10th Anniversary ”Trento” Workshop on Advanced Silicon Radiation Detectors

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Book of Abstracts

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First silicon tracking system prototype with artificial retina for fast track finding

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We report on the status of the R&D of the first prototype of a silicon tracking system with "artificial retina" for fast track finding. The "artificial retina" is a tracking algorithm inspired by neurobiology and based on extensive parallelization of data distribution and pattern recognition. It allows real time tracking and can be designed to work for HEP applications, i.e. high rates and large detectors, providing offline-like track quality results with a sub-μs latency. The tracking system prototype consists of a telescope with 8 planes of single-sided silicon strip detectors that are readout using custom ASICs providing hit position and pulse height. The "artificial retina" algorithm has been implemented using commercial FPGAs and it is organized in three main blocks: a switch for the parallel distribution of the hits, a pool of processing units for the digital processing of the hits and pattern recognition, and a block for track parameter calculations. We will discuss the implementation of the "artificial retina" algorithm in the FPGAs, the performance of the device, and the first prototype results.

Introduction / 1

Electric field and mobility in extremely irradiated silicon

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Electric field in silicon irradiated with neutrons up to 1e17 n_eq/cm^2 was investigated by edge-TCT. Methods for absolute determination of electric field were developed. From the v(E) dependence mobility degradation with fluence was extracted. A simple field structure was observed, consistent with a SCR and "ENB", a region that does not contribute to leakage current and the electric field is consistent with current transport across highly resistive silicon. The observed mobility change and the values of electric field indicate substantial reduction of trapping from linear extrapolation of low fluence values.

HV CMOS (2) and LGAD (1) / 2

Capacitively Coupled Hybrid Pixel Assemblies for the CLIC Vertex Detector

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HV-CMOS devices are currently under investigation for use in the upgrade of current collider experiments and for future accelerators. The CLIC detector requires a vertex detector with minimal material content and high spatial resolution, combined with accurate time stamping to cope with the high rate of beam-induced backgrounds. One of the current options being pursued is the use of HV-CMOS devices as active sensors, capacitively coupled to hybrid pixel ASICs. A prototype of such an assembly, using two custom designed chips (CCPDv3 as active sensor glued to a CLICpix readout chip), has been characterised extensively both in the lab and in beam tests. The use of both single and dual amplification stages implemented in the HV-CMOS is shown, along with detailed measurements of the tracking performance, taken in the SPS beam in late 2014. Pixel cross-coupling results will also be presented, showing the sensitivity to placement precision and planarity of the glue layer.

HV CMOS (2) and LGAD (1) / 3

Studies of non-irradiated and irradiated HVCMOS detectors

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The charge collection mechanism in HVCMOS detectors produced by AMS was studied by Edge-TCT and by measuring signals from minimum ionizing particles before and after neutron irradiation. The sensors were produced for investigation of HVCMOS technology for pixel and strip detectors for ATLAS upgrade. In reverse biased HVCMOS sensor thin depleted layer is formed in relatively low resistivity p-type silicon.
In addition to the charge released in the depleted layer which is collected because of drift in electric field, also the charge from the vicinity, entering the depleted region by diffusion, contributes to the total collected charge. From analysis of Edge-TCT signals it was found that the drift component of collected charge increases with irradiation while the diffusion part is diminishing.
Such behavior was attributed to the initial acceptor removal on one side and reduction of minority carrier lifetime on the other. Reduction of effective space charge concentration results in wider depleted region and therefore in high charge collection efficiency for heavily irradiated sensors which may even exceed the charge collection efficiency before irradiation.

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Initial acceptor removal in p-type silicon detectors

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The studies of initial acceptor removal in high resistivity p-type silicon detectors are scarce, mainly due to minor impact on operation of standard p-type detectors at high fluences. On the other hand initial acceptor removal is of prime importance for radiation hardness of new detector technologies such as Low Gain Amplification Detectors and HV-CMOS sensors, where the doping levels are up to several orders of magnitude higher than in standard p-type sensors.

In this work the impact of acceptor removal in different detector structures will be reviewed after neutron and charged hadrons irradiations. The initial acceptor removal rate was found to depend

on the concentration and it is faster for charged hadrons than neutrons. The removal constants for different material resistivities ranging from ~1 Ohm cm to >10 kOhm cm will be presented. Possible reasons for such behaviour will be investigated with means to mitigate or enhance the effect.

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Development of thin n-in-p planar pixel modules for the ATLAS upgrade at HL-LHC

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Thin planar pixel modules are promising candidates to instrument the inner layers of the new ATLAS pixel detector for HL-LHC, thanks to the reduced contribution to the material budget and their high charge collection efficiency after irradiation. 100-200 um thick sensors, interconnected to FE-I3 and FE-I4 read-out chips, have been characterized with radioactive source scans and beam tests at the CERN-SPS and DESY. The results of these measurements will be discussed for devices before and after irradiation up to a fluence of 1.5×10^{16} n_{eq} cm^{-2}. The charge collection and tracking efficiency will be compared for the different sensor thicknesses.
Among these samples, planar active edge sensors produced at VTT are particularly interesting given the increased fraction of active area, due to a distance as low as 50 um between the last pixel implants and the activated edge. The tracking efficiency at the edges of these devices has been investigated before and after radiation.
Finally, the outlook for future planar pixel sensor productions will be discussed, with a focus on sensor design at the pixel pitches foreseen for the RD53 Collaboration read-out chip in 65 nm CMOS technology.

