zouxb@shanghaitech.edu.cn, fanrr@ihep.ac.cn

The irradiation effect of Schottky 4H-SiC detector has been studied at the Back-n white neutron beamline at China Spallation Neutron Source (CSNS). The total irradiation flux of the white neutron with an energy peak of 1 MeV, is about 1e14n/cm2.Before and after irradiation, the alpha particle energy spectrums are compared, and the influence of neutron irradiation on the polarization effect of the detector is noticed through a long-term energy spectrum measurement.

Wide Band Gap Materials / **13**

Development of 4H-SiC Low Gain Avalanche Diode

Authors: Tao Yang[1]; Xin Shi[1]

[1] *Chinese Academy of Sciences (CN)*

Corresponding Authors: tao.yang@cern.ch, xin.shi@cern.ch

Inspired by the Low Gain Avalanche Diode (LGAD) of Silicon, we investigate the possibilities to produce similar device using 4H-SiC, benefiting from the intrinsic characteristics of the wide band gap properties of Silicon Carbide, such as higher saturated carrier velocity, higher atom displacement energy as well as the recent technological improvement of high-quality epitaxy with high resistance from industry. Two prototypes of 4H-SiC LGAD devices with different design by Nanjing University (NJU) are introduced. The leakage current, capacitance, doping level and electric field of 4H-SiC LGAD are discussed by measurement and simulation.

Monolithic devices / **14**

RD50-MPW3: Digital readout and DAQ developments

Authors: Christian Irmler[1]; Patrick Sieberer[1]; Ricardo Marco Hernandez[2]

[1] *Austrian Academy of Sciences (AT)*

[2] *Instituto de Fisica Corpuscular (ES)*

Corresponding Authors: patrick.sieberer@cern.ch, ricardo.marco@cern.ch, christian.irmler@cern.ch

This contribution can be seen as a continuation of the talk "RD50-MPW3: General details and pixel matrix". This presentation focuses on the digital periphery of the chip and how it is integrated to the DAQ system, thus it is discussing a distinct topic.
A brief overview of the digital periphery is followed by a more detailed introduction of the data acquisition concept and software. The main aspects of the digital periphery are presented and challenges during the design are discussed and links for further information are provided.
The readout framework is based on the Caribou system and details about firmware, software and integration into a test beam setup are given. This includes details about data-flow, configuration as well as synchronization with other detectors in a typical test beam environment.

As the chip has not been delivered yet, we cannot show detailed measurements. Nevertheless, preliminary tests to prove the functionality of our readout chain are shown. Finally, a short outlook including our plans for test beams and building our own telescope demonstrator are presented.

IRRAD / 15

Surface and bulk properties of silicon sensors obtained from quality control test structures for the CMS experiment

Authors: Marko Dragicevic[1]; Thomas Bergauer[2]; Moritz Wiehe[2]; Veronika Kraus[2]

[1] *HEPHY Vienna*

[2] *Austrian Academy of Sciences (AT)*

Corresponding Authors: thomas.bergauer@cern.ch, e11778941@student.tuwien.ac.at, marko.dragicevic@cern.ch, m.wiehe@cern.ch

In the following years, the LHC is going to be upgraded to the so called High Luminosity LHC (HL-LHC). Therefore, the CMS (Compact Muon Solenoid) detector will be adapted to the new conditions by incorporating new silicon sensors into the tracker and the calorimeter endcap. The strategy to monitor the quality and stability of the sensor production process is based on a test structure set, implemented at least twice on each production wafer, that provides access to critical process parameters. Process quality control parameters obtained from Metal-Oxide-Semiconductor Capacitors (MOS-C), Metal-Oxide-Semiconductor Field-Effect Transistors (MOS-FET), Diodes and other test structures are discussed. Additionally, first measurements of test structures irradiated with neutrons to study the impact of irradiation on surface and bulk properties are presented.

Low Gain Avalanche Detectors / 16

Timing Resolution Comparison between LGADs and 3D Sensors

Authors: Montague King[1]; Leena Diehl[1]

Co-authors: Dennis Sperlich [1]; Marc Hauser [1]; Ulrich Parzefall [1]; Christina Schwemmbauer [1]

[1] *Albert Ludwigs Universitaet Freiburg (DE)*

Corresponding Authors: m.king@cern.ch, marc.hauser@cern.ch, c.schwemmbauer@cern.ch, dennis.sperlich@cern.ch, ulrich.parzefall@cern.ch, leena.diehl@cern.ch

Current and future collider experiments are reaching luminosities at which pile-up causes tracking of single particles to become near impossible when using only three spatial coordinates. However, with high enough timing resolution, an additional measurement coordinate could be introduced to unambiguously discern particle paths.

When it comes to ultra fast silicon detectors (UFSD), Low Gain Avalanche Diodes (LGADs) are currently a premier choice, reaching a time resolution of below 30 ps. However, due to the limited radiation hardness (up to $\sim 2 \cdot 10^{15}\,\mathrm{n_{eq}/cm^2}$) of the gain layer, LGADs, in their current form, do not seem viable for future colliders such as the FCC, where fluences up to $10^{17}\,\mathrm{n_{eq}/cm^2}$ are expected.

An alternative approach for UFSD are 3D detectors due to their superior radiation hardness as well as high granularity allowing them to be used to resolve particle tracks precisely in four dimensions. In this talk, timing measurements conducted at the University of Freiburg with both a TCT and a Sr-90 source setup of LGADs and 3Ds are compared pre and post irradiation with reactor neutrons.

New Structures / **17**

Power dissipation and hit efficiency of CNM 3D pixel sensors irradiated to 1.6e16 neq/cm^2

Authors: David Quirion[1]; Giulio Pellegrini[2]; Juan Ignacio Carlotto[3]; Maria Manna[4]; Sebastian Grinstein[3]; Stefano Terzo[5]

[1] *IMB-CNM, CSIC*

[2] *Centro Nacional de Microelectrónica (IMB-CNM-CSIC) (ES)*

[3] *IFAE - Barcelona (ES)*

[4] *Centro National de Microelectronica - CNM-IMB-CSIC*

[5] *IFAE Barcelona (ES)*

Corresponding Authors: stefano.terzo@cern.ch, giulio.pellegrini@csic.es, jcarlotto@ifae.es, sgrinstein@ifae.es, david.quirion@imb-cnm.csic.es, maria.manna@imb-cnm.csic.es

The Large Hadron Collider (LHC) will be improved to be able to reach about seven times its current nominal instantaneous luminosity. The High-Luminosity LHC (HL-LHC), is planned to start operation in 2027. To face the consequent increase of the particle fluence close to the proton-proton interaction point, the ATLAS detector will include in its upgraded Inner Tracker (ITk) new sensor technologies. In particular, 3D pixel sensors have been chosen for the inner most pixel layer of ITk because of their high-radiation tolerance.

Novel 3D pixel sensors were manufactured at CNM using a single-side technology on Silicon on Insulator (SOI) wafers. The active thickness for those pixel sensors is 150 µm. Two kinds of pixel sensor were manufactured featuring cells of 50 x 50 µm^2 and 25 × 100 µm^2 both with one collecting electrode. In the ATLAS ITk the 50x50 µm^2 pixel sensors will be mounted in the rings of the innermost layer, while the 25x100 µm^2 will be loaded in the barrels. CNM sensors were connected to a RD53A chip prototype and irradiated with proton beams in different facilities up to a neutron equivalent fluence of 1.6E16 neq/cm^2. The modules were then tested on an electron beam at DESY. In this presentation, I am going to show their power dissipation and their hit efficiency performance measured at two different incident angles, 0º (normal to the incident beam direction) and at 15º.

Facilities / **18**

Particle beam profilers based on fluence dependent variations of carrier lifetime and scintillation intensity in Si and GaN materials

Author: Tomas Ceponis[1]

[1] *nstitute of Photonics and Nanotechnology, Vilnius University*

Corresponding Author: tomas.ceponis@ff.vu.lt

The particle beam profilers, based on fluence measurements performed by recording the changes of carrier lifetime in Si material and scintillation intensity of thin GaN layers, caused by radiation induced defects and emission centres, will be presented. The beams of penetrative (26 GeV/c) and stopped (1.6 MeV) protons will be discussed.

