

International Workshop on Semiconductor Pixel Detectors for Particles and Imaging (PIXEL2012)

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Book of abstracts

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Poster session / 1

Pixelated CdTe Detectors for Imaging X-rays on-board Solar Orbiter space mission

BEDNARZIK, Martin ¹; RESANOVIC, Rajko ¹; GRIMM, Oliver ²; COMMICHAU, Volker ²; LIMOUSIN, Olivier ³; MEURIS, Aline ³; ARNOLD, Nicolas ⁴; BENZ, Arnold ⁴; KRUCKER, Sam ⁴; ORLEANSKI, Piotr ⁵

¹ Paul Scherrer Institut, Laboratory for Micro- and Nanotechnology, 5232 Villigen PSI, Switzerland

² ETH Zürich, Institute for Particle Physics, Schaffmattstrasse 20, 8093 Zürich, Switzerland

³ CEA/DSM/Irfu, 91191 Gif-sur-Yvette Cedex, France

⁴ University of Applied Sciences for Northwestern Switzerland, Institute of 4-D Technologies, Steinackerstrasse 5, 5210 Windisch, Switzerland

⁵ Space Research Center of the Polish Academy of Sciences, 18A Bartycka, 00-716 Warsaw, Poland

Corresponding Author: martin.bednarzik@psi.ch

The STIX (Spectrometer Telescope for Imaging X-rays) instrument will be used on board the Solar Orbiter space mission to perform X-ray imaging and spectroscopy of solar flares. STIX is one of 10 instruments of the confirmed M-class mission of the European Space Agency (ESA) to be launched in 2017. The imaging is realized by a Fourier-imaging technique using tungsten grid collimators in front of 32 pixelated CdTe detectors. Solar thermal and non-thermal hard X-ray emissions from 4 keV to 150 keV will be imaged with high resolution (1 keV).

CdTe detectors dedicated for STIX are 10x10x1 mm³ in size. 8 big pixels plus 4 small pixels arranged in an asymmetrical geometrical configuration surrounded by a guard ring are read out with the Caliste-SO ASIC module developed at CEA. The pixel effective areas range from 9.7 mm² for the big and 1.0 mm² for the small ones. The pixelization process developed at the Laboratory for Micro- and Nanotechnology for the detectors purchased from Acrorad Co., Ltd Japan will be described. Our results for leakage current measurements and spectral measurements obtained after the segmentation process are presented and discussed. For the selection of flight-quality detectors two setups were developed at PSI and ETH. The setup allows a serial and fast measurement of the leakage current of each individual pixel including guard ring. All measurements are carried out at different temperature levels. Since the detectors are very sensitive to mechanical shock (brittle, increasing leakage current with decreasing spectral performance) a protecting support is needed for handling the devices. Specially developed detector holders with electrical contact to the pixels are used to ensure a safe transfer between two setups.

Session4 / 2

Toward one Giga frames per second: Evolution of In-situ Storage Image Sensors

Dr. VU TRUONG SON, Dao ¹; Dr. YAMADA, Tetsuo ²; Dr. ETOH, Takeharu ¹

¹ *Ritsumeikan University*

² *Tokyo Polytechnique University*

Corresponding Author: yb6t-etu@asahi-net.or.jp

In 2001, a video camera of one million frames per second (1 Mfps) was developed by Etoh et al. In-situ Storage with more than one hundred CCD memory elements were installed for each pixel. Simultaneous recording in all pixels realized the ultra-fast image capturing. The pixel count was 86 kpixels. The type of the sensors was named ISIS, In-situ Storage Image Sensor. They have been continuously evolving in the frame rate, the sensitivity and the pixel count. In 2011, a backside illuminated ISIS with EM-CCD achieved 16 Mfps with 165 kpixels and the sensitivity of several photons per pixel. It was a prototype image sensor. The authors are currently developing the practical version with 344 kpixels. The authors proposed a new architecture which can achieve 100 Mfps with the fill factor of 100%. The theoretical highest frame rate achievable by this architecture is 1 Gfps.

In 2012, a CMOS version was reported by Tochigi et al. The highest frame rate of the camera was 20 Mfps for 50 kpixels.

Another direction of evolvement of ISISes is introduction of new functions: among them are in-pixel signal accumulation which drastically improves S/N ratio in imaging of reproducible phenomena with very low light intensity, and user-friendly utility functions, such as a built-in multi-camera, a double-trigger system, and so forth.

The sensors are expected to be applied not only to the ultra-high-speed imaging for visible light, but also to imaging with other electromagnetic waves, imaging TOF MS, pulse-neutron radiography, etc.

This paper reviews the evolution of the ISISes.

Session5 / 3

Radiation-Hard High-Speed Parallel Optical Links

Prof. GAN, Kock Kiam ¹

¹ *Ohio State University (US)*

Corresponding Author: gan@mps.ohio-state.edu

We have designed two ASICs for possible applications in the optical links of a new layer of the ATLAS pixel detector for the initial phase of the LHC luminosity upgrade. The ASICs include a high-speed driver for a VCSEL and a receiver/decoder to extract the data and clock from the signal received by a PIN diode. Both ASICs contain 12 channels for operation with a VCSEL or PIN array. Among these channels, the outer four channels are designated as spares to bypass a broken PIN or VCSEL within the inner eight channels. The ASICs were designed using a 130 nm CMOS process to enhance the radiation-hardness. With the spacing of 250 μm between two VCSEL or PIN channels, the width of an optical array is only 3 mm. This allows the fabrication of compact parallel optical engine for installation at a location where space is at a premium such as that close to a pixel detector. The fabricated receiver/decoder properly decodes the bi-phase marked input stream with no bit error at low PIN current. The performance of the VCSEL driver at 5 Gb/s is satisfactory. We are able to program the ASICs to bypass a broken PIN or VCSEL and the power-on reset circuits have been successfully implemented to set the ASICs to a default configuration in an event of communication failure. We have irradiated the receiver/decoder to high dose and observe no significant degradation and the SEU rate is low. We plan to irradiate the VCSEL drivers in the summer to measure the radiation hardness. We will present results from the study at the conference. In addition, we will present the design of a new VCSEL driver ASIC to operate at 10 Gb/s which will yield an aggregated bandwidth of 120 Gb/s for a fiber ribbon.

Poster session / 4

The ultra low mass cooling system of the Belle II DEPFET detector

Dr. MARINAS PARDO, Carlos ¹; LACASTA LLACER, Carlos ²; OYANGUREN, Arantza ³; ACKERMANN, Karlheinz; RITTER, Martin ⁴; KIESLING, Christian; HEINDL, Stefan ⁵; BROVCHENKO, Oksana ⁶; SIMONIS, HJ ⁷; WEILER, Thomas ⁵; NIEBUHR, Carsten ⁸; GADOW, Karsten ⁹; VOLKENBORN, Robert ¹⁰; BARVICH, Tobias ⁵; Dr. VOS, Marcel ²; RUIZ VALLS, Pablo ¹¹

¹ Bonn University

² Universidad de Valencia (ES)

³ IFIC - Valencia

⁴ Werner-Heisenberg-Institut

⁵ KIT - Karlsruhe Institute of Technology (DE)

⁶ KIT

⁷ Inst. fuer Experimentelle Kernphys. - Universitaet Karlsruhe

⁸ Deutsches Elektronen-Synchrotron (DE)

⁹ Deutsches Elektronen-Synchrotron (DESY)

¹⁰ Deutsches Elektronen-Synchrotron

¹¹ University of Valencia

Corresponding Author: cmarinas@ific.uv.es

The new e⁺e⁻ colliders impose unprecedented demands to the performance of the vertex detectors. To achieve the required resolution in the vertex reconstruction, besides highly segmented pixel detectors, the material budget has to be kept at very low levels to reduce the multiple Coulomb scattering. These requirements are even more challenging in the case of the new Japanese Super Flavour Factory (SuperKEKB) where the very low momentum of the particles in the final state requires a vertex detector with less than 0.2% X₀ per layer, together with 50x50-μm² pixels, to achieve the aimed resolution of 8.5-μm.

As a consequence, there is an obvious impact on the cooling system, that has to be carefully designed, not allowing active cooling pipes inside the acceptance region. Due to the low power dissipation of the DEPFET sensor and the special geometry of the detectors (with the front end electronics placed at both ends of the ladder), the system can be cooled by circulating cold CO₂ through the massive support structures outside of the acceptance, while the sensitive area relies on forced convection with cold dry air.

In the talk not only full thermal simulations will be presented but also measurements done with a real mock up, showing that a proper cooling of the vertex detector can be made using this approach.

Session6 / 5

New fabrication and packaging technologies for CMOS pixel sensors: closing gap between hybrid and monolithic approach

DULINSKI, Wojciech ¹¹ *Institut Pluridisciplinaire Hubert Curien (FR)***Corresponding Author:** wojciech.dulinski@ires.in2p3.fr

Monolithic CMOS Pixels (MAPS) integrate on the same silicon substrate the radiation sensor element with the processing electronics. Their fabrication is possible through an easy access to commercial high-volume foundries, resulting in low costs and high yield. However in the standard implementation these devices suffer from two major limitations. First, only NMOS transistors are allowed on top of the active area. Second, even high-resistivity substrate cannot be fully depleted because of voltage limitation of CMOS transistors.

In order to overcome both limitations, we propose new CMOS fabrication procedures recently available for low-volume users. The first one (TowerJazz CIS) is a 180 nm process with high-resistivity epitaxial layer and quadruple well option. Two additional deep wells (implants) isolate electrically the substrate from standard shallow wells and allow for both types of transistors to be implemented. The second process (ESPROS Photonics Corporation) is a 150 nm CMOS on bulk high resistivity (detector quality) substrate, insulated from transistor level by deep implant (junction). Following front-end processing, wafers are back-thinned to 50 microns; back-contact is implemented and activated at low temperature. This is part of standard ESPROS foundry procedure, no post-processing is required. Resulting structure allows not only for both types of transistors on top of the sensing area but also for full depletion (or even over depletion) of entire detector thickness. Results of charge collection efficiency and irradiation study of sensors from both manufacturers are presented.

Total thickness of monolithic CMOS sensors can be very small: typically 15 μm for active silicon and 5 μm for interconnections (several metal-insulator layers). Therefore MAPS can be thinned down to less than 30 μm , without losing their tracking performance. This allows very small material budget and construction of non-planar (cylindrical) detector layers: thin silicon is quite flexible. In order to demonstrate feasibility of large area, ultra-light ($< 0.1\%$ radiation length) sensor ladders we develop novel packaging method. Thinned sensors (< 50 microns) are embedded in polymer (kapton) film, electrical connection to pads are implemented by metal deposition and metal lithography (no wire bonding). The process is based on slightly modified process (existing at CERN) for flexible multi-layer PCB fabrication, in which aluminum is used for all metal interconnections. We present details of ladder design adapted for large area, followed by minimum ionizing particle tracking tests results.

Microelectronics industry is evolving rapidly: several other foundries propose deep submicron advanced CMOS process on high resistivity bulk material. Wafer back thinning and back-contact implementation as post-processing start to be also easily available on a cost-effective way. We believe that in near future this approach will reduce hybrid pixel technology approach to the cases where the use of non-silicon detector material (like diamond or cadmium telluride) is really mandatory.

Session2 / 6

The Belle II pixel detector: high precision with low material

Dr. MARINAS PARDO, Carlos ¹

¹ *Bonn University*

Corresponding Author: cmarinas@ific.uv.es

An upgrade of the existing Japanese Flavour Factory (KEKB in Tsukuba, Japan) is under construction, and is foreseen for commissioning by the end of 2014. This new e+e- machine ("SuperKEKB") will deliver an instantaneous luminosity of $8 \cdot 10^{35} \text{ cm}^{-2}\text{s}^{-1}$, which is 40 times higher than the world record set by KEBK.

In order to be able to fully exploit the increased number of events and provide high precision measurements of the decay vertex of the B meson systems in such a harsh environment, the Belle detector will be upgraded ("Belle II") and a new silicon vertex detector, based on the DEPFET technology, will be designed and constructed. The new pixel detector, close to the interaction point, will consist of two layers of DEPFET active pixel sensors. This technology combines the detection together with the in-pixel amplification by the integration, on every pixel, of a field effect transistor into a fully depleted silicon bulk. In Belle II, DEPFET sensors thinned down to 75 μm with low power consumption and low intrinsic noise will be used.

In the talk, a general overview of the pixel detector will be presented, from the sensor description to the data transmission chain, all the way up the ASICs and the cooling concept.

Session4 / 7

3D Integration for SOI Pixel DetectorMOTOYOSHI, Makoto ¹; ARAI, Yasuo ²¹ *Tohoku-MicroTec Co., Ltd (T-Micro)*² *High Energy Accelerator Research Organization (JP)***Corresponding Author:** motoyoshi@t-microtec.com**Abstract**

Large-scale integration (LSI) technology in two dimensions has been the norm over the past three decades. However, the industry is now rapidly moving into the era of sub-20-nm nodes, and continuation of the present scaling trend will require the introduction of new transistors with three-dimensional (3D) structures and new materials and processes. This is expected to dramatically increase the development and manufacturing costs for systems-on-a-chip. 3D-LSI is one solution that can mitigate cost increases without degrading device performance. Consequently, many methods to realize 3D-LSI devices have been developed by focusing on the unit processes of 3D-LSI technology: (1) through-silicon via (TSV) formation, (2) bump formation, (3) wafer thinning, (4) chip/wafer alignment, and (5) chip/wafer bonding. However, these unit processes are incompatible in terms of various device and process requirements such as process temperature, device structure, TSV and bump dimensions, yield, reliability, and supply chain. For example, the simplest 3D pixel detectors are two-tile face-to-face stacking devices with fine-pitch μ -bump bonding, which requires bump formation, wafer thinning, accurate chip/wafer alignment, and chip/wafer stacking. For bump connection, several reported methods are available, such as Cu–Cu bonding, intermetallic-compound bonding with Cu/Sn bumps, and Au bump bonding. Cu–Cu direct bonding can provide a good and robust connection, but needs completely clean and flat surfaces. This would necessitate a dust-free environment, which is difficult to realize in practice for wafer/chip stacking with bump bonding. Therefore, although theoretically there might be many combinations of these five unit processes, the combinations do not a device structure with good yield, reliability, and cost. This study investigated the optimal combination of unit processes for manufacturing the SOI stacked pixel detector chip that has been designed by KEK. Stacking was accomplished with $2.5 \mu\text{m} \times 2.5 \mu\text{m}$ In bump connections and adhesive injection at low temperature (less than 200°C). It was found that the stacking process is affected by the layout of each tier, that adhesive injection is the key technology, and that these effects could be minimized by optimizing the layout, process parameters, and device structure. Another concern in manufacturing the pixel detector is suppressing metal contamination. Some metals such as Au, Fe, and Pt form intermediate energy level between the conduction and valence bands of Si and act as life-time killer. Cu is used as a wiring material and bump material in 3D devices. However, Cu diffuses into Si crystals and SiO₂ even at room temperature, increasing the leak current of pn junctions and deteriorating the oxide quality of MOS transistors. In our 3D integration using In bumps, Au is used to protect In from oxidation. Hence, optimizing the UBM (under bump metallization) layer is important. Therefore, we also studied the device characteristics with different UBM materials.

Poster session / 8**Silicon Strip Detectors for ATLAS at the HL-LHC Upgrade**HARA, Kazuhiko ¹; IKEGAMI, Yoichi ²¹ *University of Tsukuba (JP)*² *High Energy Accelerator Research Organization (JP)***Corresponding Author:** joost.vossebeld@cern.ch

While the Large Hadron Collider (LHC) at CERN continues to deliver increasing amounts of luminosity to the experiments, a phased upgrade of the LHC is planned, ultimately aimed at a luminosity of ten times the LHC design luminosity (HL-LHC). To cope with the expected harsh operating conditions in terms of particle rates and radiation dose, the ATLAS collaboration is developing a new tracker. In our presentation, we give an overview of the ATLAS tracker upgrade project, focusing on the silicon strip layers. We discuss technology choices for the sensors and present mechanical and electronic aspects of proposed module designs.

Session5 / 9

Experience with 3D integration techniques in the framework of the ATLAS pixel upgrade for high luminosity LHC

BARBERO, Marlon¹

¹ *Bonn University*

Corresponding Author: marlon.barbero@cern.ch

With the planned upgrades of the LHC for higher than present luminosity, the ATLAS pixel detector will be confronted to higher hit rate. R for the inner layers of the future ATLAS pixel detector has started in the direction of smaller feature size CMOS bulk processes, as well as in the direction of the new possibilities offered by 3D integration technologies. In this presentation, a report will be given on 2 different 3D integration techniques for the future pixel readout IC which were followed by the ATLAS pixel collaboration. The first one consists in the drilling of Through Silicon Via (TSV) in a via first approach, with the benefits associated to small aspect ratio and the insertion of the TSV at the pixel level, but also the technical issues of a technology still presenting challenges for the industrial partners. The second one consists in the drilling of the TSV via-last, with a potential for improved module concepts, despite the somewhat coarser technology and the associated reduction in via density. First results from both approaches are now available and will be discussed.

Session4 / 10

Front end electronics for European XFEL sensor: the AGIPD project

MARRAS, Alessandro ¹; TRUNK, Ulrich ²; KLYUEV, Alexander ³; GRAAFSMA, heinz¹ *Deutsches Elektronen-Synchrotron*² *Physikalisches Institut*³ *Moscow Engineering Physics Institute***Corresponding Author:** alessandro.marras@desy.de

The European X-ray Free-Electron Laser Facility will generate extremely brilliant, ultra-short pulses of X-rays, imposing challenging constraints to the detectors to be used in the experiments. It is expected to have a peak brilliance of 10^{33} ph/(s mm² mrad² 0.1%BW), 9 orders of magnitude more than 3rd generation synchrotron sources. The flux will be such that many pixels will have to cope with much more than one photon (up to 10^4) per pulse, while required to retain single (or better than poissonan statistics) photon sensitivity. This will also expose the system to a substantial amount of radiation, estimated for the readout ASIC to be of the order of tens of MGys. The time structure of the beam will consist in a sequence of tight bunches of Xray pulses (up to 2700 pulses in 0.6ms) separated by a period of 99.4 ms. Each pulse will be around about 100 fs long.

From the detector designer's point of view, this means that the front end has to cope with a high dynamic range, while having a noise low enough to discriminate single photons. Photon counting cannot be use (because of the high flux per pixel), and the sensor is required to provide a way to store the information from several (ideally, all) pulses on-board, to be read out in the interval between trains. At the same time, it also has to be substantially radiation-hard.

The AGIPD (Adaptive Gain Integrating Pixel Detector) is being developed as a way to cope with such challenges. It consists in a 1Mpixel hybrid pixel detector, featuring a pitch of 200 μ m; the readout will be performed by means of 16x16 ASICs, each composed of 64x64 pixels. The development is shared between DESY, PSI, the universities of Hamburg and Bonn.

The large dynamic range and single photon sensitivity issues was tackled with a dynamically adjustable charge amplifier integrated inside each pixel, ranging over 2 orders of magnitude, so that its gain is adjusted real-time to the number of absorbed photons. Tests prove the system to work correctly, both in terms of dynamic range and in terms of speed. Our target for the noise is to keep it at about 0.1 photons of 12.4 keV (300~400 e), so to allows for the requested single-photon sensitivity.

Correlated Double Sampling circuitry is included inside each pixel, as well as an embedded memory able to store up to 350 frames per pulse train. This is certainly less than the ideal case, since up to 2700 images are produced during a pulse train, but it comes as a compromise of keeping pixel dimensions reduced, and of course out of leakage minimization and radiation hard design issues. Radiation-hard design techniques have been employed, with the use of Enclosed Layout Transistors and guard rings around the critical devices.