Planar Sensor 1 / 6

Applications of Atomic Layer Deposition (ALD) on ultra-fine pitch pixel detectors

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Atomic Layer Deposition (ALD) method is a derivate of more commonly adopted Chemical Vapor Phase Deposition (CVD) thin film growth methods. The deposition of a film by ALD is based on the successive, separated and self-terminating gas–solid reactions of typically two gaseous reactants. Separation of the reactants is accomplished by pulsing a purge gas (for instance oxygen, nitrogen or argon) after each precursor pulse to remove excess gaseous precursor from the process chamber prior the following deposition cycle. ALD is known as a method producing pinhole-free thin films due to its self-limiting surface chemistry growth mechanism. The ALD grown thin films, such as hafnium oxide (HfO_2) or tantalum oxide (Ta_2O_5), have high dielectric constants compared thermally oxidized silicon (SiO_2). In particle physics applications, the cell size of pixel detectors is trending to decrease, while leakage current due to radiation defects increases. Thus, it would be favorable to isolate capacitively the DC leakage current from the input of the readout ASIC. In this case, ALD grown dielectric films could be used as capacitive coupling (AC-coupling) layers due to their potentially high

capacitance density. Furthermore, with ALD it is possible to engineer oxide and interface charge type and density at dielectric-silicon interfaces. We present measurement results and simulations of different radiation detector structures with ALD grown dielectric films. Our results, obtained with Photoconductivity Decay (PCD) method, indicate surface passivation properties comparable with thermally grown SiO_2.

Planar Sensor 1 / 7

Industrial production of silicon strip sensors with Infineon

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All modern particle physics experiments use silicon-based sensors for their vertex and tracking systems. The largest single device built so far is the CMS Tracker with more than 24,000 sensors, each made on a 6" silicon wafer. An academic institution cannot perform such a large production, and even the number of potential commercial vendors is small. Therefore we are developing planar silicon strip sensors together with the European semiconductor manufacturer Infineon Technologies AG. In this talk, the project is presented and results from electrical characterization and beam tests of prototypes in p-on-n-technology are shown. Moreover, the current work for large-area detectors in n-on-p technology for possible Phase-2-Upgrades of the LHC experiments will be discussed.

Introduction / 8

Surface effects in segmented silicon sensors

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The voltage stability and the charge-collection properties of segmented silicon sensors are strongly influenced by the charge and potential distributions on the sensor surface, the charge distribution in the oxide and passivation layers, and by Si-SiO2 interface states. To better understand these complex phenomena, measure¬ments on test structures and sensors, as well as TCAD simulations related to surface and interface effects, are being performed at the Hamburg Detector Lab. The main results of these studies are presented, and some tentative conclusions, which are relevant for the sensor design, are drawn.

It has been observed that the charge distribution on the sensor surface changes with time. The time constants, which can be as long as days and weeks, show a strong dependence on environmental parameters like humidity and temperature. Using Gate-Controlled-Diodes (GCD) and MOS-FETs, the surface resistivity of SiO2 has been determined for different relative humidities at room temperature. They can explain the observed variation of the time constants. A method of implementing different charge distributions on the sensor surface and of simulating the time dependence of surface charges with SYNOPSYS TCAD has been developed, and simulation results of the time dependence of the electric field in sensors are presented. They are relevant for the break-down beha¬viour and the charge collection. A proposal how these long-term effects could possibly be avoided is discussed.

Oxide charges, in particular close to the Si-SiO2 interface, and interface traps, strongly influence the break-down and charge collection properties of silicon sensors. Previously, the effective oxide charges and surface currents have been determined for X-ray doses of 0 Gy, and of 1 kGy(SiO2)/ to 1 GGy(SiO2) using MOS Capacitors (MOS-C) and GCDs built on <100> and <111> n-type silicon from 4 diffeent vendors. Most of the irradiations have been performed without biasing the test structures. The results have been implemented into SYNOPSYS TCAD and used to optimize the design the AGIPD p+n sensor, where a break-down voltage above 900 V for X-ray for doses between 0 Gy to 1 GGy has been demonstrated. In the simulations spatially uniform oxide-charge densities and surface recombination velocities, with the measured X-ray-dose dependencies, have been assumed.

For the <100> and <111> MOS-Cs built on n-type silicon, the time dependence of the effective oxide-charge density after biasing the MOS-C to different voltages in inversion and back to accumulation, has been determined before and after irradiation to 1 GGy. It is found that in inversion, the density of positive oxide charges increases with time and saturates after about 120 minutes. The results of the saturation values for different voltages in inversion, corresponding to different electric field values at the Si-SiO2 interface, are presented. In addition, a significant decrease of the positive oxide-charge density is observed, when the MOS-C, after having been for some time in inversion conditions, is biased in accumulation.
To study the build-up of oxide charges during and shortly after X-ray irradiations as a function of the electric field at the Si-SiO2 interface, the drain-source current for a given gate voltage of a MOS-FET has been measured and the time dependence of the threshold voltage determined. So far the measurements uses a p-channel MOSFET and X-ray doses between 10 Gy (SiO2) to 15 kGy (SiO2) have been investigated. The aim of this study is to understand to what extent the assumption of a uniform oxide-charge density, which is made in the simulations, is justified, and to provide the data, which allow implementing a non-uniform, electric field dependent oxide-charge density in future TCAD simulations.