IRRAD / 19

Update on the ATLAS ITk Silicon Strip Sensors - Pre-production

Author: Thomas Koffas[1]

[1] *Carleton University (CA)*

Corresponding Author: thomas.koffas@cern.ch

The ATLAS upgrade for HL-LHC includes the installation of an entirely new all-silicon Inner Tracker (ITk). The part of the tracker further away from the IP is instrumented with silicon micro-strip sensors comprising 165m2 of active area in a nearly hermetic way. Multiple sensor shapes are utilized: square sensors in the barrel part and a stereo-annulus sensor design with curved edges to provide continuous coverage of the disc surface in the endcap part of a detector. As a result, there are 8 different strip sensor types in the system. They all feature AC-coupled n+-in-p strips with polysilicon biasing, developed to withstand a total fluence of 1.6�1015 neq/cm2 and a total ionizing dose of 66 Mrad. Following many years of R&D and 4 prototype submissions and evaluations, in 2020 the project transitioned into pre-production, where 5% of the total volume was produced in all 8 designs. In this contribution, we will summarize the evaluation program, test results, and experience with the pre-production sensors.

Low Gain Avalanche Detectors / 20

Effect of Carbon co-implantation on radiation hardness of IHEP_IMEv2 LGAD

Authors: Alissa Shirley-Ann Howard[1]; Gaobo Xu[2]; Gregor Kramberger[1]; Joao Barreiro Guimaraes Da Costa[3]; Kewei Wu[3]; Mei Zhao[3]; Mengzhao Li[3]; Xuewei Jia[3]; Yuan Feng[3]; Yunyun Fan[3]; Zhijun Liang[3]

[1] *Jozef Stefan Institute (SI)*

[2] *Chinese Academy of Science*

[3] *Chinese Academy of Sciences (CN)*

Corresponding Authors: kewei.wu@cern.ch, xuewei.jia@cern.ch, zhijun.liang@cern.ch, y.feng@cern.ch, guimaraes@ihep.ac.cn, gregor.kramberger@ijs.si, alissa.howard@ijs.si, fanyunyun1228@gmail.com, mei.zhao@cern.ch, mzli@ihep.ac.cn

The radiation hardness of LGAD depends on the distribution and doping concentration of implanted Carbon and Boron. Based on Secondary Ion Mass Spectrometry profile of IHEP_IMEv2 LGAD devices, the impact of implantation dose and thermal load of Carbon to the radiation hardness of LGAD is discussed. A model based on the SIMS data is implemented to fit the accepter removal coefficient of LGADs and extrapolated to PIN structures. Its validity will soon be examined by the next version of IHEP LGAD.

Defect and Material Characterization / 21

Investigation of high resistivity p-type FZ silicon diodes after 60Co - gamma irradiation

Authors: Anja Himmerlich[1]; Chuan Liao[2]; Eckhart Fretwurst[2]; Erika Garutti[2]; Ioana Pintilie[None]; Joern Schwandt[2]; Leonid Makarenko[3]; Michael Moll[1]; Yana Gurimskaya[4]

[1] *CERN*

[2] *Hamburg University (DE)*

[3] *Byelorussian State University (BY)*

[4] *Universite de Geneve (CH)*

Corresponding Authors: joern.schwandt@cern.ch, anja.himmerlich@cern.ch, michael.moll@cern.ch, eckhart.fretwurst@desy.de, ioana@infim.ro, leonid.makarenko@cern.ch, chuan.liao@desy.de, yana.gurimskaya@cern.ch, erika.garutti@desy.de

In this work, the macroscopic (I-V, C-V) and microscopic (Thermally Stimulated Current(TSC) and Capacitance(TS-Cap)) measurements were used to investigate the properties of high resistivity p-type diodes irradiated with 60Co gamma-rays with dose values of 10, 20, 100 and 200 Mrad. Two types of diodes are manufactured using p-stop and p-spray to isolate pad and guard ring, and both are FZ p-type materials. For macroscopic measurements, frequency-dependent C-V only appeared on p-stop diodes and presented strongly dose-dependence; The development of leakage current density (jd) with dose value was investigated. Compared to standard FZ n-type diodes, the exponential increase of jd with dose didn't appear. In the microscopic measurements, the development of irradiation-induced defects concentration (BiOi, CiOi, VO, I) with dose is observed. And one unexpected larger peak appeared at the temperature range 80~130 K for 200 Mrad irradiated diodes. The above results were compared with data from TSC and Deep-Level Transient (DLTS) spectroscopy measurements achieved by the team of the CERN-RD50 "Acceptor removal project".

Low Gain Avalanche Detectors / 22

High-Precision Tracking with Large Pixels using Thin Resistive Silicon Detectors

Authors: Federico Siviero[1]; Nicolo Cartiglia[2]; Giulia Gioachin[3]; Leonardo Lanteri[4]; Luca Menzio[4]; Marco Ferrero[4]; Marco Mandurrino[5]; Marta Tornago[4]; Roberta Arcidiacono[4]; Roberto Mulargia[6]; Valentina Sola[4]

[1] *INFN - National Institute for Nuclear Physics*

[2] *INFN Torino (IT)*

[3] *University of Turin*

[4] *Universita e INFN Torino (IT)*

[5] *INFN*

[6] *University & INFN Turin (IT)*

Corresponding Authors: roberto.mulargia@cern.ch, marco.ferrero@cern.ch, federico.siviero@to.infn.it, marco.mandurrino@to.infn.it, valentina.sola@cern.ch, marta.tornago@cern.ch, cartiglia@to.infn.it, giulia.gioachin@edu.unito.it, roberta.arcidiacono@cern.ch, luca.menzio@edu.unito.it, leonardo.lanteri@cern.ch

The implementation of resistive read-out in the design of silicon sensors places built-in charge sharing among neighboring pixels as the basic principle of operation. Resistive Silicon Detectors (RSD),

exploiting the signals seen on the electrodes surrounding the impact point, achieve micron-level position resolution even with very large pixels. In this paper, results obtained with sensors from the second RSD production at the Fondazione Bruno Kessler are presented. A position resolution better than 3% of the pixel size is obtained for pitch ranging from 200 to 1300 µm.

Wide Band Gap Materials / 23

Measurements and Simulations of High Rate 4H-SiC Particle Detectors

Authors: Andreas Gsponer[1]; Markus Göbel[1]; Philipp Gaggl[1]; Richard Thalmeier[1]; Simon Emanuel Waid[1]; Thomas Bergauer[1]

[1] *Austrian Academy of Sciences (AT)*

Corresponding Authors: philipp.gaggl@cern.ch, simon.waid@oeaw.ac.at, markus.goebel@oeaw.ac.at, thomas.bergauer@cern.ch, richard.thalmeier@cern.ch, andreas.gsponer@cern.ch

Compared to Silicon (Si), silicon carbide (SiC) has multiple advantageous material properties, making it an interesting candidate for high beam rate detectors. SiC features a higher charge carrier saturation velocity and breakdown voltage than Si, which allows for a high time resolution and aids in mitigating pile-ups. The large band gap of SiC improves its radiation hardness, which, together with its good thermal conductivity, limits the dark current even for very high beam rates and irradiation levels.

This talk presents measurements and simulations for a $50 \mu m$ thick 4H-SiC pad sensor. We show laboratory measurements using α/β sources, as well as multiple studies performed using high energy (up to 252.7 MeV) and high rate (several 100 MHz) proton beams. In order to investigate the effects of radiation-induced damage in SiC sensors, we present UV-TCT and proton beam measurements of neutron-irradiated samples with equivalent fluxes of up to $1 \times 10^{16}\ n/cm^2$ according to the NIEL hypothesis.

To guide future measurements and the construction of SiC low gain avalanche detectors (LGADs), we aim at using Monte Carlo simulations leveraging the AllPix^2 framework together with electric fields simulated by TCAD and COMSOL. We present our simulation workflow for AllPix^2 and show preliminary comparisons between measured and simulated data. Finally, current challenges specific to simulations of SiC (and SiC LGADs) are highlighted.

Monolithic devices / 24

Stitched Passive CMOS Strip Sensors

Author: Niels Sorgenfrei[1]

Co-authors: Arturo Rodriguez Rodriguez [1]; Dennis Sperlich [1]; Fabian Simon Lex [1]; Jan Cedric Honig [1]; Karl Jakobs [1]; Leena Diehl [1]; Marc Hauser [1]; Sven Mägdefessel [2]; Ulrich Parzefall [1]

[1] *Albert Ludwigs Universitaet Freiburg (DE)*

[2] *University Freiburg*

Corresponding Authors: jan.cedric.honig@cern.ch, marc.hauser@cern.ch, leena.diehl@cern.ch, fabian.simon.lex@cern.ch, dennis.sperlich@cern.ch, sven.maegdefessel@physik.uni-freiburg.de, ulrich.parzefall@cern.ch, arturo.rodriguez.rodriguez@cern.ch, niels.sorgenfrei@cern.ch, karl.jakobs@uni-freiburg.de

As a result of a CERN market survey, CMOS sensors in pixel and strip geometries were developed. The CMOS process is an established commercial industry process, which a lot of foundries utilize to produce silicon type devices. Typical CMOS foundries are equipped for bulk productions, but

only for sensors much smaller than what is needed in e.g. the strip region of the ATLAS Inner Tracker. To produce large enough sensors, the process of stitching is utilized. The sensor structure is divided up into different regions, which individual wafer masks can imprint side by side onto the wafer to form a coherent area. With this method, the sensors can be nearly wafer-sized. The effects of stitching on charge collection, electric field strength and configuration, detection efficiency and radiation hardness have to be investigated.