Measurement performed on test prototypes confirm that in the operation range the leakage is low enough to keep the signal loss at less than 0.1% even for the last cells to be read.

As a partial solution of the limited memory depth problem, the memory has been designed to addressable RAM-like, allowing the overwriting of memory cells storing meaningless data by means of a veto schema.

A Command Serial interface has been included to address the pixels and their memory cells by means of 3 LVDS lines

An irradiation campaign has been performed on test prototype using a synchrotron source and exposing them to increasing doses, confirming a good behaviour for 1MGy-irradiated ASICs and the retention of functionality for 10MGy-irradiated ASICs. Several test prototypes have been produced on a reduced scale, mainly by means of MPW runs and I will present the results of extensive tests; we foresee the ASIC for the full detector to be ready for the end of the year.

Session3 / 11

EIGER characterization results

Dr. DINAPOLI, Roberto ¹; BERGAMASCHI, Anna ¹; RADICCI, Valeria ¹; SHI, Xintian ¹; THEIDEL, Gerd ¹; DOMINC, Greiffenberg ²; HENRICH, Beat ¹; HORISBERGER, Roland ³; JOHNSON, Ian ¹; MOZZANICA, aldo ¹; SCHMID, Elmar ¹; SCHMITT, Bernd ¹; SCHREIBER, Akos ¹

¹ Paul Scherrer Institut

² Paul Scherrer institut

³ Paul Scherrer Institut (CH)

Corresponding Author: roberto.dinapoli@psi.ch

EIGER is the next generation single photon counting x-ray detector developed at Paul Scherrer Institut for synchrotron based applications. It is a hybrid silicon pixel detector that features a 75x75 um² pixel size, a high maximum frame rate capability of ~22 kHz (independent on the detector size), double buffered storage for continuous readout and a negligible dead time between frames of ~3-4 us.

Characterization and performance measurements have been done on several single chip detector systems, produced with chips coming from two different lots, both with a lab x-ray source and at the Swiss Light Source. Results on the detector calibration, electronic noise, threshold dispersion, minimum selectable energy threshold, maximum detectable incoming photon flux and maximum frame rate will be presented. Furthermore, radiation endurance tests with doses up to ~150 Mrad in the sensor and ~60 Mrad in the chip will be shown. These tests prove that the chip is fully functional and suited for multi-chip modules and larger multi-module detectors.

An EIGER module is constructed from a ~4x8 cm² monolithic sensor bump-bonded to 4x2 readout chips, thus resulting in a 0.5 Mpixel detector. Several modules can be tiled together to form large area detectors and a 16 Mpixel system is already planned.

The first X-ray images and characterization results of a fully working module assembled with its complete readout electronics will be also presented.

Session8 / 12

Analysis of Edge and Surface TCTs for Irradiated 3D Silicon Strip Detectors

BATES, Richard ¹; KRAMBERGER, Gregor ²; MILOVANOVIC, Marko ³; PELLEGRINI, Giulio ⁴; Dr. FLETA CORRAL, Celeste ⁴; LOZANO FANTOBA, Manuel ⁴; BATES, Richard ⁵; STEWART, Graeme Douglas ⁶

¹ *Department of Physics and Astronomy-University of Glasgow*

² *Jozef Stefan Institute (SI)*

³ *Jozef Stefan Institute, Ljubljana*

⁴ *Universidad de Valencia (ES)*

⁵ *University of Glasgow (GB)*

⁶ *University of Glasgow*

Corresponding Author: gdstewart@physics.gla.ac.uk

We performed edge and surface TCT measurements of a double sided 3D silicon strip detector at the Jozef Stefan Institute. Double sided 3D devices are a useful counterpart to traditional planar devices for use in the very highest radiation environments. The TCT techniques allow the electric fields in 3D devices to be probed in a way not possible before.

Short 3D strip detectors, produced at CNM Barcelona, have been used for this study. The strip detectors had a substrate thickness of 280 micrometers and a strip pitch of 80 micrometers. The columns, that formed the electrodes, had a diameter of 10 micrometers, and were 250 micrometers deep. The junction electrodes were connected together to form the strips with 20 micrometer wide Aluminium metallisation. The Ohmic electrodes were all connected together on the backside of the device with a uniform contact. This is a similar technology as to that used for the ATLAS IBL 3D pixel sensor candidates. The detectors were tested both prior to irradiation and after irradiating to $5 \times 10^{15} \text{ N/cm}^2$. Studies were performed into the effect of varying bias voltage and also the effect of annealing on the irradiated sample. An IR laser (1064 nm) was used to scan the devices with a FWHM of 7 micrometers. Scans with a step of 2.5 micrometers were performed over the surface of the device in both x and y directions, illuminating either the front surface or the cut edge. The irradiation and edge polishing were completed at the Jozef Stefan Institute in Ljubljana.

The TCT experiment was undertaken in an atmosphere of dry air, with the irradiated samples held at a temperature of -20°C . Annealing was achieved insitue by warming to 60°C for intervals of 20, 40, 100, 300 and 600 minutes corresponding to room temperature annealing times of between 8 days and 200 days. 300 minutes is equivalent to the amount of annealing expected for 7 years of operation in an LHC experiment.

The current waveforms, as a function of illumination position and applied bias, were obtained for both pre and post irradiated devices and after annealing. This gives information on the origin of the induced signal, that is the portion from electron or hole motion. From the rise times of the signals, the velocity profile of the carriers in the devices and therefore electric fields can be determined. The collected charge was calculated from the integral of the waveforms. The results are compared to previous simulations.

The current waveforms are analysed to give results such as the collected charge as a function of illumination position for the front surface, the cut edge and the velocity profile.

There is a clear non-uniformity of the sensors prior to irradiation. While the lateral depletion between the columns is low, at approximately 4V, a uniform carrier velocity between the columns is not achieved until 5 times this value at 20V. Before irradiation, both the drift of electrons and holes provide equal contributions to the measured signals. After irradiation there is clear charge multiplication enhancement along the line between columns with a very non-uniform velocity profile in the unit cell of the device. The annealing of the detector further enhances this non-uniformity and charge multiplication effects.

Session5 / 13

3D integration of Geiger-mode avalanche photodiodes for future linear colliders

Ms. VILELLA-FIGUERAS, Eva¹; Dr. ALONSO, Oscar¹; Dr. CASANOVA, Raimon¹; Dr. DIÉGUEZ, Angel¹¹ *Department of Electronics - University of Barcelona***Corresponding Author:** evilella@el.ub.es

Geiger-mode avalanche photodiodes (GAPDs) offer excellent qualities to meet the challenging requirements of the next generation of particle colliders. High sensitivity, fast timing response, virtually infinite gain and compatibility with standard CMOS technologies are some of the properties that make these devices so attractive. In fact, owing to their extraordinary sensitivity and picosecond rise times, GAPDs enable single hit detection at each bunch crossing. In spite of all these advantages, GAPD detectors suffer from two main problems. First, they generate noise pulses that cannot be distinguished from radiation triggered events. As a consequence, the noise counts may lead to erroneous results and limit the range of detectable signals. Second, they present a low fill factor, which has a typical value around 40-50% and results in a low detection efficiency. Fortunately, the noise can be coped with advanced techniques, such as the gated operation or particle sampling at various layers. Nevertheless, it is difficult to increase the fill factor with standard technologies. In this contribution, the 3D vertical integration of a multilayer detector is proposed to overcome the fill factor limitation of standard GAPDs.

The reduced fill factor is basically due to two aspects related with the design of the pixel. On the one hand, to the readout electronics, which is monolithically integrated with the sensor to improve the dynamic response. The readout electronics usually consists of a simple inverter and a memory element. However, additional transistors are needed to perform the gated operation and also to control the outward data flow. In our case, the readout electronics is composed of a maximum of 10 transistors, which are still too many compared with a sensor area of 20 μm ×20 μm . On the other hand, in a conventional CMOS process the photodiodes are implemented by means of a p+/n-well junction and surrounded by a p-well with a lower doping profile to prevent premature edge breakdown. In particular, for those technologies below the 0.25 μm node where the shallow trench isolation (STI) is used to prevent the punchthrough and latch-up, it is necessary to increase this non-active ring to avoid a dramatic increase of the noise (up to 1MHz). As a result, the non-active area is quite large compared with the sensitive area.

This paper presents an analysis of the achievable fill factor by an array of GAPDs with the 130nm CMOS process by Tezzaron, which allows the vertical stacking of two tiers. Fill factors between 75% and 96% have been obtained considering different structures with and without interconnection between tiers. Moreover, different sensor areas have been used to maximize the overlap between the non-active area from one tier and the sensor area of the other one. A chip containing several arrays of GAPDs with different alternatives has been designed with the 130nm Tezzaron process.

Session3 / 14

A 200 Frames per Second, 1-Megapixel, Frame Store CCD camera for X-ray imaging

DOERING, Dionisio ¹; ANDRESEN, Nord ¹; Dr. CONTARATO, Devis ¹; Dr. DENES, Peter ¹; JOSEPH, John ¹; MCVITTIE, Patrick ¹; WALDER, Jean-Pierre ¹; WEIZEORICK, John ²

¹ LBNL

² ANL

Corresponding Author: ddoering@lbl.gov

At the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory (LBNL) several experiments are performed in the soft X-ray regime with energy ranging from a few hundred to a few thousand electron volts (eV). In such applications, back-illuminated, direct detection in silicon using conventional microelectronics silicon wafer thicknesses (up to 650µm), is close to 100% efficient for energies lower than 8 keV. At higher energies, detector thickness limits efficiency as silicon becomes increasingly transparent, and at lower energies, the thickness of the inert (contact) layer sets a low energy cutoff. This paper describes the performance of a 1MPixel Frame Store CCD camera for soft X-ray applications at synchrotron light sources. The camera can be operated in frame store mode with a 1Mpixel imaging area running at 200 frames per second (fps), or in full frame mode with a 2Mpixel imaging area running at 100fps. The CCD outputs are serviced by custom-designed integrated circuits for gain selection and enhancement, correlated double-sampling signal processing and digitization. The digitized data is acquired by a custom made image acquisition and camera controller board based on the Advanced Telecommunication Computing Architecture (ATCA) and later sent to off-line processing or data storage. With the exception of the image acquisition and controller board, the rest of the system is built using commercial off the shelf components. The presentation will describe the various components of the camera head, readout system and the cooling system for in-vacuum operation. The performance of the system (gain, linearity, noise, data throughput and others) has been characterized at a dedicated detector development beamline at the ALS using fluorescence X-rays from thin metal foils. We will discuss the image processing algorithm used to extract these parameters and its impact on energy resolution performance. The preliminary results show an energy resolution of 150eVrms at 8keV, with a noise of 90eVrms equivalent to 25e-

Session4 / 15

Development of Monolithic Active Pixel Sensors in 65 nm CMOS Technology

Dr. CONTARATO, Devis ¹; DENES, Peter ¹; DOERING, Dionisio ¹; JOSEPH, John ¹; KRIEGER, Brad ¹; SCHINDLER, Simon ¹

¹ Lawrence Berkeley National Laboratory

Corresponding Author: dcontarato@lbl.gov

This work presents the design and characterization of a CMOS monolithic active pixel sensor manufactured in a commercial 65 nm process. The sensor is our first prototype in this technology for next generation, ultra-high resolution and radiation-hard direct detectors for electron and X-ray imaging, and follows previous developments in 0.35 µm and 0.18 µm CMOS processes. The chip features square pixels of 2.5 µm pitch arrayed on a 400x400 pixel matrix, and subdivided in four sections implementing different pixel designs, all based on the same 3-transistor (3T) architecture but varying in diode and transistor layout. The sensor has been extensively characterized in the laboratory in order to determine its charge-to-voltage conversion gain, noise and leakage current performance. Electron detection tests have been performed on an FEI TITAN electron microscope at the LBNL National Center for Electron Microscopy (NCEM), including irradiation with 300 keV electrons to doses up to 200 Mrad. The presentation will review the results from this characterization and discuss their interpretation as a function of the various pixel design features. The impact of effects such as gate leakage, encountered in this technology but not observed in previous sensors manufactured in coarser feature size processes, will also be discussed.

Session6 / 16

PImMS1 and PImMS2, monolithic CMOS event-triggered time-stamping image sensors with storage of multiple timestamps at 25ns resolution

JOHN, Jaya John¹; TURCHETTA, renato²; Mr. SEDGWICK, Iain³; Prof. BROUARD, Mark¹; Prof. NOMEROTSKI, Andrei¹; Dr. VALLANCE, Claire¹

¹ *University of Oxford*

² *ral-stfc*

³ *STFC-RAL*

Corresponding Author: j.john1@physics.ox.ac.uk

PImMS, or Pixel Imaging Mass Spectrometry, is a family of high-speed monolithic CMOS imaging sensors tailored to the requirements of mass spectrometry and allied fields. PImMS pixels each compare step events of collected charge to an adjustable threshold, storing up to four significant events inside the pixel as 12-bit timestamps with a time resolution of 25ns. The pixels may be individually trimmed to improve the uniformity of response. The pixels are relatively complex, each containing over 600 transistors and measuring 70 μ m by 70 μ m. The first generation of these sensors, PImMS1, has an array of 72 by 72 pixels, while PImMS2 provides a larger sensor area with 324 by 324 pixels and several new features. We will present an overview of the pixel and sensor architecture, as well as presenting recent characterisation and application results for PImMS1 and first characterisation results for PImMS2.

Poster session / 17

Towards Using a Monolithic Active Pixel Sensor for In-Vivo Beam Monitoring of Intensity Modulated Radiotherapy

Dr. PAGE, Ryan ¹

¹ *University of Bristol*

Corresponding Author: ryan.page@bristol.ac.uk

R. Page, for the BEAMView collaboration

Abstract

1 Introduction

The use of Intensity Modulated Radiotherapy (IMRT) for cancer treatments is entering wider use. These treatments involve using a complex configuration of field modifying components, known as Multileaf Collimators (MLC), to dynamically shape the beam. A treatment consists of a sequence of irregular shaped fields, which means real time monitoring and verification would be highly beneficial. In the current framework the treatment plans are verified before the patient is treated, but not during. The aim of our collaboration is to monitor the treatment being given to the patient. This is achieved by placing a camera system upstream of the patient. To monitor the beam during the treatment without attenuating the beam requires such a detector to be as thin as possible. To be able to provide information about the progress of the treatment the data acquisition from the sensor must also be fast. This will allow any errors in field shape to be detected at the time of the treatment. The system is also sensitive to the beam intensity and this can be used to ensure the correct dose is being delivered. The research that is funded by the National Institute for Health Research (NIHR) Invention for Innovation (i4i) programme and presented here shows some of BEAMView's progress into achieving these goals.

¹This abstract presents independent research commissioned by the National Institute for Health Research (NIHR) under the Invention for Innovation (i4i) programme. The views expressed in this abstract are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health

2 Beam Monitoring Camera Prototype

The camera system consists of a large area (6 x 6 cm²) Monolithic Active Pixel Sensor (MAPS) and a readout system [3]. The sensor has a total thickness of ~ 100 μm and contains 4096 x 4096 pixels, with a pitch of 14 μm. A sensor at this thickness attenuates the beam by ~ 0.1% and when the light shield is included this rises ~ 0.16%, based on 2 MeV photons [1]. The sensor was operated at 10 frames per second when collecting data. During the experiments the system was attached to the linac head via an accessory holder. In this configuration the sensor was 56.4 cm from the source.

3 MLC Leaf Position Reconstruction Methodology

In a raw image from the beam camera the edge of a MLC leaf is characterised by a rapid change in signal intensity. An algorithm was developed that exploits this to locate the edge position of the MLC leaves. The approach taken is to locate the edge positions of the MLCs using an image generated using the Sobel operators [2]. Prior to using the Sobel operators, a 2D gaussian smoothing filter is used to remove small pixel to pixel signal variations. The resulting image after both filters are applied shows the edges of collimators defining the beam aperture.

This was carried out for a field size of 5 x 5 cm² with two MLC leaves, A and B protruding into the field. The frame was acquired when the linac was operating at 400 Monitor Units/Min with a pulse repetition frequency of 400 Hz. In this context a single frame was the integral of ~ 40 pulses.

This image can then be used to reconstruct the location of each of the MLC leaves, A and B. This is carried out in three steps. The first step makes a 1 pixel projection of the image onto the x-axis and locates the maximum point. A Gaussian probability distribution is then fitted around the maximum. The mean of this distribution is used to construct a contour of the MLC leaf. The edge position of the MLC leaf is modelled as a straight line.

This model is then fitted to a region of ~ 30 pixels along the contour. The value determined from this fit is defined as the MLC leaf edge. A test was then carried out where the MLC leaf position was reconstructed for 100 individual frames to determine the resolution. The mean value of this distribution, which defines the leaf edge, has an uncertainty of 0.06 ($\sim 6 \mu\text{m}$) pixels and a width of 0.5 ($\sim 50 \mu\text{m}$) pixels, where the values in the parenthesis correspond to the value at 100 cm from the source (defined as the isocentre). The width of this distribution corresponds to the single frame resolution, which is improved upon with 10 seconds worth of data to $6 \mu\text{m}$.

To study the performance of the edge reconstruction described in 3 a test was carried out using Gafchromic film. This method is standard in radiotherapy and has a precision of $\sim 0.5 \text{ mm}$. The film was placed on the patient couch under build up and exposed to 300 Monitor Units. The edge position was then reconstructed using the film, with the edge positioned defined as 50% of the maximum dose. This was carried out for different MLC leaf configurations. In the first configuration both MLC leaves are side by side. Then MLC leaf A was moved away from MLC leaf B. The result of this experiment showed a linear relationship between the two sets of measurements. The result of a linear fit to the data gave a value of 0.1 ± 0.5 for the intercept and 1.00 ± 0.05 for the gradient. This agreement shows that within the resolution of the film the reconstructed MLC leaf positions are consistent.

4 Current Status and Outlook

The results presented here show that this system in nominal operation using a thin MAPS sensor can determine a MLC leaf position to within $6 \mu\text{m}$ for 10 seconds worth of data and $50 \mu\text{m}$ for a single frame. The resulting reconstructed MLC leaf positions agree with the photon field edge determined using film to the limit of the film accuracy. Work is continuing to test and validate dose models. This combined with high resolution MLC leaf positioning will allow the system to be used as an online monitoring system.

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Session7 / 18

Results from the Pilot Run of the Pixel Luminosity Telescopes, a Luminosity Monitor for CMS Based on Single-Crystal Diamond Pixel Sensors

SCHNETZER, Stephen Richard ¹

¹ *Rutgers, State Univ. of New Jersey (US)*

Corresponding Author: stephen.schnetzer@cern.ch

The Pixel Luminosity Telescopes (PLT) is a dedicated luminosity monitor for CMS based on single-crystal diamond sensors. It is designed to measure the bunch-by-bunch relative luminosity to high precision. It consists of a set of small angle telescopes each with three planes of single-crystal diamond pixel sensors. The full PLT will be installed in CMS for the first full energy operation of the LHC in 2014. Currently, one quarter of the PLT is installed in a forward region of CMS where it has been operating since the beginning of this year's run. This is the first operation of a diamond pixel tracking detector in a high energy physics experiment and is providing the first data on diamond pixel sensors under high particle rate in a high radiation environment. We will report on the results obtained during this pilot run including the dependence of the pulse height and the efficiency on particle rates up to several tens of MHz and the long term time dependence of the detector performance under the high radiation exposure. These studies provide a unique characterization and an essential understanding of diamond detectors important both for the operation of the PLT and for the possible use of diamond sensors in the pixel detector upgrades for high luminosity running of the LHC.