The relevance of oxide charges on the charge collection properties has been investigated by long-term measure-ments on n+p-strip sensors with p-spray and p-stop strip isolation exposed to a 90Sr β source. Data with a dose rate of 50 Gy(SiO2)/day are presented. They show significant changes in the charge-collection properties already at doses as low as 10 Gy. The findings are understood with the help of SYNOPSYS TCAD simulations, and the relevance for sensor designs is discussed.

3D Sensors 2 / 9

Test Beam Results of a 3D Diamond Detector

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A prototype of a novel detector using single-crystal chemical vapor deposited diamond and resistive electrodes in the bulk forming a 3D diamond device will be presented. The electrodes of the device were fabricated with laser assisted phase change of diamond into a combination of diamond-like-carbon, amorphous carbon and graphite. The connections to the electrodes of the 3D device were made using a photo-lithographic process. A prototype detector system consisting of the 3D device connected to a multi-channel readout was successfully tested with 120GeV protons proving the feasibility of the 3D diamond detector concept for particle tracking applications. The electrical and particle detection properties of the prototype device will be presented.

LGAD (2) / 10

Study of signal saturation in LGAD sensors

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I will analyze the effect of space charge in LGAD detectors using laser signals.
I will study how the amplitude of the output signal of LGAD sensors depends on the input charge.

TCAD Simulations / 11

TCAD Simulations of Radiation Damage Effects at High Fluences in Silicon Detectors with Sentaurus TCAD

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In this work we propose the application of a radiation damage model based on the introduction of deep level traps/recombination center suitable for device level numerical simulation of radiation detectors at very high fluences (e.g. 1-2x10^16 1 MeV equivalent neutrons).

The model is based on a past modeling scheme featuring three levels with donor removal and slightly increased introduction rate to cope with direct inter-defect charge exchange. This was successfully adopted for the optimization of the substrate resistivity and geometrical configuration of the electrodes of the inner silicon strip tracker of the CMS experiment at LHC.

The new fluences expected at the SuperLHC impose new challenges and the extension of the model (valid up to 1x10^15 n/cm2) is not straightforward. New effects have to be taken into account (e.g. avalanche multiplications and capture cross section dependencies on temperature and fluences), at the same time keeping the solid physically based approach of the modeling (e.g. by using no fitting parameters). This will preserve the generality of the approach, allowing its application to the optimization of different kind of detectors.

We present the comparison between simulation results and experimental data taken from literature for p-type substrate structures in different operating conditions (temperature and biasing voltages) for fluences up 2.2x10E16 n/cm2 (Fig. 1).

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HV CMOS (2) and LGAD (1) / 12

Measurements of the Time Resolution of Low-Gain Avalanche Detectors (LGAD)

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The Time resolution of LGAD of varying thickness have been explored with lasers and in beam tests. The results agree with simulations and validate the extrapolation for future improvements.

3D Sensors 2 / 13

First concepts for 3D radiation detector manufacturing at CiS

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In the past, the CiS Forschungsinstitut für Mikrosensorik und Photovoltaik has made a mark as a manufacturer of reliable radiation hard planar silicon sensors for various important high energy particle detectors.

Radiation detectors based on 3D structures in silicon are a promising way to increase their radiation hardness. This is especially needed in the high luminosity upgrades of the large hadron collidier (LHC) at CERN. Due to the small distances between the electrodes in 3D sensors the depletion voltage can be clearly reduced and the charge collection efficiency is increased.

A first concept for realisation of a 3D radiation detector at CiS will be presented and discussed. The required holes can be implemented using a deep reactive ion etching capability of a newly installed ICP etching tool. A challenging task is the conformal doping of the trenches. Several approaches are discussed.

Non HEP projects / 14

Development of a gamma-blind neutron-efficient detector using silicon detectors and a reactive lithium film.

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The use of silicon detectors with neutron-reactive films provides a compact technology for thermal-neutron detection. A thermal-neutron detector has been developed utilizing the 6Li(n,alpha)3H reaction. A detector with a stable 6LiF layer has been produced and tested, while a detector designed to use a pure 6Li metal film is nearing completion. The challenge for this latter design is to prevent the chemical degradation of the highly reactive lithium layer and keep a stable detector/lithium assembly for long term operations.

In order to reliably identify thermal neutron capture reactions even when gamma radiation is present, techniques for gamma-ray suppression have been investigated. By having the suitably thin reactive layer sandwiched between two silicon detectors, it has been possible to detect alpha-triton coincidences, which is being explored as an efficient method of gamma-ray suppression. The identification of alpha-triton pairs through methods of pulse-height discrimination in both detectors has been investigated.

Geant4 simulations of this configuration have been performed to optimize the thickness of the 6Li and 6LiF layers for maximum neutron detection efficiency and gamma rejection. The response of a detector (with 6LiF coating) to thermal neutrons and gamma rays has been compared with simulation results.