The sensors discussed in this talk are stitched passive CMOS strip sensors produced by LFoundry in a 150 nm process with three different strip designs. The results of electrical IV characterisations, TCT and ^{90}Sr-source measurements and the effects of radiation damages are discussed. The effects of the stitches on the sensors performance were also investigated.

The results of these measurements demonstrate that the stitching process works and introduces no negative effects on the sensors performance, before and after irradiation.

Defect and Material Characterization / **25**

Update on Radiation damage investigation of epitaxial P-type Silicon using Schottky diodes

Authors: Matthew Glenn Kurth[1]; Enrico Giulio Villani[2]; Yebo Chen[3]; Hongbo Zhu[4]

Co-authors: Fergus Wilson [2]; Igor Mandić [5]; Christoph Thomas Klein [6]; Thomas Koffas [6]; Garry Tarr [7]; Robert Vandusen [7]

[1] *Institute of High Energy Physics (CN)*

[2] *Science and Technology Facilities Council STFC (GB)*

[3] *Chinese Academy of Sciences (CN)*

[4] *ZJU - Zhejiang University (CN)*

[5] *Jožef Stefan Institute*

[6] *Carleton University (CA)*

[7] *Carleton University*

Corresponding Authors: fergus.wilson@stfc.ac.uk, matthew.glenn.kurth@cern.ch, thomas.koffas@cern.ch, hongbo.zhu@cern.ch, yebo.chen@cern.ch, igor.mandic@ijs.si, christoph.klein@cern.ch, enrico.giulio.villani@cern.ch

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 sizes and flavors have been fabricated at different facilities, including RAL and Carleton University.

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

Test updates on the second batch of fabricated Schottky devices at RAL with high and medium resistivity wafers will be given. IV in the reverse and forward region, along with CV measurements of non-irradiated and n-irradiated devices will be shown.

Charge collection test results of irradiated and non-irradiated devices, using an improved laser system that allows testing at temperature down to -20 C will be shown. Details of the Laser setup will be given.

Update on TCAD scripts for the simulation of the devices will be presented as well.

IRRAD / **26**

Charge carrier mobility investigation in p-type Si after 6MeV electron irradiation

Authors: Algirdas Mekys1[1]; Juozas1 Vaitkus[1]; Leonid Makarenko2[2]; Šarūnas Vaitekonis1[1]

[1] *Vilnius University*

[2] *Byelorussian State University*

Corresponding Author: amekys@gmail.com

1 Vilnius University (LT)
2 Byelorussian State University (BY)

Corresponding author : algirdas.mekys@ff.vu.lt

Abstract: The radiation induced defects in silicon changes charge carrier transport properties, which are investigated by Hall and magnetoresistivity measurement techniques. The study concentrates on p-type Si material showing recent interest in BiOi defect formation. The irradiation of 6MeV energy electron fluence covers range from 1E+16 to 5E+16 /cm2. The analysis enables to extract free carrier thermal activation energy, the density of impurities and relate them to the irradiation fluence. The results are supplemented with the ones from thermal annealing.

Low Gain Avalanche Detectors / 27

Observation and characterisation of the charge screening effect in LGAD

Authors: Valentina Sola[1]; Mohammed Abujami[2]; Roberta Arcidiacono[1]; Patrick Asenov[3]; Maurizio Boscardin[4]; Nicolo Cartiglia[5]; Matteo Centis Vignali[6]; Marco Costa[1]; Tommaso Croci[None]; Marco Ferrero[1]; Alessandro Fondacci[7]; Giulia Gioachin[8]; Simona Giordanengo[9]; Leonardo Lanteri[1]; Felix Mas Milian[2]; Luca Menzio[1]; Vincenzo Monaco[1]; Diango M. Montalván Olivares[2]; Arianna Morozzi[10]; Francesco Moscatelli[11]; Roberto Mulargia[12]; Daniele Passeri[13]; Giovanni Paternoster[14]; Federico Siviero[1]; Amedeo Staiano[1]; Marta Tornago[1]

[1] *Universita e INFN Torino (IT)*

[2] *Università e INFN Torino (IT)*

[3] *Universita e INFN, Perugia (IT)*

[4] *FBK Trento*

[5] *INFN Torino (IT)*

[6] *FBK*

[7] *University of Perugia - Electronic engineering student*

[8] *University of Turin*

[9] *INFN Torino*

[10] *INFN, Perugia (IT)*

[11] *IOM-CNR and INFN, Perugia (IT)*

[12] *University & INFN Turin (IT)*

[13] *Universita e INFN Perugia (IT)*

[14] *Fondazione Bruno KEssler*

Corresponding Authors: paternoster@fbk.eu, patrick.asenov.asenov@cern.ch, roberto.mulargia@cern.ch, francesco.moscatelli@cer amedeo.staiano@to.infn.it, mohammed.abujami@unito.it, simona.giordanengo@to.infn.it, marco.ferrero@cern.ch, daniele.passeri@unipg.it, alessandrofondacci@gmail.com, marta.tornago@cern.ch, cartiglia@to.infn.it, arianna.morozzi@pg.infn.it, marco.costa@cern.ch, monaco@to.infn.it, luca.menzio@edu.unito.it, f.mas.milian@gmail.com, valentina.sola@cern.ch, giulia.gioachin@edu.unito.it, diango.mo87@gmail.com, matteo.centis.vignali@cern.ch, leonardo.lanteri@cern.ch, roberta.arcidiacono@cern.ch, federico.siviero@edu.unito.it, boscardi@fbk.eu, tommaso.croci@pg.infn.it

The recently observed saturation of the charge multiplication mechanism in LGAD devices has been studied and characterised with an infrared laser used to replicate the particle charge deposition

ranging from 1 to 80 equivalent MIPs. The observations are compared to the response from beta particles and impinging protons with different energies. The influence of regions with high electric field values, above 10 V/μm, on the saturation of the gain mechanism, has been studied via 2D and 3D Technology CAD device simulation.

Low Gain Avalanche Detectors / 28

Before and after irradiation performance of IHEP-IME LGAD sensors

Authors: Alissa Shirley-Ann Howard[1]; Gregor Kramberger[1]; Joao Barreiro Guimaraes Da Costa[2]; Kewei Wu[2]; Xuewei Jia[2]; Gaobo Xu[3]; Mei Zhao[2]; Mengzhao Li[2]; Mingjie Zhai[2]; Tao Yang[2]; Yuan Feng[2]; Zhijun Liang[2]

[1] *Jozef Stefan Institute (SI)*

[2] *Chinese Academy of Sciences (CN)*

[3] *Chinese Academy of Science*

Corresponding Authors: zhijun.liang@cern.ch, mei.zhao@cern.ch, y.feng@cern.ch, mzli@ihep.ac.cn, guimaraes@ihep.ac.cn, alissa.howard@ijs.si, tao.yang@cern.ch, xuewei.jia@cern.ch, mingjie.zhai@cern.ch, kewei.wu@cern.ch, gregor.kramberger@ijs.si

The High Granularity Timing Detector (HGTD) project of ATLAS will reduce the pile-up effect in HL-LHC by providing precise time measurement of tracks. The Low Gain Avalanche Detector (LGAD) with a time resolution better than 35(70) ps before(after) irradiation is the key technology that has been studied by many institutes. The Institute of High Energy Physics Chinese Academy of Science (IHEP) has been developing LGAD sensors IHEP-IME with the Institute of Microelectronics of the Chinese Academy of Sciences (IME). So far two versions of IHEP-IME LGAD sensors have been produced, IHEP-IMEv1 and IHEP-IMEv2. IHEP-IMEv1 sensors showed good potential in achieving the HGTD requirements. IHEP-IMEv2 sensors have a modified doping profile compared with the last version, especially focusing on the carbon implantation effect. Sensors with diverse producing processes and carbon doses were fabricated and have shown improved performance. What's more, full-size sensors (with 15x15 pads) were produced. Sensors were irradiated with neutron influences of 0.8e15 neq/cm2, 1.5e15 neq/cm2, and 2.5e15 neq/cm2. This talk will present the test results of IHEP-IMEv2 sensors performance before and after irradiation, including single pad and large array sensors. After irradiation, sensors with different carbon doses showed different performances. The effect of carbon implantation will be shown. Low-temperature beta test results showed that after 2.5e15 neq/cm2 irradiation sensors collect 4 fC at less than 400 V with a time resolution better than 50 ps, by far satisfying the requirements.