Session6 / 19

Monolithic Pixel on High Resistance Substrate and Sparsifying Redaout Architecture

GIUBILATO, Piero ¹; BISELLO, Dario ¹; MARCHIORO, Alessandro ²; SNOEYS, Walter ²; RIVETTI, Angelo ¹; MATTIAZZO, Serena ¹; POTENZA, Alberto ¹; PANTANO, Devis ³

¹ *Universita e INFN (IT)*

² *CERN*

³ *Padova*

Corresponding Author: piero.giubilato@cern.ch

We start by presenting the latest results on the LePix sensor, an innovative Monolithic Active Pixel Sensor (MAPS) aimed at tracking/triggering tasks where high granularity, low power consumption, low material budget, radiation hardness, and production costs are a concern. The detector is built in a 90nm CMOS process on a substrate of moderate resistivity. This allows charge collection by drift while maintaining the other advantages usually offered by MAPS, like having a single piece detector and using a standard CMOS production line.

The collection by drift mechanism, coupled to the low capacitance design of the collecting node made possible by the monolithic approach, provides an excellent signal to noise ratio straight at the pixel cell together with a radiation tolerance far superior to conventional un-depleted MAPS. We will illustrate the detector design and present measurement results obtained with first prototypes from radioactive sources, laser probing and beam test experiments. The excellent signal-to-noise performance is demonstrated by the device ability to separate the 6 keV 55Fe double peak at room temperature.

Ensuing the excellent pixel cell performances (sensitivity, size, power consumption) and considering that stitching is commercially available for such process, we will then introduce novel architectural approaches departing from the two nowadays most widely adopted solutions in pixel detectors (“rolling shutter” for the monolithic and the “intelligent pixel” for the hybrids). The potential of having single-piece, large area, high granularity and low power pixel detectors puts a premium on architectures exploiting that at most, especially from a power-consumption (and hence material budget) point of view. While illustrating the proposed architectures, a complete review of both detector behaviors and physics goals, together with quantitative references and simulations of real-word experimental scenarios, will highlight the advantages of the proposed solution for many applications in both the High Energy Physics and applied sciences field.

Poster session / 20

High Resolution X-ray Imaging Sensor with SOI Technology

Mr. TAKEDA, Ayaki ¹; Prof. ARAI, Yasuo ²; Dr. MIYOSHI, Toshinobu ²; Mr. OKIHARA, Masao ³; Mr. KASAI, Hiroki ⁴; Mr. MIURA, Noriyuki ⁴; Mr. KURIYAMA, Naoya ⁴; Mr. NAGATOMO, Yoshiki ³

¹ Graduate University for Advanced Studies (SOKENDAI)

² High Energy Accelerator Research Organization (KEK)

³ Lapis Semiconductor Co., Ltd.

⁴ Lapis Semiconductor Miyagi Co., Ltd.

Corresponding Author: atakeda@post.kek.jp

A monolithic pixel detector with a 0.2 μm fully-depleted Silicon-On-Insulator (SOI) technology, called SOIPIX, has been developed. These are utilizing thick handle wafer of SOI structure as a radiation sensor to detect charged particles and X-ray.

One of the detectors, called INTPIX4, is 10.3 x 15.5 mm in size having 512 x 832 (~426 k) pixels each 17 μm square. It has integration type pixels and implements a correlated double sampling (CDS) circuit in each pixel to suppress the reset noise. As a result of the experiments, we succeeded in the acquisition of a high resolution image with X-ray by back-illuminated. The chart pattern of 20 line pairs / mm (25 μm) was clearly obtained in exposure time of several msec at room temperature. Furthermore, we performed the cooling test. More detailed results including gain and energy resolution will be presented.

Poster session / 21

A Fast Hardware Tracker for the ATLAS Trigger System

KIMURA, Naoki ¹; ATLAS COLLABORATION, TDAQ Speakers Committee ²

¹ Waseda University (JP)

² CERN

Corresponding Author: enrico.pasqualucci@cern.ch

Selecting interesting events with triggering is very challenging at the LHC due to the busy hadronic environment. Starting in 2014 the LHC will run with an energy of 14 TeV and instantaneous luminosities which could exceed 10^{34} interactions per cm^2 and per second. The triggering in the ATLAS detector is realized using a three level trigger approach, in which the first level (L1) is hardware based and the second (L2) and third (EF) stag are realized using large computing farms.

It is a crucial and non-trivial task for triggering to maintain a high efficiency for events of interest while suppressing effectively the very high rates of inclusive QCD process, which constitute mainly background. At the same time the trigger system has to be robust and provide sufficient operational margins to adapt to changes in the running environment. In the current design track reconstruction can be performed only in limited regions of interest at L2 and the CPU requirements may limit this even further at the highest instantaneous luminosities.

Providing high quality track reconstruction over the entire detector volume for the L2 trigger decision would allow gains in efficiency and background rejection for triggers on tau leptons, b-hadrons and help reduce the luminosity dependence of isolation requirements for electrons and muons. The Fast Track Trigger (FTK) is an ongoing upgrade project aimed at providing track reconstruction over the $|\eta| < 2.5$ region using the silicon microstrip and pixel detectors. Pattern recognition and track fitting are executed in a hardware system utilizing massive parallel processing and achieve a tracking performance close to that of the global track reconstruction. The FTK system's design, based on a mixture of advanced technologies (FPGAs, ASICs, Associative Memories) and expected physics performance will be presented.

Session6 / 22

High-Voltage Pixel Detectors in Commercial CMOS Technologies for ATLAS, CLIC and Mu3e Experiments

Dr. PERIC, Ivan ¹

¹ *Ruprecht-Karls-Universitaet Heidelberg (DE)*

Corresponding Author: ivan.peric@ti.uni-mannheim.de

High voltage particle detectors in commercial CMOS technologies are detector family that allows implementation of low-cost, thin and radiation-tolerant detectors with good time resolution. The unique property of these detectors is that the pixel electronic is embedded inside sensor diodes. For this reason, we refer to the detector type as the "smart diode" array - SDA. In the R/D phase of the development, we have demonstrated a radiation tolerance of 10^{15} n_eq/cm², nearly 100% detection efficiency and a spatial resolution of about 3 micrometers.

Since 2011 SDAs have first applications: The technology is presently the main option for the pixel detector of the planned Mu3e experiment at PSI (Switzerland). Two 50-micrometer thin detector layers with 200 million pixels are planned. A prototype sensor with small pixel matrix has been designed in the standard AMS 180nm HV CMOS process and successfully tested. First tests with the thinned sensors will be performed soon.

Thanks to its high radiation tolerance, the SDA technology is also seen at CERN as a promising alternative to the standard options for ATLAS upgrade and CLIC.

In order to test the concept, within ATLAS upgrade R, we are currently exploring an active pixel detector demonstrator HV2FEI4; also implemented in the AMS 180nm HV process. This detector has a pixel pitch of 33 um x 125 um. A group of three detector pixels is coupled to one FE-I4 pixel readout channel. The contacts between the detector- and readout chip can be established either capacitively or by bump-bonding. The first measurements with the capacitively coupled pixel detectors will be performed in May and a test beam measurement is planned for June 2012.

We will present the current status of the projects and the experimental results.

Poster session / 23

Monolithic crystals with SiPMs read-out: optical coupling optimization

Dr. GONZALEZ MARTINEZ, Antonio Javier ¹; Mr. CONDE CASTELLANOS, Pablo ¹; Mr. HERNANDEZ HERNANDEZ, Liczandro ¹; Ms. MOLINER MARTINEZ, Laura ¹; Mr. ORERO PALOMARES, Abel ¹; Dr. RODRIGUEZ ALVAREZ, Maria José ¹; Dr. SÁNCHEZ MARTÍNEZ, Filomeno ¹; Mr. VIDAL SAN SEBASTIAN, Luis Fernando ¹; Dr. BENLLOCH BAVIERA, Jose Maria ²

¹ *Institute of Instrumentation for Molecular Imaging*

² *Institute of Instrumentation for Molecular Imaging*

Corresponding Author: agonzalez@i3m.upv.es

In this work we present a method to efficiently collect scintillation light at the time to reduce photosensor active area. We have applied this procedure on gamma detectors for PET devices based on continuous crystals and SiPM detectors.

The use of continuous scintillation crystals preserves the spatial distribution of scintillation light for each γ -ray event, which can be reconstructed with a small number of statistical moments, reducing the number of analogue-to-digital conversion channels. However, in contrast to pixelated crystals, they account for moderate edge effects which specially depend on the crystal thickness. Several configurations for crystal surface treatment have been studied aiming at preserving the original scintillation light distribution. The initial tests suggested, in order to optimize the light collection, a reduction of the acceptance angle of the scintillation photons in order to keep a compromise between small edge effects and statistically good light transmission. Optical devices positioned between the scintillation crystal and the photosensor, like the so-called faceplates or some light guides, make possible to reduce the acceptance angle of the incoming light.

Since it is part of this research also to design a detection block compatible with magnetic fields, we have chosen SiPM which are suitable to work under the fields of for instance magnetic resonances. However, due to their main components, they present a number of dark counts that squarely increase with their active area size and could degrade the impinging photon position determination when using multiplexing read-out approaches. Therefore, we have designed an array of SiPMs with 1 mm² detection area. In order to satisfy both requirements small acceptance angle and reduce individual detection area, we have proposed to use light guides to efficiently transfer the scintillation light to each SiPM.

The optical design of a light guide has been optimized using the ZEMAX simulation program that is based on light propagation within the crystal and guides. An optimal configuration that represents a balance between light detection efficiency and cross talk between channels was found. This configuration has already been implemented by developing a special cast for an array of 8 light guides using PMMA as material. A final matrix of 256 light guides is foreseen to be built by gluing 32 of those arrays with the help of a plastic grid, ensuring a very low cross-talk (12 dB) and good transmission of nearing 70%.

In this work we will present the first results of monolithic LYSO crystals coupled to an array of 64 and 256 SiPMs. We have tested different LYSO thicknesses, and we have found that our design allows using crystals blocks with a thickness of more than 18 mm without degrading the spatial resolution caused by edge effects.

Session4 / 24

High-Resolution Monolithic Pixel Detectors in SOI Technology

Dr. MIYOSHI, Toshinobu¹; Prof. ARAI, Yasuo²; Mr. AHMED, Mohammed Imran³; Dr. KAPUSTA, Piotr⁴; Dr. ICHIMIYA, Ryo⁵; Ms. IKEMOTO, Yukiko⁵; Mr. FUJITA, Yowichi⁶; Mr. TAUCHI, Kazuya⁵; TAKEDA, Ayaki⁷

¹ KEK

² High Energy Accelerator Research Organization (J-P)

³ AGH University of Science and Technology

⁴ Institute of Nuclear Physics Polish Academy of Sciences

⁵ High Energy Accelerator Research Organization

⁶ High Energy Accelerator Research Organization

⁷ SOKENDAI

Corresponding Author: tmiyoshi@post.kek.jp

We are developing monolithic pixel detectors in 0.2 um Fully-Deleted SOI technology. In a SOI wafer, the photodiode is formed on the handling substrate after removing the silicon oxide. The SOI-CMOS circuits are fabricated on the 40-nm SOI thin film. Since the bump-bonding process is not required, a high-gain pixel sensor with smaller pixel size less than 20 um is achievable. In general SOI-CMOS circuits have less parasitic capacitance and thus higher speed readout system compared with bulk-CMOS ones can be composed. Such detectors can be applied to a wide range of applications, not only in particle physics but also in medicine, space science and many other disciplines. We have recently developed several versions of integration-type pixel detectors with 8-17 um pixel sizes. The detectors were irradiated with visible laser, infrared laser, X-ray and ionizing radiation sources. In this talk, the recent progress of the detector development, the performance of the detectors, test results in imaging applications are presented.

Poster session / 25

Development of Silicon-On-Insulator PHoton Imaging Array Sensor (SOPHIAS) for X-ray Free-Electron Laser

Mr. OMODANI, Motohiko¹; Dr. KUDO, Togo²; Dr. KIRIHARA, Yoichi²; Mr. OKIHARA, Masao³; Mr. NAGASAKI, Motoyuki⁴; Mr. MORITA, Kazuharu⁵; Mr. NAGAI, Yosuke⁵; Dr. HATSUI, Takaki²; Mr. KOBAYASHI, Kazuo²; Mr. IMAMURA, Toshifumi⁶; Mr. OHMOTO, Takafumi⁶; Dr. IWATA, Atsushi⁶; Mr. ONO, Shun²

¹ *Japan Synchrotron Radiation Research Institute*

² *RIKEN*

³ *LAPIS Semiconductor Co., Ltd.*

⁴ *ARKUS Inc.*

⁵ *TOKYO ELECTRON DEVICE LIMITED*

⁶ *A-R-Tec Corp.*

Corresponding Author: omodani@spring8.or.jp

SPring-8 Angstrom Compact free-electron LAsER (SACLA), which is the second X-ray free-electron laser (XFEL) facility after LCLS at SLAC National Accelerator Laboratory achieved laser amplification on June 7th, 2011. In the first user run of SACLA starting in March 2012, 25 proposals from domestic/international institutions will be conducted, where more than half of the proposals will use the currently deployed Multiport CCD (MPCCD) detectors. In this talk, we present the development status of the novel X-ray 2D detector, SOPHIAS, for SACLA to cover the scientific cases, where the currently deployed MPCCD detector does not able to reach.

The pixel structure of SOPHIAS is based on multi-via concept; the closely spaced implant regions within a single pixel is used for signal charge division. Each implant region is connected to the readout circuitry by metal via. By connecting non-equal number of via metal, unproportional charge collection will be possible. Large portion of the signal is transferred to high gain amplifier sensitive to small signal regime, whereas small portion of the charge is transferred to low gain amplifier. This pixel with size of 30 μm square is realized by using silicon-on-insulator (SOI) sensor technology developed with KEK and Lapis Semiconductor Ltd. Last year, we have introduced stitching and backside processing onto KEK multi-project wafer run process. We have succeeded in manufacturing with an area of 66 mm x 30 mm by stitching 5 shots of reticule size. The production is carried out by 0.2 μm FD-SOI CMOS technology. Handle wafer, which is the photodiode for x-ray detection, has backside implanted, laser-annealed, and aluminum coated surface so to shield the optical light without sacrificing the quantum efficiency. The handle wafer is made of floating zone silicon which enables us to fully deplete 500 μm thick handle wafer. The characterization as well as the development of readout system of the sensor is now under progress.

Poster session / 26

Development of the Optical Blocking Layer for the X-ray CCD

KOHMURA, Takayoshi¹; Mr. IKEDA, Shoma¹; Prof. TSURU, Takeshi²; Dr. UCHIDA, Hiroyuki²; Prof. KITAMOTO, Shunji³; Dr. MURAKAMI, Hiroshi³; Prof. DOTANI, Tadayasu⁴; Dr. OZAKI, Masanobu⁴; Mr. KANEKO, Kenta¹; Mr. KAWAI, Kohei¹; Prof. TSUNEMI, Hiroshi⁵; Dr. HAYASHIDA, Kiyoshi⁵; Dr. ANABUKI, Naohisa⁵; Dr. NAKAJIMA, Hiroshi⁵; Mr. UEDA, Shutaro⁶; Dr. KAN, Hiroaki⁵

¹ *Kogakuin University*

² *Kyoto University*

³ *Rikkyo University*

⁴ *ISAS/JAXA*

⁵ *Osaka University*

⁶ *ueda@ess.sci.osaka-u.ac.jp*

Corresponding Author: tkohmura@map.kogakuin.ac.jp

Since an X-ray CCD, especially a Back-Illuminated-CCD (BI-CCD), has a high detection efficiency for UV light and visible light as well as soft X-ray, it is necessary for the X-ray CCD on board X-ray satellite to block visible light and UV light that become background.

The X-ray CCD cameras on board previous X-ray satellites, Suzaku, Chandra and so on, are equipped with the Optical Blocking Filter (OBF) that consists of polyimide and Aluminum to block the UV light and visible light. Therefore the OBF is a thin filter with about 250nm thick, the OBF has a risk in tearing due to the vibration during the launch.

Instead of the OBF, we have newly developed the Optical Blocking Layer (OBL) ,which is consisted with 110nm thick Aluminum and 140nm thick Polyimide, is coated directly to the surface of the BI-CCD in order to avoid the risk of corruption.

We have carried out a performance evaluation test, such as the measurement of the X-ray quantum efficiency and energy resolution, the UV, optical and X-ray transmission measurement of OBL, and so on. In the measurement of UV and X-ray transmission of OBL, we carried out our experiment at the KEK photon factory and measured the X-ray transmission of OBL between 0.2-2.0keV that covers the absorption edges around C-K, O-K, Al-K, and Si-K.

In this paper, we will show our results on the UV and Optical transmission of OBL.

We will also show the results on the measurement of the X-ray quantum efficiency of BI-CCD with OBL below 2keV.

Poster session / 27

GOTTHARD: a charge integrating silicon strip detector for XFEL and Synchrotron applications

MOZZANICA, aldo ¹; BERGAMASCHI, Anna ²; SCHMITT, Bernd ²; SHI, Xintian ²; Dr. DINAPOLI, Roberto ²; GREIFFENBERG, Dominic ²; HENRICH, Beat ¹; JOHNSON, Ian ²; MALLAKAL, Dhanya ²; RADICCI, Valeria ²; RUDER, Christian ²

¹ *PSI*

² *Paul Scherrer Institut*

Corresponding Author: aldo.mozzanica@psi.ch

The SLS Detector group at PSI has developed GOTTHARD, a charge integrating silicon strip detector which, thanks to the automatic

gain switching feature, can provide at the same time single photon resolution and a dynamic range as big as 10000 12-keV photons, with a noise well below the photon statistics limit over the full range.

The detector module is made of ten readout ASIC (Application Specific Integrated Circuit) wire bonded to a silicon sensor with a 64mmx8mm sensitive area for a total of 1280 channels at 50 um pitch. A complete readout chain, from the high speed digital converters to the Gigabit link for the data download, is also integrated on the board. Burst frame rates up to 1MHz (60kHz in continuous streaming) can be achieved.

The detector design will be presented together with the results from the commissioning phase. Operation of the device at both XFELs and Synchrotron sources will be discussed.

Session2 / 28

Upgrade of the ALICE Inner Tracking System

Dr. ROSSEGGER, Stefan ¹

¹ CERN

Corresponding Author: stefan.rossegger@cern.ch

The Inner Tracking System (ITS) is the ALICE key detector for the study of heavy flavour production at LHC. This is attained by the identification of short-lived hadrons containing heavy quarks which have a mean proper decay length in the order of 100-300 μm . To accomplish this task the ITS is composed of six cylindrical layers of silicon detectors (two pixel, two drift and two strip) with a radial coverage from 3.9 to 43 cm and a material budget of 1.1 % X_0 per layer.

In order to enhance the ALICE physics capabilities and in particular the tracking performance for heavy-flavour detection the possibility of an ITS upgrade has been studied in great detail. It will make use of the spectacular progress made in the field of imaging sensors over the last ten years as well as the possibility to install a smaller radius beampipe. The upgraded detector will have greatly improved features in terms of: the impact parameter resolution, standalone tracking efficiency at low p_t , momentum resolution and readout capabilities.