New electronics and DAQ boards required for a multi-layer detector have been designed which will allow the targeted high neutron-detection efficiencies (of ~20%).

3D Sensors 2 / 15

New 3D fabrication at CNM-Barcelona for pixel ATLAS upgrade

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We will present the new ongoing project at CNM-Barcelona, involving the fabrication of new 3D detectors for pixel ATLAS upgrades at the CNM-Barcelona. The mask for the new structures and simulations for the geometries of 50umx50umx200um and 100umx25umx200um will be shown for different irradiations.

HV CMOS (2) and LGAD (1) / 16

Measures with strips LGAD p-type detectors fabricated at CNM-Barcelona

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We will present the measures of strips LGAD fabricated on FZ and epitaxial wafers. Those measures are taken at Diamond Light Source with x-rays as also diodes measured at CNM-Barcelona.

We will present also simulations for p-on-p segmented detectors with LGAD performed with Sentaurus TCAD for possible future fabrications.

LGAD (2) / 17

Determination of the Doping profile of LGAD detector

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In this contribution I will illustrate preliminary studies towards the development of a methodology to determinate the doping profile of LGAD detectors. The method first, using the analysis of Capacitance-Frequency curve, estimates the optimal measuring frequency, then from the Capacitance-Voltage characteristic curves extracts the doping profile.
An alternative method measures the average doping profile using Current-Voltage curve is also presented.

Planar Sensors 2 / 18

Beamtests of HPK/KEK n^+-in-p pixel sensors for ATLAS HL-LHC upgrade inner tracker

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ATLAS upgrade for foreseen High Luminosity LHC will require the high radiation tolerance on Pixel Detector.
The n^+-in-p silicon technology is a promising candidate for the pixel upgrade, due to its radiation hardness and cost effectiveness.
We have developed n^+-in-p planar pixel sensors produced by HPK (Japan) connected by bump bonding to the ATLAS read out chip FE-I4.
The new sensors were irradiated with 70 MeV protons at a fluence of 5×10^{15} $\mathrm{n_{eq}/cm^2}$.
The beam tests with 4.0 GeV positron at DESY were carried out in 2013 and 2014.
From the analyses on irradiated sensors the hit efficiency under the bias rail with large offset is found to be similar to the one without bias rail.
The reconstruction and analysis for long-staggered pixel in test beams at DESY is in progress.
In addition, reconstruction in dense particle environment is on-going for the test beam with 2.5 and 14.0 GeV electrons at SLAC in 2014.
This talk presents these analysis summary.

LGAD (2) / 19

Last fabrication run of LGAD detectors at CNM-CSIC.

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This talk reports the design and the measurements of the last fabrication run of silicon radiation detector with intrinsic multiplication of the charge, called Low Gain Avalanche Detector (LGAD). These new devices are based on the standard Avalanche Photo Diodes (APD) normally used for optical and X-ray detection applications. The main differences to standard APD detectors are the low gain requested to detect high energy charged particles, and the possibility to have fine segmentation pitches: this allows fabrication of microstrip or pixel devices which do not suffer from the limitations normally found in avalanche detectors.
The work has been done in the framework of the RD50 CERN collaboration.

TCAD Simulations / 20

Design of planar p-on-n pixel sensor with an optimized active-edge region for the next generation of FELs

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Future experiments at the European X-Ray Free Electron Laser (XFEL) will require silicon pixel sensors with demanding performance: a wide dynamic range from 1 up to 104 12-keV photons per pixel, a small pixel pitch (~100 µm), minimum dead area and a radiation tolerance of 1GGy per 3 years of operation. Therefore, the development of four-side buttable tile detectors that meet such requirements is challenging. Through this work, carried out in the framework of the PixFEL project, design and TCAD simulations of planar p-on-n sensors with an active edge approach are performed with the aim of minimizing the dead area at the edge. The improvement of the breakdown characteristics in order to reach at least the minimum bias voltage required to avoid plasma effects at high charge concentration is achieved using different edge borders or layouts with the incorporation of multiple guard rings at the edge. The methodology of the sensor design, the optimization of the most relevant parameters, and the optimized layout are described. Finally, the simulated performance, in particular the breakdown voltage and the charge collection properties are presented.

LGAD (2) / 21

Numerical simulation of Low Gain Avalanche Detectors

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In this work, we present a simulation study of low gain avalanche detectors (LGAD). The doping profile of LGAD avalanche region is the most critical technological parameter to be adjusted, affectingbreakdown voltage, gain-voltage characteristics and excess noise factor. In order to better understand the multiplication mechanism, numerical simulations are conducted for LGAD design optimization.
The effect of multiplication region doping profile on the LGAD electrical characteristics has been investigated for two candidate device structures considering both boron and gallium implantations with different doses. In addition, device simulations have been used to predict the temperature dependence of the breakdown voltage and multiplication gain and the excess noise factor induced by avalanche multiplication.