IRRAD / 29

Advanced approach for parameterization of the current generation centers in irradiated silicon sensors

Author: Daria Mitina[1]

Co-authors: Vladimir Eremin [1]; Nadezda Fadeeva ; Elena Verbitskaya [1]

[1] *Ioffe Institute (RU)*

Corresponding Authors: daria.mitina@cern.ch, elena.verbitskaia@cern.ch, fadeevanadezda@gmail.com, vladimir.eremin@cern.ch

An effective approach for evaluating the scenario of Si sensor radiation degradation requires parametrization of the bulk current generation and the electric field transformation in the irradiated sensors. The presented data show that the I-V characteristics of Si sensors damaged by short-range particles allow a reliable differentiating between these processes and defining the parameters of the effective radiation defects including their type and microscopic parameters, which control independently the generated current and the electric field.

Defect and Material Characterization / 30

Radiation damage investigation of epitaxial p-type silicon using DLTS and TAS measurements of Schottky and pn-junction diodes

Author: Enrico Giulio Villani[1]

Co-authors: Christoph Thomas Klein [2]; Thomas Koffas [2]; Angela Mccormick [2]; Garry Tarr [3]; Robert Vandusen [3]; Fergus Wilson [1]; Philip Patrick Allport [4]; Laura Gonella [4]; Ioannis Kopsalis [5]; Igor Mandic [6]; Yebo Chen [7]; Matthew Glenn Kurth [8]; Peilian Liu [7]

[1] *Science and Technology Facilities Council STFC (GB)*

[2] *Carleton University (CA)*

[3] *Carleton University*

[4] *University of Birmingham (UK)*

[5] *University of Birmingham (GB)*

[6] *Jozef Stefan Institute (SI)*

[7] *Chinese Academy of Sciences (CN)*

[8] *Institute of High Energy Physics (CN)*

Corresponding Authors: philip.patrick.allport@cern.ch, thomas.koffas@cern.ch, christoph.klein@cern.ch, angelamccormick@cunet.carleton.ca, matthew.glenn.kurth@cern.ch, laura.gonella@cern.ch, peilian.liu@cern.ch, yebo.chen@cern.ch, igor.mandic@ijs.si, fergus.wilson@stfc.ac.uk, enrico.giulio.villani@cern.ch, ioannis.kopsalis@cern.ch

This project focuses on the investigation of trap energy levels introduced by radiation damage in epitaxial p-type silicon. Using 6-inch wafers of various boron doping concentrations (1e13, 1e14, 1e15, 1e16, and 1e17 cm-3) with a 50 µm epitaxial layer, multiple iterations of test structures consisting of Schottky and pn-junction diodes of different sizes and flavours are being fabricated at RAL and Carleton University.

In this talk, details on the diode fabrication and electrical measurements of the structures will be given. IV and CV scans of fabricated test structures have been performed and cross-checked between institutes, the results of which will be presented. The focus will be on the characterisation of trap parameters obtained from Deep-Level Transient Spectroscopy (DLTS) and supplemented by Thermal Admittance Spectroscopy (TAS). Spectra for various unirradiated diode samples will be shown and their details collected from Arrhenius analyses will be listed.

Finally, the on-going activities for the next round of wafer processing will be reviewed and an outlook for the detailed testing of irradiated diode samples in the coming months will be given.

Low Gain Avalanche Detectors / 31

Recent results of the carbonated USTC-IME LGADs and fabrication of the AC-LGADs at USTC NRFC

Authors: Chihao Li[1]; Jiajin Ge[2]; Kuo Ma[1]; Xiangxuan Zheng[1]; Xiao Yang[3]; Yanwen Liu[1]; Yifan Yang[4]; Yusheng Wu[3]

[1] *University of Science and Technology of China (CN)*

[2] *University of Michigan (US)*

[3] *University of Science and Technology of China (CN)*

[4] *University of Science and Technology of China*

Corresponding Authors: zxx0209@mail.ustc.edu.cn, kuo.ma@cern.ch, yanwen.liu@cern.ch, jiajin.ge@cern.ch, yusheng.wu@cern.ch, chihao.li@cern.ch, xiao.yang@cern.ch

The Low-Gain Avalanche Detector (LGAD) with timing resolution better than 35(70) ps before (after) irradiation is the key technology that has been studied by many RD50 institutes and is going to be used in the ATLAS HGTD upgrade. The University of Science and Technology of China (USTC) has been developing LGAD sensors with the Institute of Microelectronics of the Chinese Academy of Sciences (IME) and the Nano Research and Fabrication Center (NRFC) of USTC. The prototypes of DC and AC coupled LGADs have been produced. The recent development focused on carbon diffusion and large array fabrication. The prototypes have been tested by serval methods including IV/CV, beta-scope, laser-TCT as well as the electron/hadron beam test. The irradiation hardness is tested with the samples irradiated by reactor neutrons at the JSI. The c-factors are extracted and compared. The uniformity is characterized both by the on-wafer test and 5x5/15x15 array probe-card test. The latest results have shown that the prototypes can provide enough charge (>4fC) and good timing resolution(<70ps) after 2.5E15 neq/cm^2 and meet the specification of the HGTD upgrade. The novel structure LGADs fabricated by the NRFC LGADs show good performance with a yield at an acceptable level.

Defect and Material Characterization / **32**

Defect characterization studies on gamma-irradiated p-type Si diodes

Authors: Anja Himmerlich[1]; Chuan Liao[2]; Eckhart Fretwurst[2]; Ioana Pintilie[None]; Joern Schwandt[2]; Michael Moll[1]; Nuria Castello-Mor[3]; Vendula Subert[2]; Yana Gurimskaya[1]

[1] *CERN*

[2] *Hamburg University (DE)*

[3] *Universidad de Cantabria, CSIC, Instituto de Fisica de Cantabria IFCA, (ES)*

Corresponding Authors: chuan.liao@desy.de, eckhart.fretwurst@desy.de, ioana@infim.ro, joern.schwandt@cern.ch, nuria.castello.mor@cern.ch, michael.moll@cern.ch, anja.himmerlich@cern.ch, gurimskaya@gmail.com, vendula.maulerova@cern.ch

Boron-doped silicon devices used in high radiation environment like the HL-LHC show a degradation in device performance due to the radiation induced deactivation of the active boron dopant. This effect is known as the so-called Acceptor Removal Effect and depends on particle type, energy and radiation dose. Here we present defect characterization studies using TSC (thermally stimulated current technique) and DLTS (Deep Level Transient Spectroscopy) to correlate radiation induced changes in the macroscopic device properties with the formation of microscopic defects. The defect spectroscopy techniques provide us information about defect characteristics such as activation energy, capture cross section and defect concentrations, and were performed on 60Co gamma-irradiated B-doped silicon EPI-diodes of different resistivity.

Defect and Material Characterization / **33**

RD50 Project proposal: Defect engineering in PAD diodes mimicking the gain layer in LGADs

Author: Ioana Pintilie[None]

Corresponding Author: ioana@infim.ro

The proposed project is focusing on the acceptor removal process (ARP) in the irradiated gain layer of LGAD sensors, aiming to understand it and parametrize it for various content of B, C and O impurities and irradiation fluences, in order to find proper defect engineering solutions to maximize the radiation hardness of the gain layers. The studies performed so far on LGAds show that in the p+ layer of LGADs, the ARP can result in a complete disappearance of the gain at 1MeV neutron equivalent fluences higher than 2x1015 cm-2. As major obstacles preventing the achievement of enough knowledge for characterizing and proposing feasible solutions for improving the performance of the gain layers in LGADS are:

(i) the impossibility of performing the needed investigations after high irradiation fluences in the gain layer only, and determine the defects depth profile caused by B and C implantations in the p+ gain layer. This can be usually performed with DLTS when the applied voltage falls entirely only on the gain layer. However, in structures like LGAD, with Boron doped layers of different resistivity, the highly doped gain layer and the low doped bulk, DLTS cannot be applied. The only applicable method in LGAD structures is TSC which can evidence only overall signals generated by all the layers in LGAD devices, including possible also the contribution from the highly B-doped back contact, making the gain layer'ARP characterization not reliable. In addition, by TSC one cannot follow a depth profile of the defects containing implanted impurities. Therefore, a reliable, comprehensive characterization of the gain layer after large fluences cannot be performed on LGAD structures. To characterize the ARP in the gain layer of LGADs one needs special samples containing only the gain layer. Such samples are to be produced via the present common project within RD50.
(ii) the bistability of a B-containing defect with a donor level at about 0.27 eV from conduction band of Silicon (generally attributed to the BiOi complex), measurable in only one of the two configurations –the BiOiA(0/+). This leads to an underestimation of the defect generation rate, gBiOi, and to a discrepancy with the Boron removal rate, gB, as estimated from CV/IV characteristics and used further for modelling the ARP. In addition, there are long time variations of both gBiOi and gB once the samples are exposed even shortly to the ambient light when manipulate them prior to start of the measurements.
For an undoubtful characterization of the ARP process in the gain layer of the LGADs and understand the gain loss in such structures, special samples, mimicking the gain layer in the presence of different amounts of B, O and C impurities, has to be fabricated and studied. CZ and FZ silicon wafers are preferred to start with because the B and O impurities are homogeneously distributed in the bulk of the samples. The variation of C content will be achieved by implantation.