The usage of the most recent monolithic and/or hybrid pixel detector technologies allow the improvement of the detector material budget and the intrinsic spatial resolution both by a factor of three with respect to the present ITS. The installation of a smaller beam-pipe will allow reducing the distance between the first detector layer and the interaction vertex. Under these assumptions, simulations show that an overall improvement of the impact parameter resolution by a factor of three is possible.

After finalizing the Conceptual Design Report [1], which covers the design and performance requirements, the upgrade options as well as the necessary R efforts, the project has now entered the approval phase. An intensive R program has been launched with the objective to review the different technological options under consideration. The new detector should be ready to be installed during the long LHC shutdown period scheduled in 2017-2018.

This contribution will present the studies on the upgrade of the ALICE ITS detector. In particular, the different options for the detector technologies and the detector layout, as well as the first results of the R activities, will be presented.

[1] Conceptual Design Report for the Upgrade of the ALICE ITS, CERN-LHCC-2012-05, April 2012

Session7 / 30

Recent Results of the ATLAS Upgrade Planar Pixel Sensors R Project*

WEIGELL, Philipp¹

¹ *Max-Planck-Institut fuer Physik (Werner-Heisenberg-Institut) (D)*

Corresponding Author: pweigell@mpp.mpg.de

To extend the physics reach of the LHC experiments, several upgrades to the accelerator complex are planned. This upgrade, the HL-LHC, eventually leads to an increase of the peak luminosity by a factor of five to ten compared to the LHC design value.

To cope with the higher occupancy and radiation damage also the LHC experiments will be upgraded. The ATLAS Planar Pixel Sensor (PPS) R Project is an international collaboration of 17 institutions and more than 80 scientists, exploring the feasibility of employing planar pixel sensors for the upgraded tracker at HL-LHC.

Depending on the radius different pixel concepts are investigated using laboratory and beam test measurements. At small radii the extreme radiation environment and strong space constraints are addressed with very thin pixel sensors (active thickness in the range of 75-150 μm), and the development of slim as well as active edges. At larger radii the main challenge is the needed cost reduction to allow for instrumenting the large area of order 10 m^2 . To reach this goal the pixel productions will be transferred to 6 inch production lines. Additionally, more cost-efficient and industrialized interconnection techniques as well as the n-in-p technology, which as a single-sided process requires less production steps, are investigated.

An overview of the recent accomplishments obtained within the PPS R project will be given. The performance in terms of charge collection and tracking efficiency, obtained with radioactive sources in the laboratory and at beam tests, will be presented for devices built from sensors of different vendors connected to either the present ATLAS read-out chip FE-I3 or the new IBL read-out chip FE-I4. The devices, with a thickness varying between 75 μm and 300

μm , have been irradiated to several fluences up to $20 \times 10^{15} \text{ neq/cm}^2$. Finally, the different approaches followed inside the collaboration to achieve slim or active edges for planar pixel sensors will be presented.

Session4 / 31

A thin fully-depleted monolithic pixel sensor in Silicon On Insulator technology

CONTARATO, Devis¹; DENES, Peter¹; GIUBILATO, Piero²; PANTANO, Devis³; MATTIAZZO, Serena⁴; BATTAGLIA, Marco⁵; BISELLO, Dario⁴

¹ *Lawrence Berkeley National Laboratory*

² *Università di Padova (IT)*

³ *Università e INFN Padova*

⁴ *Università e INFN Padova (IT)*

⁵ *University of California, Santa Cruz (US)*

Corresponding Author: serena.mattiazzo@cern.ch

The Silicon On Insulator (SOI) technology allows the integration of CMOS electronics on a thin silicon layer which is electrically insulated from the wafer substrate by means of a thin buried-oxide layer (BOX). Monolithic pixel sensors can be built in SOI technology by contacting a high-resistivity handle wafer substrate through the BOX. A commercial deep-submicron SOI CMOS process by LAPIS, coupled with high-resistivity silicon substrates, is made available through KEK. A full CMOS circuitry can be integrated in a 40nm thick layer on top of each pixel, and the 250um thick substrate can be reverse biased and depleted to improve charge collection. In the framework of an international collaboration between the Lawrence Berkeley National Laboratory (LBNL), INFN and UC Santa Cruz, since 2006 we have designed, produced and characterized different prototypes of monolithic pixel detectors in SOI technology, both for charged particle detection and for imaging applications. SOI monolithic pixel detectors can provide high resolution vertex tracking with a limited material budget (if compared to hybrid pixels) for future experiments in which the radiation levels are moderate (SuperKEKB, SuperB b-factories).

In this contribution we will review the latest chip produced, a matrix of 256×256 analog pixels in a 0.20um SOI technology, arrayed in 8 different sectors, thinned to 50um and back-processed to allow full depletion. The chip has been successfully tested with soft X-ray photons in back-illumination at the Advanced Light Source (ALS) of LBNL and with 300GeV pion- at the CERN SPS. These results show that a thin fully-depleted SOI pixel provides charged particle detection capability with large signal-to-noise ratio and detection efficiency and achieves a single point resolution of the order of 1um.

The design of a new, larger chip has been submitted at the end of 2011 and will be tested with high momentum particles at a beam test at CERN scheduled for July 2012. Results of this work will be shown as well.

Poster session / 32

Development of Data-Acquisition Front Ends enabling High-bandwidth Data Handling for X-ray 2D Detectors: A Feasibility Study

SAJI, Choji¹; OHATA, Toru¹; HATSUI, Takaki²; KUDO, Togo¹; SUGIMOTO, Takashi¹; TANAKA, Ryotaro¹; YAMAGA, Mitsuhiro¹¹ JASRI/SPring-8² RIKEN**Corresponding Author:** saji@spring8.or.jp

X-ray 2D detectors are indispensable for synchrotron radiation and X-ray free-electron laser experiments such as coherent x-ray imaging, spectroscopies, time-resolved experiments etc. In these experiments, spatial, temporal, or photon energy information are projected onto X-ray 2D detector surface. It is generally accepted that larger pixel number and higher dynamic range will provide clearer information on the sample. These demand high-bandwidth front ends (FEs) for data acquisition (DAQ) system. In the case of SOPHIAS sensor under development at SACLA (SPring-8 Angstrom Compact free electron LASer), each sensor in the final form will have 2 M pixels running at up to 300 Hz, and produces data at upto 20 Gbps. In order to realize the front ends for SOPHIAS as well as other high-bandwidth detectors, a feasibility study has been carried out by using an evaluation board. The board has FPGA with FMC (FPGA mezzanine card) interface in order to support various physical layers of sensor readout modules and DAQ back ends (BEs). In this study, the bandwidth from FPGA to BEs were evaluated for XAUI with SFP+ (Small Form-factor Pluggable plus) physical layer. One of the advantages of XAUI is that it interfaces MAC (Media Access Control) to PHY layer of 10 Gigabit Ethernet (GbE) enabling distributed DAQ system with 10 GbE network. In many photon science applications, scalability from single to many modules is of importance. As a candidate for FEs for small detector system, a compact desktop-type DAQ system based on PCI express bus was evaluated. A FE board with PCI express will be connected to PC, and the data will be transferred to PC storage directly. Measurements of the bandwidth by using the evaluation board indicated successful effective bandwidth of 9 Gbps and 16 Gbps though SFP+ with XAUI and PCI express, respectively. Details of the evaluation scheme will be discussed in the presentation. And our developing sensor connection device, Camera Link FMC, will be reported.

Session7 / 34

Evaluation of novel n⁺-in-p pixel and strip sensors for very high radiation environment

UNNO, Yoshinobu¹; ATLAS-JAPAN SILICON, collaboration²¹ High Energy Accelerator Research Organization (JP)² JP**Corresponding Author:** yoshinobu.unno@kek.jp

We have been developing novel n⁺-in-p pixel and strip sensors that are highly radiation-tolerant, having a "planar" electrode geometry, utilize p-type silicon wafers, and being read out from highly doped n⁺ implants. Our goal of the radiation level is in the range of 10^{15} and up to 2×10^{16} 1-MeV-neutron-equivalent ($\text{n}_{\text{eq}}/\text{cm}^2$) of the particle fluence, approximately 30 and up to 600 Mrad of the dose in Silicon, in the strip and the pixel sensors, respectively, e.g., in the high-luminosity large hadron collider (HL-LHC).

The n⁺-in-p silicon sensors have the following properties: the p-type silicon wafer does not change type after irradiation (no type-inversion); read-out is from the junction side (n⁺) in all cases; and the collected carrier is the electron. These properties lead to a number of benefits: the lithographic processes is only required on a single side, which leads to lower production costs; partially-depleted operation is allowed, which is crucial after heavy irradiation in which the full-depletion voltage becomes higher than the operation voltage; and stronger and faster signals are induced by the carrier in the higher electric field in the junction side, thus leading to less charge-trapping.

For the sensors, the critical issues include operation at very high voltage, e.g., 1000 V, implementation of isolation structure and bias structures, and reduction of material. The operation voltage up to 1000 V, is to cope with the increasing full-depletion voltage caused by radiation damage. An isolation structure is to isolate the n⁺ implants from being connected by the conductive layer of attracted electrons in the surface of silicon, caused by the built-in and radiation-induced positive charge-up in the interface of the silicon and the surface oxide. A bias structure in the case of the pixel sensors is to provide a high voltage to all pixel implants for testing without connecting the implants to the read-out chip. These structures are to be designed not to introduce breakdown in leakage current, against the high electric field caused by the high operation voltage. The insensitive area caused by the structures are to be the minimum. The sensors are as thin as possible in order to reduce the multiple coulomb scattering to the traversing charged particles. The novel n(+)-in-p pixel sensors were made using a combinations of the bias structure of punch-through or polysilicon resistor, the isolation structure of p-stop or p-spray, and the thickness of 320 μm or 150 μm . The strip sensors and associated test structures were made of the polysilicon resistor and the p-stop isolation structures.

For the pixel modules, the critical issues include the need to bump bond with lead-free bumps and prevention of high voltage sparking. Usage of lead-free Tin-Silver (SnAg) solder bumps has become the industry standard. We have been tuning the lead-free bump-bonding technique in Japan. The pixel modules, the pixel sensors being connected to the readout chips, were fabricated by the established vendor in Europe and by the developing vendor in Japan. The high voltage (HV) (edge of the sensor) can, in the case of n⁺-in-p devices, be the voltage of the backplane and the ground (GND) (read-out chip) can be as close as 20 to 30 μm . The HV protection has been realized with encapsulating the edges.

The strip sensors and test structures were irradiated using 70 MeV protons to particle fluences of 5×10^{12} to 1×10^{15} , and the pixel modules using 23 MeV protons to 5×10^{15} 1-MeV neq/cm². The non-irradiated and irradiated pixel and strip sensors were evaluated in the laboratory measurements and by using charged particle beams.

In evaluating the performance of the irradiated sensors, we have observed a number of effect that we would like to understand: decreased efficiency under the bias rail, decreased potential of the p-stop implant between the n(+) strips, decreased active area in the strip end, and increased onset voltage in the punch-through protection structures. We discuss the common source that may have caused the above observations.

Poster session / 35

ATLAS Silicon Microstrip Tracker Operation and Performance

NAGAI, Koichi ¹

¹ *University of Tsukuba (JP)*

Corresponding Author: a_ciocio@lbl.gov

The Semi-Conductor Tracker (SCT) is a silicon strip detector and one of the key precision tracking devices in the Inner Detector of the ATLAS experiment at CERN LHC.

The SCT is constructed of 4088 silicon detector modules for a total of 6.3 million strips. Each module is designed, constructed and tested to operate as a stand-alone unit, mechanically, electrically, optically and thermally. The modules are mounted into two types of structures: one barrel (4 cylinders) and two end-cap systems (9 disks on each end of the barrel).

The SCT silicon micro-strip sensors are processed in the planar p-in-n technology. The signals from the strips are processed in the front-end ASICS ABCD3TA, working in the binary readout mode. Data is transferred to the off-detector readout electronics via optical fibers.

The completed SCT has been installed inside the ATLAS experimental cavern since 2007 and has been operational since then. Calibration data has been taken regularly and analyzed to determine the noise performance of the system. Extensive commissioning with cosmic ray events has been performed both with and without magnetic field. The sensor behavior in the 2 Tesla solenoid magnetic field was studied by measurements of the Lorentz angle. We find 99.3% of the SCT modules are operational, noise occupancy and hit efficiency exceed the design specifications; the alignment is very close to the ideal to allow on-line track reconstruction and invariant mass determination.

In the talk the current results from the successful operation of the SCT Detector at the LHC and its status after three years of operation will be presented.

We will report on the operation of the detector including an overview of the issues we encountered and the observation of significant increases in leakage currents (as expected) from bulk damage due to non-ionising radiation. The main emphasis will be given to the tracking performance of the SCT and the data quality during the many months of data taking (the LHC delivered 47pb⁻¹ in 2010 and 5.6fb⁻¹ in 2011 of proton-proton collision data at 7 TeV, and two times one-month periods of heavy ion collisions). The SCT has been fully operational throughout all data taking periods. It delivered high quality tracking data for 99.9% (2010) and 99.6% (2011) of the delivered luminosity.

The SCT running experience will then be used to extract valuable lessons for future silicon strip detector projects.

Poster session / 36

Optimization of the scan protocol for small-animal PET imaging: Effects on image quality, quantification accuracy, and radiation exposure

Prof. WU, Tung-Hsin¹; Prof. YANG, Ching-Ching²

¹ Department of Biomedical Imaging and Radiological Sciences, National Yang Ming University

² Department of Radiological Technology, Tzu Chi college of Technology

Corresponding Author: tung@ym.edu.tw

Purpose: Positron emission tomography (PET) imaging performance is limited by a number of physical, acquisition, and dosimetric constraints. To gain a thorough understanding of this issue, multivariate analysis was used to investigate the simultaneous effects of changes in these factors. This study investigated the relationship among the small animal imaging protocol, imaging performance, and radiation dose to achieve optimal PET image quality and minimize potential damage caused by radiation and anesthesia in preclinical studies.

Methods: A small-animal PET system with a dual-layer phoswich detector was modeled based on a Monte Carlo simulation to generate the emission image and dose distribution. A multivariate approach was used to investigate the simultaneous effects of tumor size, target-to-background ratio (TBR), scan duration, and injected radioactivity on the contrast-to-noise ratio (CNR) and recovery coefficient (RC).

Results: The object size, TBR, injected activity, and scan time were crucial predictors, whereas TBR and scan time were the most relevant contributors of CNR and RC variations, respectively. In 1.86×10^5 Bq/ml injected activity, the absorbed dose for a body and tumor with TBR of 2 were 2.46 and 5.39 cGy, respectively. A substantial improvement in CNR or RC was not observed in images acquired with radiotracer activity larger than 9.3×10^4 Bq/ml and scan duration longer than 30 min. The coefficient of determination was greater than 0.93 for both regression models, indicating an excellent fit to the data.

Conclusions: Although the improvement of counting statistics by increasing scan duration and injected activity can reduce statistical noise and improve spatial resolution, it is crucial to maintain the radiation exposure and anesthetic dose received by animals as low as possible to reduce biological damage. The results of this study provide a practical guide to determining the radiotracer concentration and scan duration to detect and quantify focal lesions in small-animal PET imaging.

Keywords: PET; small animal; imaging performance; multivariate analysis

Poster session / 37

Comparison of myocardial perfusion imaging between new ultrafast CZT camera and conventional SPECT: anthropomorphic phantom study

Prof. WU, Tung-Hsin¹; Mr. YANG, Bang-Hung²; Ms. WU, Nien-Yun²; Mr. CHEN, Yen-Lun³; Dr. WANG, Shyh-Jen²

¹ Department of Biomedical Imaging and Radiological Sciences, National Yang Ming University

² Department of Nuclear Medicine, Taipei Veterans General Hospital

³ Department of Biomedical Imaging and Radiological Sciences, National Yang-Ming University

Corresponding Author: tung@ym.edu.tw

Purpose: The solid-state detector is the novel γ -camera to reduce patient's imaging time and radiation dosage in nuclear cardiology. However, there was a discrepancy of optimal acquisition protocol between Thallium-201 and Tc-99m radionuclide in many literatures. The aim of this study was to compare new ultrafast cadmium-zinc-telluride (CZT) camera with conventional SPECT using anthropomorphic torso phantom to establish the optimal protocol for myocardial perfusion imaging (MPI).

Materials and Methods: Anthropomorphic torso phantom was filled with Thallium-201: 0.72 $\mu\text{Ci}/\text{mL}$ for cardiac insert; 0.515 $\mu\text{Ci}/\text{mL}$ for the liver; 0.06 $\mu\text{Ci}/\text{mL}$ for background as the stress state; and with 0.576 $\mu\text{Ci}/\text{mL}$ for cardiac insert; 0.412 $\mu\text{Ci}/\text{mL}$ for the liver; 0.048 $\mu\text{Ci}/\text{mL}$ for background as the rest state. Similarly, phantom was filled with Tc-99m: 1.56 $\mu\text{Ci}/\text{mL}$ for the cardiac insert; 1.04 $\mu\text{Ci}/\text{mL}$ for the liver; 0.13 $\mu\text{Ci}/\text{mL}$ for background as the stress state; and with 3.04 $\mu\text{Ci}/\text{mL}$ for the cardiac insert, 1.52 $\mu\text{Ci}/\text{mL}$ for the liver, and 0.34 $\mu\text{Ci}/\text{mL}$ for background as the rest state. All images were acquired by conventional dual-detector SPECT (e.cam; Siemens) with 15 min. Phantom immediately repeated on an ultrafast CZT camera over a 10-min acquisition time and reconstructed from list-mode raw data to obtain scan durations of 1 min, 2 min, etc., up to a maximum of 10 min. Quantitative analysis was performed on MPI polar maps with conventional SPECT MPI images and 1 to 10 min of CZT detector camera using a 20-segment model for the left ventricle. Intra-class correlation (ICC) was used to compare segmental tracer uptake between conventional SPECT and ultrafast CZT camera. Bland-Altman limits of agreement were calculated per segment for these durations.

Results: Minimal required scan times were 4 min for Thallium-201 both stress and rest ($r=0.82$; $P < 0.001$; Bland-Altman, -18% to 10.9% for stress; $r=0.88$; $P < 0.001$; Bland-Altman, -13.8% to 11.1% for rest), and minimal required scan times were 2 min for Tc-99m both stress and rest ($r=0.88$; $P < 0.001$; Bland-Altman, -6.2% to 16.6% for stress; $r=0.92$; $P < 0.001$; Bland-Altman, -10.8% to 10.9% for rest)

Conclusion: Our preliminary results from comparisons of the segmental tracer uptake revealed that the CZT detector camera requires a minimal scan time of 2 min for Tc-99m and 4 min for Thallium-201 to yield excellent image quality in MPI examination.

Keyword: solid-state detector, phantom, Thallium-201, Tc-99m, myocardial perfusion, cadmium-zinc-telluride (CZT)

Poster session / 38

Design of the AGIPD Sensor for the European XFEL

SCHWANDT, Joern¹; FRETWURST, Eckhart¹; KLANNER, Robert¹; ZHANG, Jianguo¹

¹ *Hamburg University - Institute for Experimental Physics*

Corresponding Author: joern.schwandt@cern.ch

For experiments at the European X-Ray Free-Electron Laser (XFEL), an Adaptive Gain Integrating Pixel Detector (AGIPD) system is under development. The particular requirements for the detector are a high dynamic range of 0, 1 - to more than 1E4

12.4 keV photons per pixel within a XFEL pulse duration of < 100 fs and a radiation tolerance of doses up to 1 GGy for 3 years of operation.

The sensor will have 1024 x 1024 p+-pixels with a pixel size of 200 μm x 200 μm and will be manufactured on 500 μm thick n-type silicon. The design value for the operating voltage is 500 V, however for special applications an operation at above 900 V should be possible.