Introduction / **22**

Analog circuit design in 65 nm CMOS for the readout of silicon pixel detectors

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The next generation of silicon pixel detectors at high energy physics and photon science experiments sets unprecedented and extreme requirements to the microelectronic systems that are used to read out the sensors. Front-end integrated circuits have to provide advanced analog and digital signal processing functions in pixel readout cells with a pitch of a few tens of a μm. They have to handle huge data rates and stand extreme levels of radiation without degrading their performance. Presently, the community of designers is studying the 65 nm CMOS technology as a tool to achieve the ambitious goals of future pixel systems, and has organized itself in the RD53 project to tackle the specific challenges associated with the development of readout chips for the innermost pixel layers of experiments at the High Luminosity LHC. This talk is focused on the specific features of the design of the analog front-end circuits for pixel sensors in a nanoscale CMOS process, taking into account typical constraints such as low power dissipation and small available silicon area. It provides an overview of the architectures that are currently being explored for signal amplification and filtering, hit detection and analog-to-digital conversion. A comparison is given with the different solutions that are developed in the same technology for the readout of pixel sensors for imaging at advanced X-ray sources. This makes it possible to appreciate how analog design in 65 nm CMOS can be tailored to very demanding specifications in a broad range of pixel detector applications.

HV CMOS (2) and LGAD (1) / **23**

Issues in the design of Ultrafast silicon detectors

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In this contribution I will analyze two different aspects of the design of ultrafast silicon detectors: (i) how to obtain finely pixelated detectors while retaining excellent time resolution, and (ii) how to set the best value of gain without significantly increase the noise.

HV CMOS 1 / 24

Studies and status of CMOS-based sensors research and development for ATLAS strip detector upgrade

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The talk will give an overview of the studies and status of
CMOS-based sensors research and development for ATLAS strip detector
upgrade.

CMOS sensor can provide higher granularity, costs less in sensor fabrication compared to conventional planar sensor.

Furthermore, CMOS-based sensors collect charge from thin depleted region,
and it has potential to be thinned down to 50um for reducing material
the new ATLAS tracking detector.

CMOS technology been chosen for investigation for ATLAS strip detector upgrade.
A test chip that comprises several pixel matrices with different geometry,
as well as built-in amplifier and stand-alone amplifier arrays has been fabricated
in a 0.35 μm high-voltage CMOS process.

This talk will focus on the study of the test chip characteristics.

We did a very careful measurement on the tiny leakage current from a
single pixel to characterize the its basic diode properties before and
after gamma radiation.

We also measured the inter-pixel resistance for different doses of
gamma radiation to investigate electrode isolation in high radiation environment.

The total capacitance of a pixel diode as a function of pixel size is
also measured for pixel diode size optimization.

The plan of the CMOS sensor development for ATLAS strip detector in next
three years will be covered in this talk as well.

HV CMOS 1 / 25

HVCMOS Sensors for LHC Upgrade

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High-Voltage CMOS sensors are based on depleted active diodes as sensor elements. Every sensor element – pixel – is equipped with the readout electronics that performs various tasks, from signal amplification, zero suppression, address generation to time walk correction. High-Voltage CMOS sensors are an option for pixel- and strip layers of ATLAS high-luminosity upgrade. Several prototypes have been produced and tested. In this talk the latest results will be presented.

Non HEP projects / 26

Vertigo, a vertically integrated heterogeneous microsystem

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Vertigo is a light, movable, compact vertically integrated microsystem which allows secure access, measurement and three-dimensional localization of difficult radioactive environments. The system design includes a high resolution, radiation hard, MEMS-based multiple-particle pixelated detector, a camera, data storage and high band wireless transmission, cooling system and batteries. The receiver is composed by an on-line reconstruction software and real-time display. In nuclear industry, the obvious application of Vertigo would be in characterization of nuclear facilities, particularly during decommissioning when access may be limited. In a nuclear decommissioning project or a nuclear disaster, one of the first problems is identifying what radionuclides are present in an area and where they are. This is currently heavily reliant on human operators and expensive remote equipment and has safety and financial consequences. An international collaboration has recently been formed to develop Vertigo. The presentation will show the technological state of the art of each of the system components and their implementation plans.

Planar Sensors 2 / 27

Latest development of HPK/KEK n^+-in-p planar pixel sensor modules for HL-LHC and understanding their performance with TCAD simulations

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We have been developing planar-process pixel sensors in p-type 6-in. silicon wafer for an application in ATLAS detector for the luminosity upgrade of the large hadron collider (HL-LHC). Our motivation is to develop a highly radiation-tolerant and cost-effective pixel sensor for covering large area of the pixel detector. In the 1st prototype pixel sensors, after irradiation and beamtest, inefficient regions in detecting passing-through charged particles in pixel structures were identified, especially associated with the bias rail. New pixel structures were fabricated in the 2nd prototype sensors and are shown to improve the inefficiency greatly. The source of the inefficiency has been understood with technology CAD (TCAD) simulations and improvement in the new structures is being discussed.
The pixel modules are made by bump-bonding the sensors and ATLAS pixel readout ASIC FE-I4's by

using SnAg solder bumps. The bumpbonding of thin (150 μm) sensors and thin (150 μm) ASIC has revealed an issue associated with the thickness. The issue seems to have been resolved by improving the flatness of the sensors and ASIC by depositing compensation in the backside or by improving the vacuum chucking jigs.