Defect and Material Characterization / 34

On the bistability of the Boron related donor associated with the acceptor removal process in irradiated p-type silicon

Authors: Andrei Nitescu[1]; Ioana Pintilie[None]; Cristina Besleaga Stan[2]

[1] *National Institute of Material Physics -NIMP*

[2] *National Institute of Materials Physics, Romania*

Corresponding Authors: cristina.besleaga@infim.ro, andrei.nitescu@infim.ro, ioana@infim.ro

Silicon based sensors suffer from a phenomenon called "Acceptor removal"when exposed to high fluences of radiation. This "acceptor removal"process implies the elimination of the dopant element from the substitutional place (e.g., boron for p-type silicon) and combining with a different particle, obtaining an electrical active defect complex (in the case of boron-doped p-type silicon, obtaining an acceptor level from the new defect). This change of doping affects the macroscopic electrical properties and performances of the devices.
It was found previously observed that an irradiation induced defect containing Boron and acting as a donor (assumed to be the BiOi complex) is bistable, impacting thus on the determined acceptor removal rate in p-type silicon. The defect can exist in at least two configurations, labelled as A and B in the following. The present work focus on studying the conditions the defect can change its configuration. CV measurements after different excitation conditions of the samples, at different temperatures allow us to determine the frequency factors and activation energies required for the defect to change the configuration from A to B and back.

Wide Band Gap Materials / 35

Impact of annealing on Ti/4H-SiC Schottky barrier diode radiation detector performance for fusion alpha-particle diagnostics.

Authors: Narasimha Murty N.V.L.[1]; Shilpa Aluru[1]; Sumitra Sihag[2]

[1] *Indian Institute of Technology Tirupati*

[2] *CSIR-CEERI Pilani*

Corresponding Authors: nnmurty@iittp.ac.in, ee19s501@iittp.ac.in

Advanced fusion alpha-particle diagnostics in high D-T plasmas under high-fluences require efficient wide bandgap semiconductor detectors fabricated on 4H-SiC and Diamond materials. However, acquiring high-pure single crystalline diamond is difficult to fabricate large area detectors. This motivated to explore wide bandgap semiconductor 4H-SiC possessing high thermal conductivity suitable for harsh environments. This work includes electrical and spectral measurements of (Ti/Au)/4H-SiC Schottky barrier diode detectors when exposed to a Americium 241 alpha-source. Annealing procedure at 400 degrees centigrade for 5 minutes in nitrogen ambient was involved for few samples to observe the impact of annealing on spectral characteristics. Detector performance was quantitatively measured by determining parameters of energy resolution and charge collection efficiency. Improved alpha spectral characteristics upon annealing is attributed to the reduction of surface states at the interface which were plotted using forward current-voltage characteristics in this work. Detectors resolving the peaks in spectral characteristics highly depends on reverse leakage current of detectors which significantly reduced upon annealing is explained by finding out possible current conduction mechanisms.

IRRAD / 36

Study of depth-dependent charge collection profiles in irradiated pad diodes

Author: Mohammadtaghi Hajheidari[1]

[1] *Hamburg University (DE)*

Corresponding Author: mohammadtaghi.hajheidari@desy.de

In this work, charge collection profiles of non-irradiated and irradiated 150 μm p-type pad diodes were measured using a 5.2 GeV electron beam traversing the diode parallel to the readout electrode. Four diodes were irradiated to 1 MeV neutron equivalent fluences of 2, 4, 8, and 12×10^{16} cm^{-2} with 23 MeV protons. By unfolding the measured charge collection profiles, the Charge Collection Efficiency profiles are extracted as a function of depth. The results of the measurements are compared to the simulation using three radiation damage models from literature which were tuned to different irradiation types and fluences.

Defect and Material Characterization / 37

The A_Si-Si_i-defect - a possible candidate to explain acceptor removal in LGADs

Author: Kevin Lauer[1]

Co-authors: Aaron Flötotto ; Katharina Peh ; Wichard Beenken ; Stefan Krischok ; Thomas Ortlepp ; Erich Runge ; Dirk Schulze

[1] *CiS Institut fuer Mikrosensorik GmbH (DE) / TU Ilmenau (DE)*

Corresponding Author: kevin.lauer@cern.ch

Experimental evidence for the explanation of light-induced degradation (LID) in silicon by the A_Si-Si_i-defect is summarized [1, 2]. Based on these findings, a possible involvement of the B_Si-Si_i-defect in the acceptor removal phenomenon of low-gain avalanche detectors (LGAD) [3] with a boron-doped gain layer is discussed. An outlook on density functional theory (DFT) based calculations of the A_Si-Si_i-defect configurations and energy barriers in-between is given.

[1] K. Lauer, C. Möller, D. Schulze, and C. Ahrens, "Identification of photoluminescence P line in indium doped silicon as InSi-Sii defect,"AIP Advances, vol. 5, no. 1, p. 017101, Jan. 2015, doi: 10.1063/1.4905066.
[2] K. Lauer, C. Möller, C. Tessmann, D. Schulze, and N. V. Abrosimov, "Activation energies of the InSi-Sii defect transitions obtained by carrier lifetime measurements,"physica status solidi (c), vol. 14, no. 5, p. 1600033, 2017.
[3] K. Lauer, K. Peh, S. Krischok, S. Reiß, E. Hiller, and T. Ortlepp, "Development of low gain avalanche detectors (LGAD) in frame of the acceptor removal phenomenon,"physica status solidi (a), doi: 10.1002/pssa.202200177.

Low Gain Avalanche Detectors / **38**

The gain reduction mechanism in Low Gain Avalanche Detectors investigated with the TPA-TCT

Author: Sebastian Pape[1]

Co-authors: Cristian Quintana San Emeterio [2]; Esteban Curras Rivera [3]; Francisco Rogelio Palomo Pinto [4]; Ivan Vila Alvarez [5]; Marcos Fernandez Garcia [2]; Michael Moll [3]; Raul Montero

[1] *Technische Universitaet Dortmund (DE)*

[2] *Universidad de Cantabria and CSIC (ES)*

[3] *CERN*

[4] *Universidad de Sevilla (ES)*

[5] *Instituto de Física de Cantabria (CSIC-UC)*

Corresponding Authors: cristian.quintana.san.emeterio@cern.ch, francisco.rogelio.palomo.pinto@cern.ch, ivan.vila@cern.ch, esteban.curras.rivera@cern.ch, marcos.fernandez@cern.ch, raul.montero@ehu.es, michael.moll@cern.ch, sebastian.pape@cern.ch

The Two Photon Absorption –Transient Current Technique (TPA-TCT) setup at CERN uses fs pulse infrared fiber lasers, with a wavelength of 1550nm. Highly focusing optics are used to mainly generate excess charge carriers in a small volume (approximately 1µm × 1µm × 20µm) around the focal point of the laser beam, which enables a resolution in all three spatial directions. The setup was used to study plasma effects in a PIN sensor, and the gain reduction mechanism in a 300µm thick LGAD sensor. Furthermore, the impact of diffusion on the gain reduction mechanism was modeled and employed towards the data.

New Structures / **39**

Time resolution of single cell 3D devices on SPS pion beams

Author: Vagelis Gkougkousis[1]

Co-authors: Oscar David Ferrer Naval [2]; Victor Coco [1]; Efren Rodriguez Rodriguez [3]; Jakob Haimberger [4]

[1] *CERN*

[2] *Consejo Superior de Investigaciones Cientificas (CSIC) (ES)*

[3] *Universidade de Santiago de Compostela (ES)*

[4] *Technische Universitaet Wien (AT)*

Corresponding Authors: victor.coco@cern.ch, jakob.haimberger@cern.ch, oscar.ferrer@imb-cnm.csic.es, efren.rodriguez.rodriguez@cern.ch, egkougko@cern.ch

The proven potential of 3D pixel at higher than 10^{16} n$_{eq}/cm^2$ radiation fluences, in combination with a small cell approach, makes them an ideal choice for a precision timing tracker. In this study, the timing resolution of several different geometry 3D pixel cells is presented using 160 GeV SPS pion beams. Through a varied incidence angle study, field uniformity, Landau contribution and collected charge are studied at incidence angles of $+/-12^o$. Using state of the art numerical methods, the choice of instrumentation on signal composition and induced result bias is also evaluated. The study is expanded for four radiation fluences, up to $10^{17}n_{eq}/cm^2$ with the use of the EUDAQ telescope, providing sub-pixel timing maps with a 5μm spacial resolution.