Experimental data on the dose dependence of the oxide-charge density N_{ox} at the Si-SiO₂ interface and the surface-current density J_{surf} have been implemented in the SYNOPSIS TCAD simulation program in order to optimize the design of the pixel and guard ring layout. The methodology of the sensor design, the optimization of the most relevant parameters and the layout are discussed. Finally the simulated performance, in particular the breakdown voltage, dark current and inter-pixel capacitance as function of the X-ray dose will be presented.

Poster session / 39

Development of X-ray detector using optical switching readout for high-speed imaging

Mr. KIM, Jung-Seok¹; Prof. LEE, Ho-Jun²; Dr. HEO, Duchang³; Dr. CHA, Bo Kyung³; Mr. MOON, B. J.¹; Dr. YOON, Jungkee¹; Dr. KIM, Ryun Kyung⁴; Dr. JEON, Sung Chae³

¹ *2. DRTECH Corporation, Seongnam-si, 463-782, Korea*

² *3. Pusan National University, Busan, 609-735, Korea*

³ *1. Korea Electrotechnology Research Institute (KERI), Ansan-si, 426-910, Korea*

⁴ *Korea Electrotechnology Research Institute (KERI)*

Corresponding Author: rkkim@keri.re.kr

We demonstrate an x-ray detector with dual amorphous-Selenium (a-Se) layer using optical switching readout for high-speed x-ray imaging. The x-ray detector consists of a negative voltage bias electrode, a thick a-Se layer for photoelectric conversion of x-ray photons, an As₂Se₃ layer as an electron-trapping layer for accumulating a latent image, a thin a-Se layer for optical readout, an opaque-, and transparent-electrodes formed alternately, and a plasma display panel (PDP) optical source for optical switching readout. The readout PDP source with peak wavelength of blue 470nm was operated to line by line with electrical scanning for high-speed x-ray imaging. The developed x-ray detector has 512 x 512 with 200 μm pixel.

Poster session / 40

The relation of pre-diabetes and region-specific visceral adipose tissue: quantified by multi-detector computed tomography

Dr. YUN, Chun-Ho¹; Ms. SUN, Jing-Yi²; Dr. HUNG, Chung-Leih¹; Mr. LIN, Yang-Hsien²; Dr. TSAI, Jui-Peng¹

¹ Department of Radiology, Mackay Memorial Hospital

² Department of Biomedical Imaging and Radiological Sciences, National Yang Ming University

Corresponding Author: med202657@gmail.com

Background: Central obesity in relation to insulin resistance is strongly linked to the development of diabetes. However, data regarding the association between peri-cardial and peri-aortic fat amount, a real estimate of visceral adipose tissue and pre-diabetes status remained elusive.

Objective: The aim of this study was to examine whether pericardial and thoracic peri-aortic adipose tissue, when quantified by multi-detector computed tomography (MDCT), may differ substantially among subjects in normal, pre-diabetes and overt diabetes status.

Materials and Methods: We consecutively studied 562 participants including 357 healthy, 155 pre-diabetes and 50 diabetes who underwent health survey. Pre-diabetes status was defined by impaired fasting glucose or impaired glucose intolerance by American Diabetes Association guidelines. Pericardial (PCF) and thoracic peri-aortic (TAT) adipose tissue was assessed by non-contrast 16-slice multi-detector computed tomography (MDCT) data set with off-line measure (Aquarius 3D Workstation, TeraRecon, San Mateo, CA, USA). Body fat composition (Tanita 305 Corporation, Tokyo, Japan), serum high-sensitivity C-reactive protein (Hs-CRP) level and insulin resistance (HOMA-IR) were all obtained.

Results: Patients with diabetes and pre-diabetes had greater volume of PCF (89 ± 24.6 , 85.3 ± 28.7 & 67.6 ± 26.7 ml, $p < 0.001$) as well as higher volume of TAT (9.6 ± 3.1 ml vs 8.8 ± 4.2 & 6.6 ± 3.5 ml, respectively, $p < 0.001$) when compared to normal group, though there was no significant differences between diabetes and pre-diabetes groups. For those without overt diabetes in our study, increasing TAT burden, rather than PCF, seemed to correlate with higher HOMA-IR and Hs-CRP in the multivariable models while there seemed to be a borderline relationship between PCF and coronary artery calcium score.

Conclusion: Pre-diabetic status was associated with much higher pericardial and peri-aortic adipose tissue than normal subjects, which is actually comparable to overt diabetes. In addition, for those visceral fat accumulated surrounding aortic area seemed to exert effects on insulin resistance and systemic inflammation.

Key Words: Pre-diabetes, type II diabetes mellitus, MDCT, visceral adipose tissue, coronary calcium score

Poster session / 41

Compared Myocardial Deformation between Cardiovascular Magnetic Resonance and Cardiac Computed Tomography

Dr. YUN, Chun-Ho¹; Prof. HUANG, Tzung-Chi²; Mr. LIN, Yang-Hsien³; Dr. TSAI, Jui-Peng⁴; Dr. YANG, Fei-Shih¹; Prof. WU, Tung-Hsin³

¹ Department of Radiology, Mackay Memorial Hospital

² Department of Biomedical Imaging and Radiological Science, China Medical University

³ Department of Biomedical Imaging and Radiological Sciences, National Yang Ming University

⁴ Department of Cardiology, Mackay Memorial Hospital

Corresponding Author: med202657@gmail.com

Introduction: In the fields of heart failure diagnosis, expect for the evaluation of heart valve abnormality, the myocardial wall motion is another important indication which has been concluded in many studies. Cardiovascular magnetic resonance (CMR) imaging provides highly reproducible data of myocardial deformation. Recently, the cardiac computed tomography (CT) imaging technique has become a new tool because of its advantages of good dynamic resolution, low cost and breath hold not required.

Materials and Methods: In this study, we analyzed the wall motion of heart by using Optical Flow Method (OFM), and compared the correlation between CMR and Cardiac CT imaging. The Cardiac CT scan was performed on the 64-slice DSCT scanner (Definition, Siemens Medical Systems, Forchheim, Germany) with a gantry rotation time of 330 ms. CMR was performed on a 3.0-T system (Achieva, Philips Medical Systems, Best, the Netherlands) using a 32-channel cardiac phased array receiver coil.

Results: According to the analysis results of Cardiac CT and CMR, the average wall motions between the diastole and systole phase in the left ventricle was 2.15 ± 0.47 mm and 2.21 ± 0.46 mm, respectively. The regression equation between the Cardiac CT and CMR was $y = 0.06 + 1.00x$ with $R^2 = 0.83$ and the correlation coefficient was 0.91, which means the data were highly positively correlated.

Conclusion: Using OFM motion estimate could accurately track myocardial deformation. The highly positive correlation between CMR and Cardiac CT images with OFM. Therefore, the Cardiac CT assessment myocardial motion may assist analysis in the diagnosis of heart failure.

Key Words: Myocardial Deformation, Cardiovascular magnetic resonance, Cardiac computed tomography, Optical Flow Method

Poster session / 42

Optimal Temporal Windows and Dose-reducing Strategy for Coronary Artery Bypass Graft Imaging with 256-Slice CT

Mr. LU, Kun-Mu¹; Dr. LEE, Yi-Wei²; Dr. CHEN, Liang-Kuang¹; Dr. LAW, Wei-Yip¹; Dr. SU, Cheng-Tau¹; GUAN, YU-XIANG³

¹ Department of Radiology, Shin Kong Wu Ho-Su Memorial Hospital

² Department of Radiology, Kaohsiung Chang Gung Memorial Hospital and Chang Gung University College of Medicine

³ National Yang-Ming University

Corresponding Author: t000071@ms.skh.org.tw

Objective: To determine the optimal image reconstruction windows in the assessment of coronary artery bypass grafts (CABGs) with 256-slice CT, and to assess their associated optimal ECG pulsing windows for tube-current modulation (ETCM).

Methods: We recruited 18 patients (three female; mean age 68.9 years) having mean heart rate (HR) of 66.3 bpm and a heart rate variability of 1.3 bpm for this study. A total of 36 CABGs with 168 segments were evaluated, including 12 internal mammary artery (33.3%) and 24 saphenous vein grafts (66.7%). We reconstructed 20 data sets in 5%-step through 0%-95% of the R-R interval. The image quality of the bypass grafts was assessed by a 5-point scale (1=excellent to 5=non-diagnostic) for each segment (proximal anastomosis, proximal, middle, distal course of graft body, and distal anastomosis). Two reviewers discriminated optimal reconstruction intervals for each CABG segment in each temporal window. Optimal windows for ETCM were also evaluated.

Results: The determined optimal systolic and diastolic reconstruction intervals could be divided into 2 groups with threshold HR = 68. The determined best reconstruction intervals for low heart rate (HR < 68) and high heart rate (HR > 68) were $76.0 \pm 2.5\%$ and $45.0 \pm 0\%$ respectively. Average image quality scores were 1.8 ± 0.6 with good inter-observer agreement ($\kappa=0.79$). Image quality was significantly better for saphenous vein grafts versus arterial grafts ($P < 0.001$). The recommended windows of ETCM for low HR, high HR and all HR groups were 40-50%, 71-81% and 40-96% of R-R interval, respectively. The corresponding dose savings were about 60.8%, 58.7% and 22.7% in that order.

Conclusions: We determined optimal reconstruction intervals and ETCM windows representing a good compromise between radiation and image quality for following bypass surgery using a 256-slice CT.

Key Words: CT coronary angiograms; Coronary artery bypass graft; Image quality; ECG-based tube current modulation; Radiation dose

Poster session / 43

Attenuation correction in PET/CT: optimum imaging parameters derived from ultra low dose calcium score CT

Mr. LU, Kun-Mu¹; Dr. LEE, Yi-Wei²; Ms. SUN, Jing-Yi³; Dr. CHEN, Yen-Kung⁴; Dr. SU, Cheng-Tau⁴; GUAN, YU-XIANG⁵

¹ Department of Diagnostic Radiology, Shin Kong Wu Ho-Su Memorial Hospital

² Department of Radiology, Kaohsiung Chang Gung Memorial Hospital and Chang Gung University College of Medicine

³ Department of Biomedical Imaging and Radiological Sciences, National Yang Ming University

⁴ Department of Radiology, Shin Kong Wu Ho-Su Memorial Hospital

⁵ National Yang-Ming University

Corresponding Author: t000071@ms.skh.org.tw

Introduction: In cardiac PET/CT, coronal calcium scoring CT (CCSCT) not only is a noninvasive assessment of the presence and location of calcified plaque but also could provide as attenuation correction (AC) maps. However, the optimal radiation dose saving of CCSCT scan has not been studied. The purpose of this study is to determine optimum imaging parameters for attenuation correction in PET/CT based on ultra-low dose CCSCT with various body size.

Materials and methods: The study was performed using a modified QRM-cardiac phantom including CCSCT scan and emission scan. The phantom containing calibration inserts and additional phantom rings were used to simulate small, medium-size, and large patients. Agaston scores were calculated using CCSCT images (120 kV, 300 mA) as standard and compared with low-dose parameter scans (from 300 to 10 mA, 50 intervals). The assessment of Agaston scores and standard uptake value (SUV) were carried out by paired t test and Pearson's correlation coefficient. Radiation doses from CCSCT were expressed by using CT dose index (CTDI).

Result: The result showed optimum tube current in small, medium, and large size was 50, 100, and 150 mA, respectively. It was good correlation between Agatston score values, calculated by 300 mA and low-dose CCSCT images, as expressed by correlation coefficient and p value ($r > 0.9$, $p < 0.002$). There was no difference when comparing the SUV between 300 mA and each low-dose parameter scans. Radiation dose was reduced by 83.34, 66.67, and 50 % when using 50, 100, and 150 mA CCSCT image, compare to 300 mA CCSCT image.

Conclusion: The data of this preliminary study demonstrates that increasing body size is associated with increasing radiation exposure and image noise. Using low-dose CCSCT scan results in good assessment of Agatston score and SUV and make it possible to reduce radiation dose by more than 50 %.

Session5 / 44

New prototypes for components of a control system for the new ATLAS pixel detector at the HL-LHC

PULLEN, Lukas¹; KERSTEN, Susanne²; BOEK, Jennifer²; ZEITNITZ, Christian²; MATTIG, Peter²; KIND, Peter²

¹ Uni-Wuppertal

² Bergische Universitaet Wuppertal (DE)

Corresponding Author: lukas.puellen@cern.ch

In the years around 2020 an upgrade of the LHC to the HL-LHC is scheduled, which will increase the accelerators luminosity by a factor of 10. In the context of this upgrade, the inner detector of the ATLAS experiment will be replaced entirely including the pixel detector. This new pixel detector requires a specific control system which complies with the strict requirements in terms of radiation hardness, material budget and space for the electronics in the ATLAS experiment. The University of Wuppertal is developing a concept for a DCS (Detector Control System) network consisting of two kinds of ASICs. The first ASIC is the DCS Chip which is located on the pixel detector, very close to the interaction point. The second ASIC is the DCS Controller which is controlling 4x4 DCS Chips from the outer regions of ATLAS via differential data lines. Both ASICs are manufactured in 130nm deep submicron technology. We present results from measurements from new prototypes of components for the DCS network.

Session7 / 45

Study of the collection of charge carriers generated close to the Si-SiO₂ interface of silicon strip sensors before and after 1 MGy X-ray radiation

POEHLSEN, Thomas ¹; KLANNER, Robert ²; SCHWANDT, Joern ³; ZHANG, Jiaguo ⁴

¹ *Hamburg University*

² *UHH - Institute for Experimental Physics*

³ *Hamburg University (DE)*

⁴ *Institute of Experimental Physics, University of Hamburg*

Corresponding Author: thomas.poehlsen@cern.ch

The collection of charge carriers generated in p+-n-strip sensors close to the Si-SiO₂ interface before and after 1 MGy of X-ray irradiation has been investigated using the transient current technique (TCT) with sub-nanosecond focused light pulses of 660 nm wavelength, which has an absorption length in silicon at room temperature of 3.5 μm .

Depending on the applied bias voltage, bias history, humidity and irradiation, incomplete collection of either electrons or holes has been observed when illuminating the strip side of the sensor. The data are described by a model which allows a quantitative determination of the losses of holes, the losses of electrons and the width of the accumulation layer below the Si-SiO₂ interface.

For non-irradiated sensors little or no charge losses are observed in equilibrium. However, immediately after changing the biasing voltage the sensors are in a non-equilibrium state:

Electron losses occur when the voltage is increased, and hole losses occur when it is decreased. For irradiated sensors electron losses are observed in equilibrium. When the voltage is ramped up the fraction of electrons lost increases, when it is ramped down it decreases.

The time it takes to reach equilibrium is a strong function of humidity: Several days in a dry and of the order 60 minutes in a humid atmosphere. The charge losses and their dependence on bias history and humidity can be qualitatively explained by the time it takes until the charges on the surface of the sensor are distributed in a way that the longitudinal electric field on the surface vanishes and a constant potential is reached. The difference in time it takes to reach the equilibrium is explained by the increase of the surface conductivity with increasing humidity.

The number of charges lost in one laser pulse decreases with the number of charges lost and thus accumulated in preceding pulses. The amount of charge which has to be accumulated until the charge losses vanish, and the time it takes that the initial charge losses are reestablished, have been determined with the laser operated in burst mode.

The observations for sensors from two vendors built from silicon with different crystal orientations and different coupling of the read-out strips to the p+ implants are qualitatively similar.

The relevance of the results for the operation of sensors is discussed.

Poster session / 47

Development of neutron two-dimensional position detector systems by using MPPC

Mr. SATOH, Setsuo¹; Dr. MUTO, Suguru¹

¹ KEK

Corresponding Author: setsuo@post.kek.jp

KEK KENS-DAQ group is developing several neutron detectors and readout systems. 2 systems are developed by using a ZnS/6LiF neutron scintillator and MPPC (Multi Pixel Photon Counter: a semiconductor light sensor).

One is named M-PSD (MPPC position-sensitive detector) which uses charge-division method like the ³He-PSD [1,2]. Therefore a NEUNET (neutron network) system [1] which is widely used in the J-PARC (Japan Proton Accelerator Research Complex) can be used for its readout system. A 2-dimensional detector which consists of 21 M-PSD boards at intervals of 5 mm. The detection area of the detector is 128 × 105 mm². Each board has 32 MPPCs at intervals of 4 mm, and the spatial resolution is about 1mm.

The other is named MHPD (MPPC high count pixel detector) which processes data at each MPPC independently to obtain high count rate.

We will present the latest development of the detector systems.

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Session7 / 50

Proton Radiation Damage Experiment on P-Channel CCD for an X-ray CCD camera onboard the Astro-H satellite

MORI, koji¹; Mr. NISHIOKA, Yusuke¹; Mr. OHURA, satoshi¹; Mr. KOURA, yoshiaki¹; Dr. HAYASHIDA, kiyoshi²; Mr. IKEDA, shouma³; Dr. KOHMURA, takayoshi³; Dr. ANABUKI, naohisa²; Dr. YAMAUCHI, makoto¹; Prof. TSUNEMI, hiroshi²; Dr. MAEDA, yukie¹; Prof. SAGARA, kenshi⁴; Mr. UEDA, Shutaro²; Dr. NAKAJIMA, hiroshi²; Mr. KAN, hiroaki²

¹ University of Miyazaki

² Osaka University

³ Kogakuin University

⁴ Kyushu University

Corresponding Author: mori@astro.miyazaki-u.ac.jp

We report on a proton radiation damage experiment on P-Channel CCD newly developed for an X-ray CCD camera onboard the Astro-H satellite. The device has been exposed up to 10⁹ protons/cm² at 6.7 MeV. The charge transfer inefficiency (CTI) is measured as a function of radiation dose. In comparison with the CTI actually measured in the CCD camera onboard the Suzaku satellite for 6 years, we confirm that the new type of P-Channel CCD is radiation tolerant enough for space use. The temperature dependence of the CTI is also reported.

Session8 / 51

Thin n-in-p pixel sensors and the SLID-ICV vertical integration technology for the ATLAS upgrade at HL-LHC

MACCHIOLO, Anna ¹; ANDRICEK, Laci ²; MOSER, Hans-Guenther ³; Dr. NISIUS, Richard ¹; RICHTER, Rainer ⁴; WEIGELL, Philipp ¹

¹ Max-Planck-Institut fuer Physik (Werner-Heisenberg-Institut) (D

² Werner-Heisenberg-Institut-Max-Planck-Institut fuer Physik-Max-

³ MPI fuer Physik

⁴ MPI for Physics

Corresponding Author: anna.macchiolo@cern.ch

The R activity here presented is focused on the development of a new module concept for the upgrade of the ATLAS pixel system at the High Luminosity LHC (HL-LHC). It employs thin pixel sensors together with a novel vertical integration technology offered by the Fraunhofer Institute EMFT in Munich, consisting of the Solid-Liquid-InterDiffusion (SLID) interconnection, which is an alternative to the standard bump-bonding, and Inter Chip Vias (ICV) for routing signals vertically through the readout chips.

Two productions of thin pixel sensors, with an active thickness of 75 μm and 150 μm , were completed using a process developed at the Semiconductor Laboratory of the Max-Planck-Institute for Physics (HLL) and connected to the FE-I3 and FE-I4 ATLAS read-out chips, respectively.

Due to their cost effectiveness and radiation hardness n-in-p silicon devices are a promising candidate to replace the present n-in-n sensors in the radiation environment of HL-LHC and to instrument the large area of the new ATLAS pixel system. Furthermore thin pixel sensors offer a reduced contribution to the material budget and a higher charge collection efficiency (CCE) at the radiation levels expected in the inner pixel layers at HL-LHC.