Non HEP projects / 28

Simulation and testing of thin silicon microdosimeters realized with planar technology

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Modern cancer treatments have become increasingly more sophisticated in the past years and therefore require a real-time, reliable radiation dose monitoring system. Silicon microdosimeters are excellent candidates as they are small in size and have high spatial resolution. The ease of coupling to readout electronics makes them the first choice for a real time on-line system.

The devices in this study were realized with a standard planar technology and were thinned down to ~10μm using a wet chemical etchant to achieve the best possible tissue equivalency. The device layout was based on information from previous microdosimeters developed by the Centre for Medical Radiaton Physics at the University of Wollongong, Australia based on silicon-on-insulator technology. The fabricated process is set as a benchmark for the design and fabrication of a novel type of silicon microdosimeters to be realized with state of the art full 3D technology.

Electrical, functional testing and comparison with numerical simulations will be presented and discussed. The functional tests were performed at the ESRF, Grenoble, France, using a sub-micron X-ray beam, up to ~10^10 ph/s. The aim of these tests was to investigate the uniformity and reliability of the fabricated devices in addition to the heavy ion experiments at HIMAC (Japan) using Carbon-12 Ions, and at ANSTO (Australia) with Helium atoms.

3D Sensors 1 / 29

Status of 3D silicon pixel detectors for the ATLAS Forward Physics experiment (AFP)

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The ATLAS Forward Physics (AFP) project plans to install 3D silicon pixel detectors 210 m away from the interaction point and very close to the beamline at a radius of about 2-3 mm. This implies the need of slim edges in the order of 100 µm for the sensor side facing the beam to minimise the dead area. Another challenge is an expected non-uniform irradiation of the pixel sensors with high radiation levels of about 5e15 p/cm² close to the line of diffractively scattered protons and orders of magnitude lower for the detector parts away from it. To study if these requirements can be met using slightly-modified IBL FE-I4 3D pixel sensors, standard IBL devices are diced to obtain slim edges and are irradiated non-uniformly with protons. The resulting performance and the status of the project will be presented.

3D Sensors 1 / 30

Experience with 3D in ATLAS IBL

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3D sensors has been developed for the Insertable B-Layer (IBL), an additional pixel layer that has been installed in ATLAS during the present shutdown of the LHC collider at CERN. It is presented in the talk the experience in designing, testing and qualifying sensors and detector modules that have been used to equip part of the IBL. Some very preliminary results will be presented from the commissioning of the detector with cosmic particles and magnetic field.

3D Sensors 2 / 31

Status of single-sided 3D detector development at SINTEF

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In order to fulfil the requirements of the tracking detectors for the future upgrades of the LHC experiments such as the ITK detector, the 3D community now has to address the challenges of smaller pixels and thinner substrates. The single-sided approach for 3D detectors, which has been developed at SINTEF MiNaLab in collaboration with Stanford Nanofabrication Facility, allows active edges and thinner sensor substrates. An overview of the 3D detector development at SINTEF will be given with a focus on the efforts to identify the yield factors. A new SINTEF 3D run is currently at the design phase, targeting smaller electrodes (3-4 µm) and pixels (50 x 50 µm2 and possibly 100 x 25 µm2) on 6 inch Silicon-on-insulator wafers with device layer thicknesses of 100 µm and 50 µm. Status and planned fabrication processes with a focus on technological aspects related to the yield optimization will be presented.

Non HEP projects / 32

Status of the proton Computed Tomography project developed within the RDH INFN experiment

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Proton Computed Tomography (pCT) is a new imaging method with a potential for increasing accuracy of treatment planning and patient positioning in hadron therapy. A pCT system based on a silicon tracker and a YAG:Ce calorimeter has been developed within the PRIMA/RDH INFN CSN5 collaboration. Tests under proton beams gave promising results on radiography and tomographic reconstructions. Recent developments are reviewed in this talk.

Planar Sensors 2 / 33

Test beam data analysis of ATLAS planar pixel sensor with alternative bias rail geometries.

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It is known that for the current design of planar pixel sensors, there is a drop of efficiency at the punch-through structure of the biasing system at the edge of pixels. Various geometries, as part of the ATLAS Inner Tracker (ITK) upgrade, are being investigated to reduce this inefficiency.

A planar pixel sensor with multiple alternative bias rail geometries has been tested at the SPS beam test facility at CERN in late 2014. Measurements were taken with the FE-I4 beam telescope and results from the beam test are presented, focusing on the efficiency within the pixel. Future plans for further investigations are also discussed.

LGAD (2) / 34

Investigation of long-term operation of charge multiplication sensors

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Measurements of silicon sensors having charge multiplication are candidates for radiation hard detectors for future high energy physics experiments. Important to understand is their applicability in

terms of long-term biasing and high voltage cycling, especially in case of a use as tracking devices. The talk will show measurement results of various p-type strip sensors after days to weeks of biasing with very high voltages. The collected charge obtained with beta source measurements and details on the cluster sizes are investigated.
On several sensors, irradiated to fluences of around 2*10^15 Neq/cm2, a decrease in collected charge of up to 25% has been observed. Partial recovery of the signal is possible after turning of the high voltage for a short time, although the maximum signal is never recovered. Further new measurements and data analysis results will be presented aiming for an improved understanding of the effect of reduced charge.