Monolithic devices / 40

DMAPS activities of the PSI high energy physics group

Author: Tilman Rohe[1]

[1] *Paul Scherrer Institute (CH)*

Corresponding Author: tilman.rohe@cern.ch

The high energy physics group of PSI is involved in the CMS experiment. Since 2018 the group is also gaining experience in monolithic devices. This talk gives a summary of the group's DMAPS activities.

Wide Band Gap Materials / 41

Caracterization of neutron irradiated IMB-CNM SiC planar diodes with TPA-TCT

Authors: Cristian Quintana San Emeterio[1]; Ivan Vila Alvarez[2]; Raul Montero[None]; Marcos Fernandez Garcia[1]

Co-authors: Esteban Curras Rivera [3]; Richard Jaramillo Echeverria [1]; Michael Moll [3]; Francisco Rogelio Palomo Pinto [4]; Sebastian Pape [5]; Giulio Pellegrini [6]; Joan Marc Rafí [7]; Gemma Rius

[1] *Universidad de Cantabria and CSIC (ES)*

[2] *Instituto de Física de Cantabria (CSIC-UC)*

[3] *CERN*

[4] *Universidad de Sevilla (ES)*

[5] *Technische Universitaet Dortmund (DE)*

[6] *Centro Nacional de Microelectrónica (IMB-CNM-CSIC) (ES)*

[7] *Consejo Superior de Investigaciones Cientificas (CSIC) (ES)*

Corresponding Authors: mfgarcia@cern.ch, francisco.rogelio.palomo.pinto@cern.ch, richard.william.jaramillo.echeverria@cern.ch, giulio.pellegrini@csic.es, sebastian.pape@cern.ch, esteban.curras.rivera@cern.ch, jm.rafi@csic.es, gemma.rius@imb-cnm.csic.es, michael.moll@cern.ch, ivan.vila@cern.ch, cristian.quintana.san.emeterio@cern.ch, raul.montero@ehu.es

A radiation tolerance study of planar diodes fabricated on a SiC substrate will be presented. TPA-TCT was used to characterize the samples. The measurement campaign was carried out at the laser facility of the EHU-UPV university.

Wide Band Gap Materials / 42

Study of the spectrometric performance of SiC detectors at high temperature

Author: Maria Del Carmen Jimenez Ramos[1]

Co-authors: Javier Garcia Lopez [2]; Adrián García-Osuna [3]; Giulio Pellegrini [4]; Philippe Godignon [4]; Joan Marc Rafí [5]; Gemma Rius ; Sofia Otero Ugobono [5]

[1] *Universidad de Sevilla (ES)*

[2] *University of Seville*

[3] *Universidad de Sevilla*

[4] *Centro Nacional de Microelectrónica (IMB-CNM-CSIC) (ES)*

[5] *Consejo Superior de Investigaciones Cientificas (CSIC) (ES)*

Corresponding Authors: giulio.pellegrini@csic.es, agosuna@us.es, philippe.godignon@imb-cnm.csic.es, gemma.rius@imb-cnm.csic.es, jm.rafi@csic.es, maria.del.carmen.jimenez.ramos@cern.ch, sofia.otero.ugobono@cern.ch, fjgl@us.es

In future nuclear fusion reactors, it will be essential to diagnose suprathermal ions escaping from the plasma. The escaping suprathermal ions imply a loss of energy that leads to plasma cooling, in addition to compromising the integrity of the reactor wall material [1]. For the future ITER (International Thermonuclear Experimental Reactor) project, it will be of crucial importance to detect the 3.5 MeV alpha particles resulting from the D-T reaction. Nowadays, Fast Ion Loss Detectors (FILD) based on scintillation materials are the most widely used in magnetic plasma confinement devices [2], but these diagnostic systems have limitations in accomplishing the specifications needed to perform this task due to the high radiation and temperature levels.
At this time, one of the best alternatives is to use semiconductor detectors. Silicon carbide is a broad bandgap material with high thermal conductivity (3.7 W/(cm-℃)), which makes it suitable for high temperature applications. In this work, the spectroscopic performance of a 4H-SiC Schottky diode, fabricated by the Institute of Microelectronics of Barcelona (IMB), for the detection of 3.5 MeV alpha particles in the temperature range from room temperature (RT) to 450 ℃ is studied. In addition, the measured spectra have allowed to obtain the average electron-hole pair creation energy as a function of temperature with higher precision than in other works that can be found in the literature.

[1] A. Fasoli et al., Chapter 5: Physics of energetic ions. Nuclear Fusion 47, S264 (2007).
[2] M. Rodríguez-Ramos, M.C. Jiménez-Ramos, M. García-Muñoz, J. García López, Temperature response of several scintillator materials to light ions. Nuclear Instruments and Methods B 403 (2017) 7-12.

Low Gain Avalanche Detectors / 43

Guard-ring design optimization in thin UFSD

Authors: Andrea Ficorella[1]; Federico Siviero[2]; Giacomo Borghi[1]; Gian-Franco Dalla Betta[3]; Giovanni Paternoster[4]; Luca Menzio[5]; Lucio Pancheri[6]; Marco Ferrero[5]; Marta Tornago[5]; Matteo Centis Vignali[7]; Maurizio Boscardin[8]; Nicolo Cartiglia[9]; Roberta Arcidiacono[5]; Roberto Mulargia[10]; Valentina Sola[5]

[1] *Fondazione Bruno Kessler*

[2] *INFN - National Institute for Nuclear Physics*

[3] *INFN and University of Trento*

[4] *Fondazione Bruno KEssler*

[5] *Universita e INFN Torino (IT)*

[6] *University of Trento and TIFPA-INFN*

[7] *FBK*

[8] *FBK Trento*

[9] *INFN Torino (IT)*

[10] *University & INFN Turin (IT)*

Corresponding Authors: lucio.pancheri@unitn.it, roberto.mulargia@cern.ch, valentina.sola@cern.ch, boscardi@fbk.eu, matteo.centis.vignali@cern.ch, gianfranco.dallabetta@unitn.it, marco.ferrero@cern.ch, luca.menzio@edu.unito.it, paternoster@fbk.eu, gborghi@fbk.eu, marta.tornago@cern.ch, federico.siviero@to.infn.it, roberta.arcidiacono@cern.ch, cartiglia@to.infn.it, aficorella@fbk.eu

In this contribution, the performances of several different guard-ring designs implemented in thin UFSD are compared. The sensors used in the analysis are part of the UFSD 4 production of the Fondazione Bruno Kessler.
The designs include different edge widths, numbers and layouts of floating guard-ring. The results include the measurement of noise and break-down voltage before and after irradiation.

Low Gain Avalanche Detectors / 44

The interpad distance study in Trench Isolated LGAD (TI-LGAD) using Femtosecond laser based SPA and TPA

Authors: Gordana Lastovicka Medin[1]; Gregor Kramberger[2]; Jakob Andreasson[3]; Mateusz Rebarz[3]; Tomas Lastovicka[3]

[1] *University of Montenegro (ME)*

[2] *JSI*

[3] *ELI Beamlines*

Corresponding Authors: mateusz.rebarz@eli-beams.eu, gordana.lastovicka.medin@cern.ch, tomas.lastovicka@eli-beams.eu, jakob.andreasson@eli-beams.eu, gregor.kramberger@ijs.si

In this presentation we will present the preliminary results from the interpad study in TI-LGADs using Femtosecond laser based SPA and TPA. The selected samples are from the latest FBK TI-LGAD production (RD50 project). To our best knowledge, the femtosecond laser based SPA and TPA has not been yet tested and tuned for the IP studies. .