The 75 μm thick FE-I3 compatible sensors have been connected with SLID to read-out chips and were irradiated up to fluence of $5 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$. A CCE close to 100% has been measured at bias voltages as low as 500 V and the SLID interconnection efficiency proved not to be affected by these radiation levels.

The 150 μm thick sensors were interconnected by bump-bonding to the new ATLAS pixel read-out chip FE-I4. An excellent performance in terms of charge collection efficiency and noise occupancy were obtained before and after irradiation at $5 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$.

The results, obtained with laboratory and beam tests, for these two thin pixel productions will be compared with those of n-in-p pixels of standard thickness.

On the thin FE-I3 modules ICVs, with a cross section of 3 μm x 10 μm , are going to be etched at the positions of the original wire bonding pads of the FE-I3 chip. This step is meant to prove the feasibility of the signal transport to the newly created readout pads on the backside of the chips, allowing for four side buttable devices without the presently used cantilever for wire bonding. The status of the ICVs preparation on the FE-I3 wafer will be presented.

Poster session / 52

Beamtest of novel n-in-p strip sensors for very high radiation environment

KUBOTA, Tomonori ¹; SILICON, collaboration ATLAS-Japan ²

¹ *Tokyo Institute of Technology (JP)*

² *JP*

Corresponding Author: tomonori.kubota@cern.ch

Results on a beam test of n-in-p silicon strip sensors aimed for the ATLAS SCT(Semi-Conductor Tracker) upgrades for High Luminosity LHC(HL-LHC) are presented. This Beam test was operated with a new DAQ system consisting of a universal read-out board called 'SEABAS'and a beam tracking system with the spacial resolution less than 5 micro meters, and held at RCNP in December 2011. Behaviors of the new 1 cm x 1 cm n-in-p miniature sensors before and after irradiation up to 10^{15} n_eq/cm² are discussed. Collected charge of non-irradiated is sensor is 6fC at full depletion voltage, while of 10^{15} n_eq/cm² irradiated sensor is 4.2fC. The effective region on the strip edges around PTP structures of the non-irradiated sensor reached to the bias rail, while of the 10^{15} n_eq/cm² irradiated sensor it reached only up to strip edges.

Poster session / 53

Development of the Pixel OR SOI Detector for High Energy Physics Experiments

ONO, Yoshimasa ¹; ARAI, Yasuo ²; Dr. TSUBOYAMA, Toru ³; ISHIKAWA, Akimasa ¹; ONUKI, Yoshiyuki ⁴; IWATA, Atsushi ⁵; IMAMURA, Toshifumi ⁵; OHMOTO, Takafumi ⁵

¹ *Tohoku University (JP)*

² *High Energy Accelerator Research Organization (JP)*

³ *KEK, High Energy Accelerator Research Organization (JP)*

⁴ *Tokyo University (JP)*

⁵ *A-R-Tec Corp.*

Corresponding Author: ono@epx.phys.tohoku.ac.jp

A Silicon-On-Insulator (SOI) technology is suitable for vertex detector for high energy physics experiments since complex functionalities can be fabricated on the SOI wafer with small material thanks to the monolithic structure.

We developed a new sensor processing scheme "PIXOR(PIXel OR)" for pixel detectors using a Lapis 0.25um SOI process.

An analog signals from each pixelated sensor is divided into two dimensional directions, and $2n^2$ signal channels from small n by n pixel matrix are taken OR as n column and n row channels, then the signals are processed by readout circuit in each small matrix.

This PIXOR scheme reduces number of readout channels and avoids a deterioration of intrinsic position resolution due to large circuit area, that was common issue for monolithic pixel detectors.

This feature allows high resolution, low occupancy and on-sensor signal processing at the same time.

We present the successful results of the PIXOR readout scheme using the first prototype.

Session7 / 54

Impact of pixel size and shape on physics analysis

NAGELI, Christoph ¹; HORISBERGER, Roland ²

¹ *Eidgenoessische Tech. Hochschule Zuerich (CH)*

² *Paul Scherrer Institut (CH)*

Corresponding Author: christoph.nageli@cern.ch

A Monte Carlo study will be presented to quantify the impact of the z resolution of the pixel detector to a new physics search.

The choice of the pixel shape and size in the r- ϕ and z-directions results in different position resolutions, that in turn

influence the selection power for the analysis of a certain physics channel. The presented study illustrates the effect of the pixel z

resolution on signal and background candidates in the case of the search for the rare decay $B_s \rightarrow \mu\mu$. Within the framework of the

SM this decay channel is expected at the level of $\sim 10^{-9}$ and therefore requires a very high background rejection ratio to reach

the sensitivity necessary to observe a signal. The study will compare and illustrate the physics performance of this rare decay for different

scenarios.

Session1 / 55

Status of the ATLAS Pixel Detector at the LHC and its performance after three years of operation.

ANDREAZZA, Attilio ¹

¹ *Università degli Studi e INFN Milano (IT)*

Corresponding Author: clara.troncon@cern.ch

The ATLAS Pixel Detector is the innermost detector of the ATLAS experiment at the Large Hadron Collider at CERN, providing high-resolution measurements of charged particle tracks in the high radiation environment close to the collision region. This capability is vital for the identification and measurement of proper decay times of long-lived particles such as b-hadrons, and thus vital for the ATLAS physics program.

The detector provides hermetic coverage with three cylindrical layers and three layers of forward and backward pixel detectors.

It consists of approximately 80 million pixels that are individually read out via chips bump-bonded to 1744 n-in-n silicon substrates.

In this talk, results from the successful operation of the Pixel Detector at the LHC and its status after three years of operation will be presented, including monitoring, calibration procedures, timing optimization and detector performance. The detector performance is excellent: ~96 % of the pixels are operational, noise occupancy and hit efficiency exceed the design specification, and a good alignment allows high quality track resolution.

Session1 / 56

Overview of the ATLAS Insertable B-Layer (IBL) Project

ROHNE, Ole ¹

¹ *University of Oslo (NO)*

Corresponding Author: clara.troncon@cern.ch

The upgrades for the ATLAS Pixel Detector will be staged in preparation for high luminosity LHC. The first upgrade for the Pixel Detector is the construction of a new pixel layer which will be installed during the first shutdown of the LHC machine, in 2013-14. The new detector, called the Insertable B-layer (IBL), will be installed between the existing Pixel Detector and a new, smaller radius beam-pipe at a radius of 3.3 cm. The IBL has required the development of several new technologies to cope with increased radiation and pixel occupancy and also to improve the physics performance through reduction of the pixel size and a more stringent material budget. The IBL presents several changes to the design of the present hybrid pixel system: two different and promising silicon sensor technologies, planar n-in-n and 3D, will be used for the IBL. A new read-out chip FE-I4 has been designed in 130 nm technology, the material budget is minimized by using new lightweight mechanical support materials and a CO₂ based cooling system has been developed. An overview of the IBL project, of the module design and the qualification for these sensor technologies with particular emphasis on irradiation and beam tests will be presented.

Poster session / 57

Monitoring radiation damage in the ATLAS Pixel Detector

TRONCON, Clara ¹; ANDREAZZA, Attilio ²

¹ *Milano Universita e INFN (IT)*

² *Università degli Studi e INFN Milano (IT)*

Corresponding Author: clara.troncon@cern.ch

The record breaking instantaneous luminosities of 10^{33} cm⁻² s⁻¹ recently surpassed at the Large Hadron Collider generate a rapidly increasing particle fluence in the ATLAS Pixel Detector. As the radiation dose accumulates, the first effects of radiation damage are now observable in the silicon sensors. A regular monitoring program has been conducted and reveals an increase in the silicon leakage current, which is found to be correlated with the rising radiation dose recorded by independent sensors within the inner detector volume. Such measurements are useful to validate the digitization model that has been developed to simulate radiation damage effects, including charge trapping, electric field modification and realistic signal induction on the electrodes. In the longer-term crystal defect formation in the silicon bulk is expected to alter the effective doping concentration, producing type-inversion and ultimately an increase of the voltage required to fully deplete the sensor.

Poster session / 58

Neural network based cluster creation in the ATLAS silicon Pixel Detector

ANDREAZZA, Attilio¹

¹ *Università degli Studi e INFN Milano (IT)*

Corresponding Author: clara.troncon@cern.ch

The read-out from individual pixels on planar semi-conductor sensors are grouped into clusters to reconstruct the location where a charged particle passed through the sensor. The resolution given by individual pixel sizes is significantly improved by using the information from the charge sharing between pixels. Such analog cluster creation techniques have been used by the ATLAS experiment for many years to obtain an excellent performance. However, in dense environments, such as those inside high-energy jets, clusters have an increased probability of merging the charge deposited by multiple particles. Recently, a neural network based algorithm which estimates both the cluster position and whether a cluster should be split has been developed for the ATLAS Pixel Detector. The algorithm significantly reduces ambiguities in the assignment of pixel detector measurement to tracks within jets and improves the position accuracy with respect to standard interpolation techniques by taking into account the 2-dimensional charge distribution. The implementation of the neural network, the training parameters and performance of the new clustering will be presented. Significant improvements of the track and vertex resolution obtained using this new method will be presented using Monte Carlo simulated data and compared to data recorded with the ATLAS detector will be given. The resulting improvements to both track reconstruction and the identification of jets containing b-quarks will be discussed.

Poster session / 59

Track and vertex reconstruction in the ATLAS Experiment

HAMANO, Kenji¹

¹ *University of Melbourne (AU)*

Corresponding Author: clara.troncon@cern.ch

The track and vertex reconstruction algorithms of the ATLAS Inner Detector have demonstrated excellent performance in the early data from the LHC. However, the rapidly increasing number of interactions per bunch crossing introduces new challenges both in computational aspects and physics performance. The combination of both silicon and gas based detectors provides high precision impact parameter and momentum measurement of charged particles, with high efficiency and small fake rate. Vertex reconstruction is used to identify with high efficiency the hard scattering process and to measure the amount of pile-up interactions, both aspects are crucial for many physics analyses. The performance of track and vertex reconstruction efficiency and resolution achieved in the 2011 data-taking period and for the 2012 data-taking, where improved algorithms will be used, are presented.

Poster session / 60

Development of Readout System of FE-I4 Pixel Module Using SiTCP

UNNO, Yoshinobu ¹; TERADA, Susumu ¹; HANAGAKI, Kazunori ²; TEOH, Jia Jian ²; TAKUBO, Yosuke ³; IKEGAMI, Yoichi ¹

¹ *High Energy Accelerator Research Organization (JP)*

² *Osaka University (JP)*

³ *Tohoku university*

Corresponding Author: yosuke.takubo@cern.ch

The pixel detector of the ATLAS will be replaced at the future upgrade of LHC to keep the performance at high luminosity operation. For the upgrade, the sensor modules have been developed by using new front-end chips (FE-I4). Since design of the FE-I4 chip is different from the chip used for the current pixel detector, new DAQ system is necessary to read the sensor modules. For that reason, we have developed DAQ system by using a "SEABAS" DAQ board. SEABAS processes the data from the FE-I4 chips with an FPGA (User-FPGA) and transfers data to a computer via Ether-net with SiTCP. SiTCP is a technology to realize direct access and transfer of the data in the memory of User-FPGA from the PC by utilizing TCP/IP and UDP communication with a dedicated FPGA. We have developed firmware and software for SEABAS, together with readout hardware chain, and established basic functionality for reading out the FE-I4 chips.

Poster session / 61

Low mass carbon based support structures for the ATLAS pixel forward disks for the HL-LHC

BATES, Richard ¹; BUTTAR, Craig ¹; BONAD, Isaac ²; CANFER, Simon ³; Mrs. MCEWAN, Fiona ⁴; Dr. CUNNINGHAM, Liam ⁴; Mr. LOCKETT, Cyril ⁵; PATER, Joleen ⁶; JONES, Tim ⁷; Dr. THOMPSON, Ray ⁸

¹ *University of Glasgow (GB)*

² *UK ATC*

³ *STFC - Science Technology Facilities Council (GB)*

⁴ *The University of Glasgow*

⁵ *STFC*

⁶ *University of Manchester (GB)*

⁷ *University of Liverpool (GB)*

⁸ *The University of Manchester*

Corresponding Author: richard.bates@glasgow.ac.uk

For the proposed upgraded pixel and strip detector systems of the ATLAS experiment on the HL-LHC near all carbon support structures are a candidate. These consist of two low-density carbon fibre reinforced polymer (CFRP) sheets (low areal weight), consisting of ultra-high modulus fibres, with metallic cooling tubes filled with refrigerant sandwiched between them. Low-density carbon foam is glued around the cooling tubes to connect them thermally and physically to the CFRP skins. The pixel modules are mounted onto the skins which provide the modules with both a thermal and a mechanical support.

Measurements of the thermal and mechanical properties of prospective low density foams and CFRP sheets are presented. Foams from two suppliers are investigated. Their different physical properties are discussed and the impact on their thermal and mechanical properties shown. The interfaces between the foam and the CFRP skin and the foam and cooling pipe are crucial for the performance of the structure. The thermal resistance of these interfaces are measured. Due to the difference in the coefficient of thermal expansion of the metallic cooling pipe and the CFRP skins the foam and interfaces will undergo a shear force. The effects of the shear force on the thermal conductivity of the interfaces and the foam are presented.

To minimize the material used in the supporting structure the design must be optimized based on the moduli of the material under the relevant low forces experienced by the structure. To this end the moduli under tension, compression and shear are measured for the foam and under tension for the CFRP skins. A custom made jig was used to remove twist in the sample to allow the modulus under tension at the very low stresses of interest to be measured.

The material characteristics extracted are used as input values to finite element analysis (FEA) models of proposed designs of the forward disks of the ATLAS HL-LHC upgrade. FEA simulation results are compared to measurements made on mechanical test structures. From these results extrapolation to a proposed design for the disks are presented. The disks thermal performance is shown from the perspective of maintaining the pixel sensor temperature from thermal run away and as robustness against variation in coolant temperature.

Session6 / 62

Test of TRAPPIS^{Te} Monolithic Detector System

ALVAREZ RENGIFO, Paula Liliana ¹; SOUNG YEE, Lawrence ²; MARTIN, Elena ¹; CORTINA GIL, Eduardo ³; FERRER, Carles ¹¹ *Universitat Autònoma de Barcelona*² *Universite catholique de Louvain*³ *Université catholique de Louvain***Corresponding Author:** paulaliliana.alvarez@uab.cat

The use of different semiconductor technologies in the field of particle detector has been always limited by the effects of radiation in both the sensors and the processing circuitry. This fact has encouraged the teams working in future developments to evaluate the use of different technological approaches to minimize the impact of radiation by using new detector material, connections and read-out architectures.

A monolithic Active Pixel sensor for charged particle tracking has been developed. This sensor is within the frame of an R project called TRAPPIS^{Te} (Tracking Particles for Physics Instrumentation in SOI Technology), with the aim of studying the feasibility of developing a Monolithic Active Pixel Sensor (MAPS) with Silicon-on-Insulator (SOI) technology. Two different architectures are being evaluated, 3-transistor (3T) and charge sensitive amplifier (CSA). To compare the results, two chips have been fabricated: TRAPPIS^{Te}-1 and TRAPPIS^{Te}-2. The first prototype TRAPPIS^{Te}-1 was produced at the WINFAB facility at the Université catholique de Louvain (UCL) in Belgium in a 2 μ m fully depleted (FD-SOI) CMOS process. TRAPPIS^{Te}-2 is the second prototype in this series and was fabricated with the OKI 0.20 μ m FD-SOI CMOS process. Each one of the prototypes analyzed implements two different approaches, 3-transistor read-out and charge sensitive amplifier.

The TRAPPIS^{Te}-1 prototype is an 8x8 pixel matrix with a shift register used to control signal readout. Each pixel contains simple 3-transistor readout and has dimensions 300 μ m x 300 μ m. An additional layout of charge sensitive amplifiers was implemented separately in order to validate the architecture in SOI, although no connection with the detector was included. The second phase of this project was developed with the TRAPPIS^{Te}-2 prototype. This version included similar readout architectures for evaluation and several test transistors, although the size of the pixel cells is 150 μ m x 150 μ m.

The TRAPPIS^{Te} chips have been measured using a custom built PCB to provide the necessary bias and control signals. The test system is controlled by an Altera DE2 FPGA and data is collected on a PC via an Ethernet connection.

The charge sensitive amplifiers were implemented in both WINFAB and OKI technologies. The amplifiers were based on a standard folded cascade core with a feedback capacitor. DC measurements of the amplifiers agree with simulations and the effect of varying the back voltage can be clearly observed. Different effects have been measured, such as the influence of the bias current and the effect of varying the feedback transistor gate voltage. Transient output measurements were performed by injecting a voltage pulse onto a test input capacitor and changing the amplifier bias currents and voltages. The 3-transistor read-out architecture was also implemented in both WINFAB and OKI technologies. The architecture is based on a simple structure where an external shift register is responsible for transferring the charge information. This structure has been used to characterize the whole matrix electrically.

A laser system named LARA (Laser for Radiation Analysis) has been developed to characterize silicon sensors. LARA contains a remote controlled 3-axis motorized stage that can position a test device under a laser beam. An infrared laser at 1060nm wavelength and a red laser at 670nm wavelength are available. The system is controlled by a PC via a LabVIEW interface. The laser measurements are being tested on both the 3T and the CSA architectures.

Poster session / 63

Characterization of SOI Monolithic Detector System

ALVAREZ RENGIFO, Paula Liliana ¹; SOUNG YEE, Lawrence ²; MARTIN, Elena ¹; CORTINA GIL, Eduardo ³; FERRER, Carles ¹¹ *Universitat Autònoma de Barcelona*² *Universite catholique de Louvain*³ *Université catholique de Louvain***Corresponding Author:** paulaliliana.alvarez@uab.cat

The use of different semiconductor technologies in the field of particle detector has been always limited by the effects of radiation in both the sensors and the processing circuitry. Large numbers of research teams are evaluating the use of different technological approaches to minimize the impact of radiation in new developments by using new detector material, connections and read-out architectures. Although most pixel detectors that are in operation are hybrid active pixel sensors, they present clear limitations for particle physics applications. These problems have led to increased efforts related to monolithic solutions, where the sensor, amplification and logic circuitry are found in the same Si-wafer. One of the possible technology solutions is SOI technology, which is the one that has been studied in this project.

Silicon-on-Insulator CMOS technology has been widely used for high gain and low power consumption circuitry, but now, some research groups are studying its use for developing monolithic radiation detectors. This is done by producing an opening and implantation below the thin oxide that connects the top active circuitry and the handle wafer. The use of this technology for particle radiation detectors is subject to the back gate effect because of the voltage applied to deplete the detector. Since the area under the transistor acts as a back gate, its potential affects the threshold voltage and the leakage current of the transistor. The back gate effect depends on many factors, such as the thickness of the bulk substrate, the voltage applied for detection and the guard ring patterns that can be introduced below the oxide to improve signal acquisition. To minimize this effect, different approaches can be made, from increasing the oxide thickness to include different well implantations below the read-out circuitry. One of the main goals of the TRAPPIS^TE (Tracking Particles for Physics Instrumentation in SOI Technology) project is to analyze these effects and study how to minimize them. In this study/project, two different technologies are used and different read-out approaches are evaluated. Initially a first prototype (TRAPPIS^TE-1) was developed at the Université catholique de Louvain (UCL) in Belgium at the WINFAB facility in Louvain-la-Neuve. WINFAB provided a 2 μ m FD-SOI CMOS process with one metal layer. For this prototype, a p-type wafer with a resistivity about 25 Ω cm was used. A second prototype, Trappiste-2, was fabricated with a 0.20 μ m FD-SOI CMOS technology, provided by OKI Semiconductors through the SOIPIX collaboration. The OKI process provides five metal layers and high resistivity n-type substrates of 700 Ω cm and 10k Ω cm. Both prototypes have been used to study the problem of back gate effect. The interest of using WINFAB technology is because it provides a thicker oxide layer. The second technology, the OKI technology, provides a method to mitigate the back gate effect with a buried P-well (BPW). The first results that will be presented are based on measurements of the test structures performed at different back voltages.