3D Sensors 1 / 35

Results on FBK 3D pixel detectors for CMS

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For the CMS-TOTEM Precise Proton Spectrometer, tracking and timing detectors will be installed next year along the LHC beamline at ~220 m from the CMS interaction point. To measure protons scattered at very small angles, detectors will be placed within Roman Pots at a few mm from the LHC beam. Tracking detectors are supposed to receive an irradiation fluence up to $5x10^{15}$ p/cm^2. The chosen technology, capable to stand this irradiation level, is 3D pixel sensor, where columnar electrodes ensure extremely good radiation hardness. Results of laboratory and test beam measurements will be presented for FBK 3D silicon pixel detectors for CMS. In particular, 1E sensors (single readout electrode for each pixel), coming from the same wafers of the ATLAS-IBL production, read out by the new PSI46 digital chip developed for the Phase I upgrade of the CMS silicon pixel detector, have been tested on a 120 GeV proton beam at Fermilab, before and after being irradiated

with 23 MeV protons at KIT, within the AIDA project, to different fluences up to $1x10^{16}$ n_{eq}/cm^2. Laboratory measurements and the calibration and optimization of the readout chip were performed in Torino.

Planar Sensor 1 / 36

CMS Silicon Strip Tracker Readiness for LHC Run II

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With an active area of 200 square meters and 10 million readout channels, the CMS silicon strip tracker is the largest silicon detector ever constructed. We present the latest status and results of the detector following the first LHC long shutdown and as CMS prepares for the next high-energy discovery run. Results from detector calibration and commissioning, radiation measurements and detector performance are shown.

TCAD Simulations / 37

Doping profiles and radiation damage

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Radiation hardness constrains imposed by the High luminosity LHC upgrade, demand detailed modelling and simulation of substrate damage in the most basic level. In that direction, several implanted samples, which have undergone the first steps of the fabrication process, are simulated and measured. Results are then transposed to a diode test production of similar characteristics, fabricated using equivalent parameters. The samples are studied before and after proton irradiation up to doses as high as 1016 neq/cm2, while a comparison of simulation and measurements pre and post irradiation is presented in an attempt to configure and calibrate a detailed model.

3D Sensors 1 / 38

Investigation of the Electrical Characteristics of Double-Sided 3D Sensors after Proton and Neutron Irradiation up to HL-LHC Fluencies

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This report addresses the experimental characterization of Double-Sided 3D radiation sensors, fabricated at FBK, irradiated with protons and neutrons up to fluencies in the order of 10^{16} n_{eq}/cm^2 as the foreseen HL-LHC compliance. The study is mainly aimed at comparing different designs and technological solutions in terms of full depletion voltage and breakdown voltage in order to predict the possibility to bias these sensor at the most suitable voltage after several years of operation at the HL-LHC.

Non HEP projects / 39

Identification of nuclear fragments using digitized signals from a partially depleted Si detector

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The performance of a silicon detector in partially depleted condition has been studied. The detector has been used for Pulse Shape (PS) identification of charged nuclear fragments. Particles entered the detector from the ohmic (low field) side, to enhance PS identification performance. Five different bias voltages have been used, one corresponding to full depletion (used as reference of the standard performance of the detector), the others associated with a silicon depleted layer ranging from 90% to 60% of the total detector thickness. Charge collection efficiency has been evaluated quantitatively and the possibility of energy calibration corrections has been considered. Collection efficiency from the not depleted region was found unexpectedly high, even for particles stopped in that region. A sudden reduction of the collection time was observed for particles having range close to the thickness of the not depleted region, indicating that the so-called "funneling" effect could play a role in charge collection. Isotopic separation capability via PS analysis improves at lower bias voltages with respect to full depletion, though charge identification thresholds are higher than at full depletion. Moreover, though the doping uniformity was not good enough for isotopic identification at full depletion, good isotopic identification via PS analysis has been obtained in partial depletion.

3D Sensors 2 / 40

Design and TCAD simulation of a new generation of 3D Sensors for HL-LHC within the INFN (ATLAS-CMS) R&D program in collaboration with FBK

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We report on the joint INFN ATLAS-CMS R&D program, in collaboration with FBK, aimed at the development of pixel sensors for the phase 2 upgrade of the LHC (HL-LHC). The sensor technology and design will have to be optimized and qualified for extreme radiation hardness, and pixel designs will have to be compatible with present (for testing) and future (65nm) FE chips of ATLAS and CMS. In particular, the talk will focus on a new generation of 3D pixel sensors coping with the high demands of HL-LHC: increased granularity, (e.g., 100×25 or 50×50 μm^2 pixel size), higher radiation tolerance (up to a fluence of 2x10^{16} n$_{eq}cm^{-2}$), reduced material budget and better geometrical efficiency. Compared to the double-sided 3D sensors successfully produced for the ATLAS IBL, these requirements call for a modified technology allowing for thinner sensors, narrower electrodes, reduced electrode spacing, and very slim (or active) edges.
The talk will cover aspects relevant to the design, TCAD simulation and layout of the first batch of these new 3D sensors to be fabricated at FBK on 6" wafers.