Low Gain Avalanche Detectors / 45

Geometry optimization of AC-coupled LGADs for high precision 4D tracking

Authors: Abraham Seiden[1]; Simone Michele Mazza[1]; Bruce Andrew Schumm[1]; Eric John Ryan[1]; Hartmut Sadrozinski[2]; Hartmut Sadrozinski[1]; Jennifer Ott[1]; Mohammad Nizam[None]; Mohammad Nizam[3]

[1] *University of California,Santa Cruz (US)*

[2] *SCIPP, UC santa Cruz*

[3] *University of California Santa Cruz*

Corresponding Authors: baschumm@ucsc.edu, jeott@ucsc.edu, abraham.seiden@cern.ch, nizamphys@gmail.com, simone.michele.mazza@cern.ch, hartmut@scipp.ucsc.edu, mohammad.nizam@tifr.res.in, hartmut@ucsc.edu, eric.john.ryan@cern.ch

Low Gain Avalanche Detectors (LGADs) are thin silicon detectors capable of providing measurements of minimum-ionizing particles with time resolution as good as 17 ps. These properties make LGADs the prime candidate technology for achieving 4D tracking in future experiments. Furthermore 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. Granularity in traditional DC-LGADs is limited to the mm scale due to protection structures preventing breakdown caused by

high electric fields at the edge of the segmented implants. The structure, called Junction Termination Extension (JTE), causes a region of 50-100 μm of inactive space in between electrodes.
In this contribution, a set of measurements on AC-coupled LGADs (AC-LGADs, also named Resistive Silicon Detectors, RSD) will be presented. AC-LGADs overcome the granularity limitation of traditional LGADs and have been shown to provide spatial resolution of the order of 10s of μm. This remarkable feature is achieved with an un-segmented (p-type) gain layer and a resistive (n-type) N-layer. An insulating di-electric layer separates the metal readout pads from the N+ resistive layer. Because of the AC-coupled nature of AC-LGADs the pulse is bipolar with a theoretical zero area. The high spatial precision is achieved by using the information from multiple metal pads, exploiting the intrinsic charge sharing capabilities of the AC-LGAD provided by the common resistive N-layer. The following detector parameters have been investigated: sheet resistance (resistivity of the N+ layer), oxide thickness, doping profile of the gain layer, pitch, size and shape of the readout metal pads. The response of non-conventional metal structures in AC-LGADs such as crosses and microstrips was also evaluated. AC-LGADs fabricated at the Fondazione Bruno Kessler (FBK) and at Brookhaven National Laboratories (BNL) were studied extensively with a focused IR-Laser and the result of the studies will be reported in this contribution. Sensors were mounted on fast analog electronic boards (with 1 GHz of bandwidth) and digitized by a fast oscilloscope. Sensors mounted on boards are measured in a laser TCT system using an infrared (IR) 1064 nm laser with a penetration length in silicon of several mm. The IR laser produces linear ionization across its path mimicking the behavior of a minimum ionizing particle (MIP). The laser beam is focused by a lens system that can produce a laser spot of 20-30 μm. The board is placed on micrometer motorized stages to allow to study the response of the sensor as a function of laser position.

Low Gain Avalanche Detectors / 46

Review of our understanding on the limits of LGAD as studied by the low energy ions, low energy protons and femtosecond laser beams: Past, present and future experiments

Authors: Gordana Lastovicka Medin[1]; Gregor Kramberger[2]

[1] *University of Montenegro (ME)*

[2] *JSI*

Corresponding Authors: gregor.kramberger@ijs.si, gordana.lastovicka.medin@cern.ch

In this presentation I will overview our accumulated knowledge about limits of LGAD as studied using the low energy ions, low energy protons and femtosecond laser beams. A new insight into old data will be given as well. A proposal for a new experiment that will explore 30 MeV proton beams at the Cyclotron in Prague will be announced as well as the the future plans at RBI through Radiate user scheme.

Defect and Material Characterization / 47

Non-Ionizing Energy Loss: Geant4 simulations and OPTICS clustering towards more advanced NIEL concept for radiation damage modelling and prediction

Authors: Anja Himmerlich[1]; Erika Garutti[2]; Vendula Subert[2]; Ian Dawson[3]; Michael Moll[1]; Yana Gurimskaya[4]

[1] *CERN*

[2] *Hamburg University (DE)*

[3] *University of London (GB)*

[4] *Universite de Geneve (CH)*

Corresponding Authors: yana.gurimskaya@cern.ch, anja.himmerlich@cern.ch, ian.dawson@cern.ch, michael.moll@cern.ch, erika.garutti@desy.de, vendula.maulerova@cern.ch

The Non Ionizing Energy Loss (NIEL) concept compares and scales the damage impacted on semiconductor devices in different radiation fields. A particular weakness of the present NIEL concept consists in the inability to predict the different formation rates of cluster and point defects in the silicon (Si) crystal for different particles and particle energies. Specifically, differences between radiation damage produced by neutrons and protons of the same displacement energies (i.e. damage parameters
normalized to the NIEL) has been observed experimentally. In previous RD50 contribution the interactions of neutrons and protons of different energies in a 100 um thick Si target were studied and the kinematics of the Primary Knock-on Atoms (PKA) has been characterized. In this work, we present subsequent silicon cascade studies.
A full Si cascade is simulated in Geant4 and results are further proceeded by an OPTICS (Ordering points to identify the clustering structure) algorithm. The dependency of the isolated vs clustered defects ratio along with the cluster sizes and quantities is explored as a function of Si-recoil energy.

Wide Band Gap Materials / 48

GaN/AlGaN high electron mobility transistor characteristics after 1016 neq/cm2 neutron irradiation

Author: Jean-Paul Noel[1]

Co-authors: Alex Walker [2]; Philip Patrick Allport [3]; Philippe Godignon [4]; Laura Gonella [3]; Ryan Griffin [5]; Thomas Koffas [6]; Ioannis Kopsalis [7]; Igor Mandic [8]; Joan Marc Rafí [9]; Enrico Giulio Villani [10]; Gary Zhang [11]

[1] *National Research Council Canada*

[2] *National Research Council*

[3] *University of Birmingham (UK)*

[4] *Centro Nacional de Microelectrónica (IMB-CNM-CSIC) (ES)*

[5] *National Research Council Canada - Carleton University*

[6] *Carleton University (CA)*

[7] *University of Birmingham (GB)*

[8] *Jozef Stefan Institute (SI)*

[9] *Consejo Superior de Investigaciones Cientificas (CSIC) (ES)*

[10] *Science and Technology Facilities Council STFC (GB)*

[11] *STFC-RAL*

Corresponding Authors: alexandre.walker@nrc-cnrc.gc.ca, zhige.zhang@stfc.ac.uk, ioannis.kopsalis@stfc.ac.uk, philip.patrick.allport@cern.ch, thomas.koffas@cern.ch, jean-paul.noel@nrc-cnrc.gc.ca, philippe.godignon@imb-cnm.csic.es, ryan.griffin@nrc-cnrc.gc.ca, jm.rafi@csic.es, enrico.giulio.villani@cern.ch, laura.gonella@cern.ch, igor.mandic@ijs.si

Gallium nitride (GaN) and its related hetero-structure alloy AlGaN are wide band gap semiconductors which offer radiation-hard alternatives to silicon, particularly as the focus in the HEP community shifts toward technologies capable of operating in extremely high radiation fields such as fast hadron fluence greater than 1017 neq/cm2. High-electron mobility transistors (HEMTs) fabricated in epitaxial barrier/channel layers of AlGaN/GaN take advantage of the two-dimensional electron gas (2DEG) that forms naturally at the hetero-interface, producing a high density (1013 e-/cm2), high mobility (2000 cm2/V-s) conductor with a sheet resistance of ˜ 300 Ω/square. This enables RF amplifier designs that can operate up to 40 GHz with 10 dB gain for 150 nm gate length, and switch designs with slew rates (dV/dt) greater than 100 V/ns, which is superior to Si MOSFETs. GaN and related alloys also have a higher critical field and higher threshold displacement energy than silicon, which inherently makes them more radiation-hard than Si.

In this work, irradiation results from NRC's standard AlGaN/GaN HEMT process are presented. Nine chips, each containing a pattern of four discrete HEMTs with different gate lengths (Lg = 500 nm,

1000 nm, 1500 nm, 2450 nm) and constant gate width (Wg = 80 μm) were fabricated in-house on a SiC substrate then diced. HEMT DC I-V characteristics were subsequently measured before and after neutron irradiation at 1016 neq/cm2. Pre-irradiation values of the output current density and drain leakage current density were ˜ 1.0 A/mm and ˜ 10-6 A/mm, respectively at room temperature, falling within the yield norms for the NRC GaN HEMT process and indicative of good quality devices. After 1016 neq/cm2 neutron irradiation, the threshold voltage between ON and OFF states remained stable from an IC-design point of view, shifting consistently by ˜ +0.4V (-4.1V before, -3.7V after) for all gate lengths. The average drain output current density was reduced by 16% for all gate lengths except 500 nm which fell by 21%. Since Lg primarily determines RF characteristics (fmax > 40 GHz measured for Lg = 500 nm pre-irradiation), this implies that future IC designs such as TIAs would not need to trade-off Lg (hence fmax) for radiation resistance. The average OFF-state drain leakage current density also fell (i.e., improved) between 77% and 86% on average from the initial ˜ 10-6 A/mm values, but in this case a negative linear dependence for all gate lengths was measured, suggesting that two different mechanisms are affecting output current and leakage current densities during neutron irradiation.