The first steps were used to validate our methodology and tried to characterize the transistors used at different Back Gate. The transistor test area contains single transistors whose gate, source and drain inputs are connected to test pads. It contains seven columns of transistors representing the source tied transistors provided by the OKI process. All of the transistors have a W/L of 10 μ /2 μ except for the I/O n-type Depleted MOS (DMOS) transistors which are size 2 μ /10 μ . The parameters such as threshold voltage (V_{TH}), mobility (μ_0) and transconductance (g_m) have been characterized. The method used to characterize the transistors is based on the linear-extrapolation technique in which V_{TH} is obtained by the linear extrapolation of the $I_D/(g_m)$. Another additional method, based on the calculation derivative is used, to validate the results obtained. These measurements have been performed at different back voltages (to deplete the sensor). The extraction of parameters is an important part of the device modeling and characterization process. Parameter calculations at two drain voltage conditions are used, 20mV and 50mV. The four calculations obtained agree with the values given by the technology.

The charge sensitive amplifiers were the first circuits tested. They were implemented in both WINFAB and OKI technologies. The amplifiers were based on a standard folded cascade core with a feedback capacitor. To

aid in the circuit design and dimensioning of the transistors, a gm/Id methodology was used. This methodology provides a rapid process-independent method of dimensioning transistors. Detector and amplifier specifications are used as inputs to a dimensioning plan to determine transistor sizes. The result is then simulated in ELDO to verify the functioning of the circuit. Measurement results will be presented and discussed, as the results agree with the simulations performed.

Session4 / 65

Development and characterization of the latest X-ray SOI pixel sensor for a future astronomical mission

Mr. NAKASHIMA, Shinya¹; Prof. TSURU, Takeshi¹; Mr. OHMOTO, Takafumi²; Dr. IWATA, Atsushi²; Mr. RYU, Syukyo¹; Prof. ARAI, Yasuo³; Mr. TAKEDA, Ayaki³; Dr. MIYOSHI, Toshinobu³; Dr. ICHIMIYA, Ryo³; Ms. IKEMOTO, Yukiko³; Mr. IMAMURA, Toshifumi²

¹ *Kyoto Univ.*

² *A-R-Tec Corp.*

³ *KEK*

Corresponding Author: shinya@cr.scphys.kyoto-u.ac.jp

We have been developing a novel active pixel sensor, X-ray SOIPIX (Silicon-On-Insulator Pixel Sensor), for a future X-ray astronomical mission.

It offers wide-band and high-time-resolution imaging spectroscopy with a low non-X-ray background rate.

The most distinguished feature of X-ray SOIPIX is an intra-pixel trigger system for the timing detection.

We have so far demonstrated that prototypes have the 10 us time resolution with the trigger system and the full depletion layer of 250 um.

A new prototype, named XRPIX2, has been produced in 2012.

It consists of two different size pixel arrays for evaluation of the design; one is 30 um pixel pitch with the format of 144 x 64 (small pixel array), and the other is 60 um pixel pitch with the format of 72 x 36 (large pixel array).

We increased the sense-node gain with reducing the parasitic capacitance in both pixel size arrays.

In order to improve the charge collection efficiency, we applied multi-via structure in the part of the large pixel array.

We will talk about the detailed design and characterization of XRPIX2.

Session3 / 66

CdTe pixel detector development for synchrotron radiation experiments

HIRONO, Toko ¹; TOYOKAWA, Hidenori ¹; WU, Shukui ¹; KAWASE, Morihiro ¹; FURUKAWA, Yukito ¹; OHATA, Toru ¹; IKEDA, Hirokazu ²; SATO, Goro ²; WATANABE, Shin ²; TAKAHASHI, Tadayuki ²

¹ *Japan Synchrotron Radiation Research Institute*

² *JAXA*

Corresponding Author: hirono@spring8.or.jp

This study describes a CdTe pixel detector development for the next generation high energy X-ray diffraction experiments at synchrotron radiation facilities. In such applications, a high stopping-power semiconductor material for the sensor and an X-ray photon counting capability for the ASIC are required. A Custom-designed ASIC (SP8-02) has been developed with TSMC 0.25 micron CMOS process, where each pixel has a preamplifier, a shaper, a window comparator, and a 20-bit counter. The analog circuit was characterized with a fast setting of 100 nsec and a dynamic range from 10 keV to 100 keV. The window comparator has advantage to avoid electric noise and fluorescent X-ray background by the lower threshold and higher-harmonics beam contamination by the upper threshold. We have fabricated a Pt/CdTe/Al-pixel sensor performing a Schottky diode detector with the electron-readout operation. This electrode-metal configuration realized a low leakage current and a long-term stability in near room temperature. The sensor was bump-bonded to the ASIC by the gold-stud bonding. The presentation will describe the features of SP8-02 and SP8-02B ASICs forming the 200 um x 200 um pixel size with the 20 x 50 matrix. The Pt/CdTe/Al-pixel sensor performance will be also discussed in comparison with Pt/CdTe/Pt-pixel and In/CdTe/Pt-pixel sensors.

Session1 / 67

CMS pixel status

GAZ, Alessandro ¹

¹ *University of Colorado at Boulder (US)*

Corresponding Author: alessandro.gaz@cern.ch

The core of the CMS experiment is a three layers pixel detector. Installed in 2008 the CMS pixel system is essential for track seeding and reconstruction of secondary vertexes. The Pixel detector was designed for a peak luminosity of $1E34 \text{ cm}^{-2}\text{s}^{-1}$. The presentation will summarize the operational experience of the first three years of collisions at the LHC. We will present the measured performance evolution as the Instantaneous luminosity delivered increased by several order of magnitude including dynamic data-losses, efficiency and resolution. The focus of the presentation will be on operational parameters, online calibrations and a overview of the challenges encountered to present.

Poster session / 68

Silicon Sensors for HL-LHC Tracking Detectors – RD50 Status Report

DERVAN, Paul ¹; PARZEFALL, Ulrich ²

¹ *University of Liverpool (GB)*

² *Albert-Ludwigs-Universitaet Freiburg (DE)*

Corresponding Author: ulrich.parzefall@cern.ch

It is foreseen to significantly increase the luminosity of CERN's Large Hadron Collider (LHC) by upgrading the LHC towards the HL-LHC (High Luminosity LHC) in order to harvest the maximum physics potential of the machine. Especially the final upgrade (Phase-II Upgrade) foreseen for 2021 will mean unprecedented radiation levels, exceeding the LHC fluences by roughly an order of magnitude. Due to the radiation damage limitations of the silicon sensors presently used, the physics experiments will require new tracking detectors for HL-LHC operation. All-silicon central trackers are being studied in ATLAS, CMS and LHCb, with extremely radiation hard silicon sensors to be employed on the innermost layers.

Within the CERN RD50 Collaboration, a massive R programme is underway across experimental boundaries to develop silicon sensors with sufficient radiation tolerance. One research topic is to gain a deeper understanding of the connection between the macroscopic sensor properties such as radiation-induced increase of leakage current, doping concentration and trapping, and the microscopic properties at the defect level. We also study sensors made from p-type silicon bulk, which have a superior radiation hardness as they collect electrons instead of holes, exploiting the lower trapping probability of the electrons due to their higher mobility. Another sensor option under investigation is to use silicon produced with the Czochralski-process. The high oxygen content in the Czochralski-Silicon has been shown to have a beneficial influence on some of the effects of radiation damage. A further area of activity is the development of advanced sensor types like 3D silicon detectors designed for the extreme radiation levels expected for the vertexing layers at the HL-LHC. These detectors in general have electrodes in the form of columns etched into the silicon bulk, which provide a shorter distance for charge collection and depletion, which reduces trapping and full depletion voltage. We will present results of several detector technologies and silicon materials at radiation levels corresponding to HL-LHC fluences. Based on these results, we will give recommendations for the silicon detectors to be used at the different radii of tracking systems in the LHC detector upgrades.

This presentation will cover the most recent RD50 results in a number of areas. Amongst these is the performance of 3D detectors before and after HL-LHC irradiation, demonstrating that the 3D technology has become a reliable candidate for LHC-Upgrades. Electric field measurements in heavily irradiated planar detectors will be presented, obtained in an edge-TCT setup with an infrared laser shining onto the polished edge of silicon detectors parallel to the detector surface. The field measurements are showing surprisingly high electric fields in the range of 0.5 V per micrometer in the undepleted silicon. The existence of this strong field can help to explain the unexpectedly good performance of planar silicon detectors after more than $10E16$ Neutron-equivalent per cm^2 .

Observations of charge multiplication effects at very high bias voltages in a number of detectors will be reported. In this context, we will show first measurements from a set of dedicated detectors designed in order to better understand the charge multiplication mechanism, thought to originate from avalanche multiplication in the high-field region of the detectors.

Session8 / 69

Future trends of 3D silicon sensors

Dr. DA VIA, Cinzia ¹

¹ *University of Manchester (GB)*

Corresponding Author: cinzia.da.via@cern.ch

Vertex detectors for the next LHC experiments upgrades will need to have low mass while at the same time be radiation hard and with sufficient granularity to fulfill the physics challenges of the next decade. Based on the gained experience with 3D silicon sensors for the ATLAS IBL project and the ongoing developments on light materials, interconnectivity and cooling, this paper will discuss possible solutions to these requirements.

Session5 / 70

Towards third generation pixel readout chips

GNANI, Dario ¹; TBD, TBD ²; GARCIA-SCIVERES, Maurice ³; Dr. MEKKAOU, Abderrezak ¹

¹ *LBNL*

² *TBD*

³ *Lawrence Berkeley National Lab. (US)*

Corresponding Author: mgarcia-sciveres@lbl.gov

We present concepts and prototyping results towards a third generation pixel readout chip. We consider the 130nm feature size FE-I4 chip, in production for the ATLAS IBL upgrade, to be a second generation chip. A third generation chip would have to go significantly further. A possible direction is to make the IC so generic that different experiments can configure it to meet significantly different requirements, without the need for everybody to develop their own ASIC. In terms of target technology, a demonstrator 500-pixel matrix containing analog front ends only (no complex functionality), was designed and fabricated in 65nm CMOS and irradiated with protons in Dec. 2011 and May 2012. We present the design and measurement results.

Session3 / 71

64-pixel linear-array Si-APD detector for X-ray time-resolved experiments

Prof. KISHIMOTO, Shunji ¹; Dr. YONEMURA, Hiroki ¹; Prof. ADACHI, Shinnichi ¹; Mr. SHIMAZAKI, Shoichi ¹; Mr. IKENO, Masahiro ¹; Mr. SAITO, Masatoshi ¹; Dr. TANIGUCHI, Takashi ¹; Prof. TANAKA, Manobu ²

¹ *High Energy Accelerator Research Organization*

² *High Energy Accelerator Research Organization*

Corresponding Author: syunji.kishimoto@kek.jp

We have developed a silicon avalanche-photodiode (Si-APD) array detector for time-resolved measurements using pulsed synchrotron X-rays. The Si-APD detector had 64 pixels of a linear array, where the pixel size was 100 μm by 200 μm with a 50- μm gap between pixels and a depleted thickness was 10 μm . The detector system was equipped with 64-channel front-end ASICs, FPGAs and SiTCP (a network processor). The prototype system resolved a 10-ns interval of X-ray pulses at a count rate of $> 10^7$ cps per channel. The nanosecond response and the high count-rate property are extremely valuable for time-resolved X-ray diffraction measurements in pulsed synchrotron radiation. If a detector system can resolve a time interval of shorter than 2 ns, the system will be very efficient for recording an intensity- or position-change of X-ray diffraction spots in nanosecond-order period. We are now in progress of test for the 64-channel Si-APD array detector with synchrotron X-ray beam. The detail of the test results will be presented in the workshop.

Session8 / 72

Results of a Multi Project Wafer Process of Edgeless Silicon Pixel Detectors

Dr. KALLIOPUSKA, Juha¹; Dr. WU, Xiaopeng¹

¹ VTT

Corresponding Author: juha.kalliopuska@vtt.fi

The edgeless or active edge silicon pixel detectors have been gaining a lot of interest recently due to improved silicon processing and interconnection technology capabilities. VTT has been one of the drivers of the edgeless process technology on 6" (150 mm) wafers. Last year we were able to gather 17 institutions and industrial companies to join for a multi project wafer process of edgeless silicon detectors. These participants come from different fields of applications, such as high energy physics, X-ray imaging, photon science and other medical and spatial applications. Their demands for the detector and design are very diverse and thus the process needed to be carefully designed. In total, 80 pieces of 150 mm wafers were processed to yield a given number of detector variations. The fabricated detector thicknesses were 100, 200, 300 and 500 nm. The polarities of the fabricated detectors on the given thicknesses were p-on-n, n-on-n, n-on-p and p-on-p. The wafer materials were high resistive Float Zone and Magnetic Czochralski silicon with crystal orientation.

The presentation gives an overview of the process and statistically summarizes the electrical characteristics of the edgeless diodes with varied polarities. The characteristics include leakage current, breakdown voltage and capacitance-voltage measurements. The first measurements have indicated reasonable leakage currents of 1-4 nA/cm² at full depletion voltage. Pixel detector characterization results from number of participants are presented with their permission. These include X-ray images, charge collection efficiency and operation of the edgeless detectors after heavy irradiation. Special focus is given on a new edgeless detectors designed for the Timepix and Medipix3 readout ASIC chips.

Session5 / 73

3D Electronics for Tracking Triggers

Dr. LIPTON, Ronald¹; TRIMPL, Marcel²

¹ Fermi National Accelerator Lab. (US)

² Fermilab

Corresponding Author: ronald.lipton@cern.ch

We describe our current efforts in sensor/electronics integration, including 3D and SOI devices. Application of these technologies to track triggers for CMS and Atlas as well as x-ray imaging will be described. A central question is whether these technologies will be sufficiently affordable with high enough yield to build large area modules such as those required for CMS. We will discuss the development "active tiles" which combine 3D and active edge technologies as a possible solution to the yield problem. Such building blocks would enable the fabrication of fully active pixelated large area arrays.

Session7 / 74

Single Event Effect Characterization of the Analog ASIC Developed for CCD Camera in Astronomical Use

NAKAJIMA, Hiroshi ¹; Ms. FUJIKAWA, Mari ¹; Dr. HAYASHIDA, Kiyoshi ¹; Prof. TSUNEMI, Hiroshi ¹; Dr. DOTY, John ²; Prof. IKEDA, Hirokazu ³; Dr. KITAMURA, Hisashi ⁴; Dr. UCHIHORI, Yukio ⁴; Mr. MORI, Hideki ¹; Mr. KAN, Hiroaki ¹; Mr. UEDA, Shutaro ¹; Ms. KOSUGI, Hiroko ¹; Dr. ANABUKI, Naohisa ¹

¹ *Osaka University*

² *Noqsi Aerospace Ltd.*

³ *ISAS/JAXA*

⁴ *NIRS*

Corresponding Author: nakajima@ess.sci.osaka-u.ac.jp

Single-event measurements on the analog ASIC developed for astronomical CCD camera systems are reported. The experiments using several heavy ions and protons exhibited positive correlation between the particle's LET (linear energy transfer) and the probability of the SEU (single event upset). The predictive SEU rate in the low earth orbit was derived on the assumption of the CCD camera (SXI) onboard ASTRO-H, the next Japanese X-ray astronomical satellite. The upper limit of the SEU rate of 4.6×10^{-3} evts/sec is sufficiently low compared with the non X-ray background of SXI. We also report on the radiation tolerance of our device against SEL (single event latch-up).

Session8 / 76

Recent results on 3D double sided detectors at CNM-IMB

PELLEGRINI, Giulio ¹

¹ *Instituto de Microelectrónica de Barcelona, IMB-CNM-CSIC, Barcelona, Spain*

Corresponding Author: giulio.pellegrini@cnm.es

The upgrade of the LHC to HL-LHC envisaged for 2020 requires silicon detectors of unprecedented radiation tolerance for the silicon tracking detectors. The very high luminosity foreseen ($2.5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$) implies that the innermost layers detectors, at about 3 cm from the interaction point, of the vertex detector will be exposed to fluence up to $1.4 \times 10^{16} \text{cm}^{-2}$ 1 MeV neutron equivalent for the 2020 upgrade over the expected years of operation. Present vertex detectors, relying on highly segmented silicon sensors, are designed to survive fast hadron fluence of about 10^{15}cm^{-2} . Under these conditions, detector performance is limited since a large number of defects are introduced into the device. During detector operation, the charge carriers created by ionizing radiation are trapped into those defects with discrete energy levels in the band-gap of the silicon substrate, resulting in incomplete charge collection.

Silicon detectors with cylindrical electrodes (so called 3D detectors) offer advantages over standard planar photodiodes as more radiation hard radiation sensors. 3D detectors with the double sided geometry have been fabricated at CNM clean room facilities. Different geometries including pixel detectors for high energy physics experiment and synchrotron imaging, short strip detectors with the same inter-column spacing as proposed for the ATLAS and CMS pixel detector upgrades foreseen for 2020.

The 3D detector is shown to have superior charge collection characteristics even at the highest fluences even when compared to planar devices operating at 1000V, which is in excess of that presently possible in the ATLAS experiment. Annealing studies of the collection efficiency and the main electrical characteristics of the detectors are also investigated. The experimental results are compared to the simulation of charge transport in the devices.

Session8 / 77

Results with p-type pixel sensors with different geometries for the HL-LHC

CASSE, Gianluigi¹; DERVAN, Paul²; FORSHAW, Dean Charles¹; BATES, Richard³; BUTTAR, Craig³; TSURIN, Ilya¹¹ *University of Liverpool (GB)*² *Department of Physics-Oliver Lodge Laboratory-University of Liv*³ *Department of Physics and Astronomy-University of Glasgow***Corresponding Author:** gianluigi.casse@cern.ch

Pixel detectors will be extensively used for the four innermost layers of the upgraded ATLAS experiment at the future High Luminosity LHC (HL-LHC) at CERN. The total area of pixel sensors will be over 5 m². The silicon sensors that will instrument the pixel volume will have to face several technology challenges. They will have to withstand doses up to 2×10¹⁶ neq cm⁻², to have a reduced inactive area at the edge of the sensors still being able to hold 1000V bias voltage and to be relatively low cost considering the large area to be covered. N-side readout on p-type bulk is the most promising technology for satisfying the various requirements. Several sensor types have been produced in the UK, conceived for various readout systems, for studying the properties of n-in-p and n-in-n sensors before and after irradiation with test beam and laboratory measurements. The status of these studies is here presented in term of charge collection efficiency and charge sharing performances.