3D Sensors 1 / 42

Preliminary results from the first batch of Si 3D sensors fabricated at FBK on 6 inch wafers

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FBK has recently upgraded the pilot line from 4 inch to 6 inch wafers, a fact that brings both advantages and disadvantages for the fabrication of 3D sensors.
The talk will focus on the fabrication of the first internal batch of 3D sensors carried out on the new line in 2014. We report on: i) the main modifications introduced in the fabrication process with respect to the baseline process used for ATLAS IBL production, ii) the process issues encountered during the fabrication of the detectors, and iii) the first results obtained from the electrical characterization of diodes, pixels and strips.
Within the INFN ATLAS-CMS R&D program, we have planned to bump bonded some wafers in order to proceed with the functional characterization of 3D pixel detectors

3D Sensors 2 / 43

Development of a new technology for the next generation of 3D Pixel Sensors for HL-LHC within the INFN (ATLAS-CMS) R&D program in collaboration with FBK.

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We report on the joint INFN ATLAS-CMS R&D program, in collaboration with FBK, aimed at the development of pixel sensors for the phase 2 upgrade of the LHC (HL-LHC).
In this talk we describe the development of the main technological steps allowing for the fabrication of a new generation of Si 3D pixel detectors with small pixel and thin active thickness. In particular, we report on the results of the process tests carried out at FBK in order to optimize the etching by DRIE and the filling (at least partial) with poly-Si of narrow (5 micron) columnar electrodes.

Non HEP projects / 44

New developments in high-density SiPM technology at FBK

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The recently proposed (2013) high-density SiPM technology (HD-SiPM) is based on a redesigned border region of the microcells, allowing a small cell size with high fill factor. The separation between microcells is obtained with trenches, which provide electrical isolation and optical attenuation of the photons emitted during the avalanche. These features translate into high photo detection efficiency, low correlated noise, fast cell recovery time and a very high number of cells per unit area, improving the linearity of the detector. New developments and refinements in the fabrication technology provide a reduced dark count rate and further increased fill factor. We present the full characterization of new RGB-HD SiPM prototypes, featuring peak sensitivity around 550 nm. We produced a set of devices with cell sizes of 12×12, 15×15, 20×20, 25×25 and 30×30 μm^2. For the smallest cell, we measured a photo-detection efficiency close to 30% around the green region of the light spectrum whereas for the larger ones it reached 50%. Setting a limit of 10% to the optical cross-talk, the PDE reaches a remarkable value of 40% in the last three structures. We coupled 4×4 mm^2 SiPMs to a $3\times3\times5$ mm^3 CsI(Tl) scintillator and we measured an energy resolution at 122 keV of 8.4% FWHM using the 25×25 μm^2 cell size. We also measured the performance of the same devices coupled to $3\times3\times5$ mm^3 LYSO crystal at 511 keV. For both the 20×20 μm^2 and 25×25 μm^2 cell sizes, the energy resolution is better than 10% FWHM and the coincidence resolving time is close to 130 ps FWHM at 20℃.

HV CMOS 1 / 46

TCAD Simulation of HVCMOS sensors

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We present a TCAD simulation study of the properties of HVCMOS sensors as a function of substrate resistivity, pixel topology and biasing scheme. The effect of these parameters on the timing and detection efficiency will be discussed.

HV CMOS 1 / 47

Laboratory characterization of CCPDv2 and CCPDv4 capacitively coupled to FEI4

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We present a detailed characterization of the CCPDv2 and CCPDv4 CMOS sensors capacitively coupled to FEI4. We discuss the equalization procedure and the strategy for lowering the CCPD threshold, its temperature dependence and the intrinsic limits of the system.

HV CMOS 1 / 48

SPS Test Beam characterization results with CCPDv2 and CCPDv4 capacitively coupled to FEI4

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We present the results of the characterization of CCPDV2 and CCPDv4 sensors, before and after irradiation, at the SPS using the FEI4 Telescope. The effects of bias, threshold and irradiation on the efficiency and timing properties of the CCPD family of sensors will be discussed.

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The RD53 programme and the CHIPIX65 / INFN project for the development of pixel readout chip for extreme rate and radiation

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The scope of RD53 is the development of pixel readout Integrated Circuits (IC) for the next generation of pixel readout chips to be used for the ATLAS and CMS Phase 2 pixel detector upgrades and future CLIC pixel detectors.
This does not imply that ATLAS and CMS must use the same exact pixel readout chip, as most of the development, test and qualification effort needed is independent of the specific implementation of the final chips. Multiple implementations are possible using the same technology foundation. In order to be effective, this collaboration is specifically focused on the design of pixel readout chips, and not on more general chip design or on other aspects of pixel technology.
The IC challenges include: smaller pixels to resolve tracks in boosted jets, very high hit rates, unprecedented particle fluence, much higher output bandwidth, and large IC format with low power consumption in order to instrument large areas while keeping the material budget low

Seven INFN units are participating to RD-53 and have formed the CHIPIX65 / INFN project, with 35 members experts on the field, of which 20 are actual VLSI designers, constituting a substantial fraction of INFN expertise on microelectronics. This makes
CHIPIX65 a unique opportunity for an efficient propagation across INFN of CMOS 65nm technology and
constitutes the greatest collaboration on a microelectronics project ever made across INFN

The talk will report on recent progress of RD53 and in particular on the contributions from the CHIPIX65 / INFN project.