These irradiation results show the relative stability of standard NRC GaN HEMTs subjected to 1016 neq/cm2, and are promising for our upcoming next generation GaN HEMTs incorporating process improvements for high-temperature and high-dose operation. The results also validate the parallel phase of the project plan to fabricate Schottky diode test structures for DC and DLTS measurements using 2"GaN wafers epitaxially grown on bulk GaN substrates. In the last part of this presentation, our first experience with the new GaN on GaN material and the follow-up steps in preparation of Schottky diode fabrication will be given.

New Structures / 49

Graphene-Enabled Silicon-Integrated Radiation Detector for Low Penetrating Particles

Authors: Gemma Rius[None]; Giulio Pellegrini[1]; Jairo Antonio Villegas Dominguez[2]; Neil Moffat[2]

[1] *Centro Nacional de Microelectrónica (IMB-CNM-CSIC) (ES)*

[2] *Consejo Superior de Investigaciones Cientificas (CSIC) (ES)*

Corresponding Authors: gemma.rius@imb-cnm.csic.es, neil.moffat@cern.ch, giulio.pellegrini@csic.es, jairo.antonio.villegas.doming

We present a novel scalable graphene-silicon hybrid photodiode that enables deep UV imaging. We have a created a photodiode with a reduced dead layer entrance window. Existing photodiodes are limited in sensitivity for low wavelengths due to the low penetration depth of photons of < 400 nm. Typical photodiodes have a junction implant which causes the low penetrating photons to be recombined in this dead layer. Here, we have utilized the near transparent nature of single layer graphene to create a junction with a minimum dead layer. To have a full active bulk volume we have combined a single junction ring (n++ bias ring) with single layer graphene. The graphene acts as a large field plate which overhangs the junction ring, on top of a thin dielectric, and covers the entire active area, 5x5 mm2. When a reverse bias is applied the detector depletes as one would expect the region underneath a field plate to deplete. Transient Current Technique (TCT) measurements have been performed to study the charge uniformity of the device and it has been shown that the charge collected is 100% across the entire area of the detector, however the collection time increases as you move further away from the junction ring this is due to the path length of the electrons along the surface of the device. Additional characterizations have been performed to evaluate the sensitivity of the device as a function of wavelength in comparison to a device with an ultra-shallow junction implant. The results show that the graphene-enhanced device shows far greater performance in the 200-400 nm wavelength range. It has been shown that this technology can be used to create a hybrid pixel detector for DUV imaging

Low Gain Avalanche Detectors / 50

New impact ionization parameters

Authors: Esteban Curras Rivera[1]; Michael Moll[1]

[1] *CERN*

Corresponding Authors: michael.moll@cern.ch, esteban.curras.rivera@cern.ch

In order to understand better the performance of LGADs, in particular in terms of Gain and breakdown voltage, it is important to know with high precision the structure of the devices and have a very accurate impact ionization model. There are several impact ionization models in the literature and many studies have been done in this respect, but no one is able to fit the empirical data taken in the lab with LGADs. Combining simulation and measurements, we extracted more accurate impact ionization parameters: alpha and beta as a function of the electric field and temperature. The work is presented in this talk.

Low Gain Avalanche Detectors / 51

TCAD simulation of impact ionization in non-irradiated LGADs

Authors: Esteban Curras Rivera[1]; Michael Moll[1]

[1] *CERN*

Corresponding Authors: esteban.curras.rivera@cern.ch, michael.moll@cern.ch

We present TCAD simulations of non-irradiated LGAD sensors (HPK and CNM). CV curves are used in combination with SIMS/SRP/TPA-TCT measurements to determine the doping profiles and with them the electric field within the LGAD bulk and gain layers.

Various impact ionization models available within the Synopsys TCAD framework, as well as the Masetti model are evaluated and finally a fit to experimental gain measurements (TCT) is performed to extract model parameters that can be used for further studies. In this presentation we concentration on the concept of fitting. In the second presentation (see E.Curras talk) we focus on Temperature dependence of the impact ionization parameters.

Wide Band Gap Materials / 52

Discussion: Wide Band Gap Materials

Corresponding Authors: giulio.pellegrini@csic.es, giulio.pellegrini@cnm.es

Low Gain Avalanche Detectors / 53

Discussion: LGADs

Corresponding Authors: hidalgo.salvador@cern.ch, cartiglia@to.infn.it, gregor.kramberger@ijs.si

Monolithic devices / 54

Discussion: Monolithic Devices

Corresponding Author: vilella@hep.ph.liv.ac.uk

IRRAD / 55

Discussion: IRRAD

Corresponding Author: marko.mikuz@cern.ch

Facilities / 56

Discussion: Facilities

New Structures / 57

Discussion: New structures

Corresponding Authors: gregor.kramberger@ijs.si, giulio.pellegrini@csic.es, giulio.pellegrini@cnm.es

Defect and Material Characterization / 58

Welcome

Corresponding Author: michael.moll@cern.ch

Defect and Material Characterization / 59

Discussion: Defects and Material Characterization

Author: Ioana Pintilie[None]

Co-author: Michael Moll [1]

[1] *CERN*

Corresponding Authors: michael.moll@cern.ch, ioana@infim.ro

Open CB: ECFA roadmap implementation plans / 60

The Detector Roadmap

Corresponding Author: giulio.pellegrini@csic.es

Open CB: ECFA roadmap implementation plans / 61

Detector Roadmap implementation - ECFA proposal

Corresponding Author: philip.patrick.allport@cern.ch

IRRAD / 62

Polymer Based Ionizing Radiation Detectors

Author: Sadullah Ozturk[1]

Co-authors: Arif Kosemen [2]; Yalcin Kalkan [3]

[1] *Istanbul University-Cerrahpasa (TR)*

[2] *Mus Alparslan University (TR)*

[3] *Muş Alparslan University (TR)*

Corresponding Authors: yalcin.kalkan@cern.ch, arif.kosemen@cern.ch, sadullah.ozturk@cern.ch

Recently, semiconductive polymeric materials have attracted attention as an active layer for the detection of ionizing radiation because of their excellent properties such as flexibility, easy production, solution processability and low-cost production. This paper presents X-ray detection properties of Poly(3-hexylthiophene) (P3HT) : Phenyl C61 butyric acid methyl ester (PCBM) blend structure with different PCBM loading ratios. P3HT:PCBM active layer based X Ray detectors were fabricated and effect of PCBM ratio was investigated. All devices were constructed bulk resistive type with ohmic contacts. Spray coated graphite electrode was used as top ohmic contact for all devices. P3HT:PCBM ratio was chanced as (1:0), (1:0.5), (1:1), (1:2) and investigate PCBM concentrations how effect X Ray detection parameters with different X Ray dose rate under 10 V bias. Photocurrent of the pure P3HT (1:0) based device increase under X Ray exposure but never reached to steady state level. However, when PCBM loaded into the P3HT photocurrent reached steady state current for all PCBM concentrations. X ray dose rates were changed form 0.35 mGy.s-1 to 8.74 mGy.s-1 for all devices. The photocurrent versus time graph characteristic for PCBM loaded P3HT based devices was saw-tooth shaped. The saw-tooth structure of the photocurrent by applying different dose X-Ray can be indicating potential usage for the X-ray detection.

IRRAD / 63

Announcement: Special Journal Issue on "Radiation Sensors and Detectors"

Author: Michael Moll[1]

Co-author: Xin Shi [2]

[1] *CERN*

[2] *Chinese Academy of Sciences (CN)*

Corresponding Authors: xin.shi@cern.ch, michael.moll@cern.ch

Dear Colleagues,

Radiation sensors and detectors are widely used in fundamental physics, nuclear reactors, aerospace science, medicine, environmental monitoring, etc. One of the most important aspects of these application areas is the extremely harsh radiation environment, driven by the next-generation fusion energy reactors and future high-energy particle detectors. It is crucial to develop radiation-resistant, easy-to-operate, high-spatial/temporal-resolution devices that can survive in environments with high radiation fluences and high temperatures, as expected in plasma diagnostics and high-energy particle collisions. Solid-state sensors, especially wide-bandgap semiconductors, are good candidates for these applications.

This Special Issue is addressed to all types of solid-state sensors designed for extremely harsh environments.

Dr. Xin Shi
Dr. Michael Moll
Guest Editors

New Structures / **64**

Workshop Dinner - Instructions

Corresponding Authors: gurimskaya@gmail.com, yana.gurimskaya@cern.ch

Monolithic devices / **65**

Goodbye

Corresponding Author: michael.moll@cern.ch