Session6 / 78

Monolithic Active Pixel Matrix with Binary Counters (MAMBO) ASIC, using a nested well structure to decouple the detector from the electronics

FAHIM KHALID, Farah¹; DEPTUCH, grzegorz²; Mr. YAREMA, Ray³; Ms. SHENAI, alpna¹; Mr. HOLM, scott¹¹ *Fermilab*² *fnal*³ *FNAL***Corresponding Author:** farah@fnal.gov

Monolithic Active Matrix with Binary Counters (MAMBO) V ASIC has been designed for detecting and measuring low energy X-rays from 6-12keV. A nested well structure with a buried n-well (BNW) and a deeper buried p-well (BPW) is used to electrically isolate the detector from the electronics. BNW acts as an AC ground to electrical signals and behaves as a shield. BPW creates a homogenous electric field in the entire detector volume. The ASIC consists of a matrix of 50×52 pixels, each of 105×105µm². Each pixel contains analogue functionality accomplished by a charge preamplifier, CR-RC2 Shaper and a baseline restorer. It also contains a window comparator with Upper and Lower thresholds which can be individually trimmed by 4 bit DACs to remove systematic offsets. The hits are registered by a 12 bit counter which is reconfigured as a shift register to serially output the data from the entire ASIC. Test results indicate good analogue and digital performance.

Session7 / 79

Microchannel cooling for the LHCb VELO Upgrade

MAPELLI, Alessandro ¹; PETAGNA, Paolo ¹; Dr. NOMEROTSKI, Andrey ²; DUMPS, Raphael ¹; VERLAAT, Bart ³; BUYTAERT, Jan ¹¹ CERN² University of Oxford (GB)³ NIKHEF-CERN**Corresponding Author:** paula.collins@cern.ch

Local thermal management of detector electronics through ultra-thin micro-structured silicon cooling plates is an extremely promising technique for HEP with wide potential application in other fields. It combines a very high thermal efficiency with a very low addition of mass and space, and suppresses all problems of CTE mismatch between the heat source and the heat sink.

Typical micro-fabrication techniques such as photolithography, etching, wafer bonding and thinning are all involved in the process. The technique is very suited to the LHCb VELO upgrade, where there is the challenge of constructing an efficient cooling system which is radiation hard, adds minimal material to the system, and provides an excellent CTE match to the silicon sensing elements and ASICs. The microchannel designs under development have to be specially adapted for the use of CO₂ as the coolant, with the additional challenges of thinner channels, constrictions to allow an evaporative CO₂ cooling process, and the higher pressures involved. The numerical simulations also have to be enhanced to describe the turbulent flow within the channels. In addition to the design of the microchannels within the wafers themselves, the connectivity has also to be adapted to cope with the higher pressures, and to allow close packing of the forward silicon planes. A series of designs have already been prototyped and tested for LHCb. The challenges, current status of the measurements, and the solutions under development will be described.

Session5 / 80

VELOpix ASIC development for LHCb VELO Upgrade

Dr. VAN BEUZEKOM, Martin ¹¹ NIKHEF (NL)**Corresponding Author:** paula.collins@cern.ch

The upgrade of the LHCb experiment, planned for 2018, will transform the readout of the entire experiment to a triggerless system operating at 40 MHz. All data reduction algorithms will be run in a high level software farm, and will have access to event information from all subdetectors. This approach will give great power and flexibility in accessing the physics channels of interest in the future, in particular the identification of flavour tagged events with displaced vertices. The data acquisition and front end electronics systems require significant modification to cope with the enormous throughput of data. For the silicon vertex locator (VELO) a dedicated development is underway for a new ASIC, VELOpix, which will be a derivative of the Timepix/Medipix family of chips. The chip will be radiation hard and be able to cope with pixel hit rates of above 500 MHz, highly non-uniformly distributed over the ~2 cm² chip area. The chip will incorporate local intelligence in the pixels for time-over-threshold measurements, time-stamping and sparse readout. It must in addition be low power, radiation hard, and immune to single event upsets. In order to cope with the data rates and use the pixel area most effectively, an on-chip data compression scheme will be integrated. This contribution will describe the requirements of the LHCb VELO upgrade, give an overview of the digital architecture being developed specifically for the readout chip, and describe the off-detector signal processing, including time ordering, clustering and pattern recognition algorithms. First results from prototype sensors and ASICs will be presented.

Session2 / 81

The LHCb VELO UpgradeCARVALHO AKIBA, Kazuyoshi ¹¹ *Nikhef***Corresponding Author:** paula.collins@cern.ch

The LHCb VELO (silicon Vertex Locator) will be upgraded in 2018, as part of the general upgrade of the LHCb experiment, which will transform the entire detector readout to a triggerless system operating at 40 MHz. The current L0 hardware trigger will be removed, and all data reduction algorithms will be executed in a high level software farm, with access to all event information. This will enable the detector to run at luminosities of above $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ and explore New Physics effects in the beauty and charm sector with unprecedented precision. The new vertex detector will have to cope with radiation levels of up to $10^{16} \text{ MeV neutron equivalents / cm}^2$, more than an order of magnitude higher than those expected at the current experiment. At the same time, the sensors must approach the beam as closely as possible (7mm or below) without introducing dead material, hence the design of the sensor guard ring is crucial. New sensor designs have been launched for the 55 x 55 micron square pixel technology options with a number of manufacturers, and are being prototyped in lab and testbeam measurements. The lightweight radiation-hard assembly will integrate evaporative CO₂ cooling for which microchannel cooling is being considered as an alternative to diamond or TPG heat spreading planes. Technological challenges include the module design, the construction of a lightweight foil to separate the primary and secondary LHC vacuua, the use of high speed cables, and the metallisation and radiation qualification of the module. In order to cope with the huge data flow special techniques will be applied, with the major areas of R focussing on techniques for data compression in the chips, time ordering in the FPGAs, and the use of GPUs for pattern recognition and tracking. The current status of the LHCb VELO upgrade developments will be described, and the latest results from the mechanical prototyping and sensor tests in the testbeams will be shown.

Poster session / 82

GEANT4 and GDML detector simulation frameworkREID, Matthew Michael ¹; BUYTAERT, Jan ²¹ *University of Warwick*² *CERN***Corresponding Author:** paula.collins@cern.ch

An accurate description of the geometry and material density in modern particle detectors becomes ever more critical as the mass of these devices decreases, and the detectors aim to be sensitive to low pt physics. An example in point is the LHCb VELO upgrade, where the pixel planes at the upgrade will be situated very close to the beam line, but separated from the primary vacuum by a thin foil with a complex corrugated shape. Understanding the shape optimization for physics performance and the expected performance has led to the development of a new software approach for simulating the material, whereby the mechanical CAD drawings can be directly imported into the GEANT4 material via a GDML (Geometry Description Markup Language) interface which converts shapes into tessellated solids made up of triangular or quadrangular facets forming a closed space. This allows a more accurate and less labour intensive geometry implementation than traditional XML approaches. First results will be shown from this method, together with the approaches taken to generalize, test, and optimize the CPU performance of the method.

Poster session / 83

Performance of the X-ray CCD coated with Optical Blocking Layer for SXI onboard ASTRO-H

Mr. IKEDA, Shoma¹; Mr. KOHMURA, Takayoshi¹; Mr. UCHIDA, Hiroyuki²; Mr. OHNISHI, Takao²; Mr. DOTANI, Tadayasu³; Mr. OZAKI, Masanobu³; Mr. TOMIDA, Hiroshi⁴; Mr. KITAMOTO, Shunji⁵; Mr. MURAKAMI, Hiroshi⁵; Mr. KANEKO, Kenta¹; Mr. TSUNEMI, Hiroshi⁶; Mr. HAYASHIDA, Kiyoshi⁶; Mr. ANABUKI, Naohisa⁶; Mr. NAKAJIMA, Hiroshi⁶; Mr. UEDA, Shutaro⁶; Mr. KAN, Hiroaki⁶; Mr. TSURU, Takeshi²

¹ Kogakuin University

² Kyoto University

³ JAXA/ISAS

⁴ JAXA

⁵ Rikkyo University

⁶ Osaka University

Corresponding Author: am11009@ns.kogakuin.ac.jp

We have developed the back-illuminated X-ray CCD camera (BI-CCD) for Soft X-ray Imager (SXI) onboard ASTRO-H. Since the X-ray CCD, especially BI-CCD has a high sensitivity not only for in X-ray but also in both visible light and UV light, X-ray CCD for SXI is directly coated the 100nm thick aluminum on the surface of the CCD in order to block visible light, and we name this aluminum layer OBL (Optical Blocking Layer). We will install Contamination Blocking Filter (CBF) in front of the CCD to protect the CCD from contaminants adsorbed onto the CCD. This CBF is made from 30nm thick aluminum and 200nm thick polyimide, and CBF can also cut off visible light as well as UV light.

We have developed the prototype CCD for SXI coated with OBL and we have measured the energy resolution, dark current, quantum efficiency, and so on by irradiating the soft X-ray at KEK-PF and the X-ray from ⁵⁵Fe. We have also measured the optical transmission of OBL and confirmed the optical transmission of OBL is an order of 10⁻⁵ which was the same order of our expected value.

We will show the performance of the proto-type CCD for SXI, mainly focusing on QE at soft X-ray range below 2keV, as well as the optical transmission of OBL.

Session5 / 84

Frontend Electronics development for the CMS pixel detector upgrade

Dr. KAESTLI, Hans-Christian ¹; HORISBERGER, Roland ¹; Mr. MEIER, Beat ²; ERDMANN, Wolfram ¹

¹ *Paul Scherrer Institut (CH)*

² *ETHZ*

Corresponding Author: hans-christian.kaestli@psi.ch

The performance of the LHC accelerator at CERN has been outstanding since its startup in 2010. It seems likely that the delivered instantaneous luminosity exceeds its design value of 10^{34} cm⁻² s⁻¹ soon after the recommissioning in 2014. Tracking in such a dense environment is challenging. This is especially true for the main tasks of the pixel detector such as b-tagging. In order to compensate for the expected decrease in performance due to the high number of simultaneous interactions, an upgrade of the pixel detector has been proposed. The innermost barrel layer moves closer to the interaction region and a fourth barrel layer and a third endcap disk on each side have been added.

In order to cope with this substantial increase of data rates, an improved version of the front end electronics is needed. The new CMS pixel readout chip (ROC) is developed in two steps, based on the present ROC. In a first step, several measures have been taken to lower the inefficiencies inside the ROC and to improve analog performance. The output data format has been changed to a digital scheme to increase data throughput. In a second step, the core of the so called Column Drain architecture needs substantial modifications to cope with the data rates expected in the innermost barrel layer.

We will present the overall concept of the front end electronics development and show results from measurements of the first step prototype chip.

Session3 / 85

Developing a CCD camera with high spatial resolution for RIXS in the soft X-ray range

SOMAN, Matthew¹; HALL, David²; TUTT, James²; MURRAY, Neil¹; SCHMITT, Thorsten³; RAABE, Joerg⁴; SCHMITT, Bernd³; HOLLAND, Andrew¹

¹ *Open University*

² *The Open University*

³ *Paul Scherrer Insitut*

⁴ *Paul Scherrer Institut*

Corresponding Author: m.r.soman@open.ac.uk

The Super Advanced X-ray Emission Spectrometer (SAXES) at the Swiss Light Source contains a high resolution Charge Coupled Device (CCD) based camera used for Resonant Inelastic X-ray Scattering (RIXS) [1]. Using the current CCD based camera system, the energy-dispersive spectrometer has an energy resolution ($E/\Delta E$) of approximately 12000 at 930 eV [2]. A recent study [3] predicted that through an upgrade to the grating and camera system, the energy resolution could be improved by a factor of two. In order to achieve this goal in the spectral domain, the spatial resolution of the CCD must be improved to better than 5 μm from the current 24 μm spatial resolution (FWHM) [2].

The 400 to 1600 eV energy X-rays detected by this spectrometer primarily interact within the field free region of the CCD, producing electron clouds which will diffuse isotropically until they reach the depleted region and buried channel. This diffusion of the charge leads to events which are split across several pixels. Through the analysis of the charge distribution across the pixels, various centroiding techniques can be used to pinpoint the spatial location of the X-ray interaction to the sub-pixel level, greatly improving the spatial resolution achieved.

Using the PolLux soft X-ray microspectroscopy endstation at the Swiss Light Source, a beam of X-rays of energies from 200 to 1200 eV can be focused to a spot size of approximately 20 nm [4]. Scanning this spot across the 16 μm square pixels allows the sub-pixel response to be investigated. Previous work has demonstrated the potential improvement in spatial resolution achievable by centroiding events in a standard CCD [5]. An Electron Multiplying-CCD (EM-CCD) has been used to improve the signal to readout noise ratio achieved. Centre of mass centroiding algorithms have been corrected for their non-linearity using a non-linear η algorithm [6]. Various non-linear correction algorithms have been investigated to optimise performance. The spatial resolution of an EM-CCD is demonstrated to be better than 2 μm (FWHM) in a photon counting mode.

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Poster session / 86

A study on the dynamic range of integrating SOI chips

Dr. LU, Yunpeng ¹

¹ *Institute of High Energy Physics, Beijing*

Corresponding Author: yunpeng.lu@cern.ch

In the SOI process developed by KEK and LAPIS, transistors can be divided into two groups by their nominal power supply, 1.8V and 2.5V respectively. All the past integrating SOI chips use 1.8V transistors in core circuit and 2.5V in IO buffers. To verify the idea of increasing dynamic range of integrating charge, a chip using 2.5V transistors in core circuit was submitted to MPW run in 2011. The test results show that an increment of 50% of dynamic range can be achieved by this way.

Session5 / 87

Multi-Channel LuAG-APD Pixel Array with ToT Readout System

Dr. SHIMAZOE, Kenji ¹; Prof. TAKAHASHI, Hiroyuki ¹

¹ *The University of Tokyo*

Corresponding Author: shimazoe@it-club.jp

A 144-channel Pr:LuAG-APD detector is designed and fabricated for medical application. The pixel of the crystal is 2mm x 2mm x 10mm and individually coupled with UV-enhanced 12 x 12 Avalanche Photo Diode array. The APD's pixels are individually connected with Time over Threshold based ASIC and sent to DAQ FPGA. ToT-ASIC is fabricated with 0.25um TSMC CMOS and the power dissipation is 230mW/board. FPGA is programmed to calibrate individual thresholds and digital multiplexing. The measured timing resolution is 4ns/module and transmission image is successfully acquired.

Session2 / 88

Status of PHENIX Silicon Pixel Detector

Dr. TAKETANI, Atsushi ¹

¹ *RIKEN*

Corresponding Author: taketani@riken.jp

The PHENIX detector at RHIC has been equipped Silicon Pixel Detector for identifying the bottom and charm particle by measuring secondary vertex point in the $\sqrt{s_{NN}} = 200\text{GeV}$ Au-Au collisions and $\sqrt{s}=500\text{GeV}$ polarized collisions, with Silicon stripixel detectors. The detector consists of 50*400 micron pixel sensors, bump bonded readout chips, high density readout flexible print circuit board and carbon composite holders. 25 micron aluminum wires connect among readout chips and print circuit boards. They are encapsulated by the silicone adhesives to protect mechanically and vibration force from Lorentz force in the strong magnetic field. Due to differences in CTE between the pixel stave and the silicone encapsulant, thermal cycling promoted the breaking of wire bonds. The encapsulated silicone and wires were removed from broken ladders, bonding pad were cleaned, and then wires were bonded. Since Silicone has 300 ppm/deg expansion coefficient and other materials have 30 ppm/deg, another Silicone, which has similar expansion coefficient, but is much softer, was chosen. New re-assembled ladders was tested with some heat shock test and survived. We would like to report the status of the PHENIX Silicon Pixel Detector operations as well as the repairing process of the broken wires.

Poster session / 90

Applications of a High-contrast X-ray CT to Polymers, Insects, Plants, Foods, etc.

NISHIKAWA, Yukihiro¹; Dr. BABA, Sueki²; Prof. TAKAHASHI, Masaoki¹

¹ *Kyoto Institute of Technology*

² *Beamsense Co. Ltd. Japan*

Corresponding Author: kiro@kit.ac.jp

Since polymers mainly consist of the light atomic elements, the transmission of polymers against X-rays is usually too high to be visualized in X-ray microscopy, and hence, it has been considered that the polymers are not suitable for the X-ray computerized tomography (XCT). We calculate the X-ray absorption coefficients of various polymers and find the reasonably good conditions for the XCT observations of polymers: the use of 15 KeV X-rays on average can resolve the polystyrene and poly(methy methacrylate) in 3 μm spatial resolutions. According to this calculation, we build a XCT and experimentally confirmed the visualization of the phase-separation structures of PS/PMMA blends. Thus developed apparatus is applied to many kinds of subjects, such as insects, plants, foods, and so on.

Poster session / 92

X-ray characterization of CMOS imaging detector with high resolution for fluoroscopic imaging application

Dr. CHA, Bo Kyung¹

¹ *KERI*

Corresponding Author: goldrain99@gmail.com

In recent years, CMOS(Complementary metal oxide semiconductor)-based X-ray imagers have been researched and used for high resolution and real time X-ray imaging application. The CMOS image sensor has many advantages such as the higher readout speed, low noise and high system integration compared to amorphous silicon flat panel detector. Besides the lower noise and higher speed, the smaller pixel size can be able to acquire X-ray image with higher spatial resolution. The drawback of CMOS technology is the limited size and less resistive to X-ray irradiation in comparison with a-Si TFT array X-ray imager. However, the small size limitation of CMOS image sensor can be overcome by tiling the detector into larger mosaics.

In this work, The CMOS detector was fabricated using a 0.35 μm 1poly/4metal standard CIS process. The CMOS detector has 94x24 pixel array of 100 μm x100 μm pixel size. The column-parallel readout architecture was used to reduce the operating speed and the random noise. The 14-bit extended counting ADC was used to reduce the area and simultaneously improve the image resolution. The CMOS detector of different frame rates with 30fps (frame per second) in normal mode and 60fps in binning mode was developed for low dose fluoroscopic application.

For measurement of the X-ray imaging characterization, a thallium-doped CsI(CsI:Tl) scintillator film of 200 μm thickness was directly deposited on the CMOS photodiode array by thermal evaporation method. The Gd₂O₂S:Tb scintillation screen with different thickness was also used for comparisons of X-ray image performance. The X-ray imaging performance such as the light response to X-ray exposure dose, signal-to-noise-ratio (SNR) and modulation transfer function (MTF), image lag etc. were measured under practical fluoroscopic systems.

Poster session / 93

Structural and electrical properties of polycrystalline CdTe films for direct X-ray imaging detectors

Dr. CHA, Bo Kyung¹

¹ *KERI*

Corresponding Author: goldrain99@gmail.com

In recent years, direct conversion flat-panel X-ray imaging detectors have been researched and used in various medical applications such as chest radiography, mammography and fluoroscopy imaging. In direct detection method, an X-ray photoconductor is used as a conversion material to transform the absorbed X-ray photons to electrical charge, which carries the corresponding signal. In addition to amorphous selenium, the various photoconductor materials such as lead iodide (PbI₂), mercury iodide (HgI₂), lead oxide (PbO) and cadmium telluride (CdTe) or cadmium zinc telluride (CdZnTe) have reported the significant potential. Among many photoconductors mentioned, CdTe direct-conversion material has been considered as very an attractive candidate for high energy X-ray imaging application.

In this work, polycrystalline CdTe films were fabricated on ITO/glass substrate by both physical vapor deposition (PVD) with slow deposition rate and pressure of 10⁻⁶ torr and closed space sublimation (CSS) method with high deposition rate and low vacuum pressure(10⁻³ torr). The various polycrystalline CdTe films were grown by different deposition rate, substrate temperature, annealing condition. Physical properties such as microstructures, crystal structure of the polycrystalline samples were investigated by SEM and XRD pattern respectively. The microstructures with columnar shape and more uniform surface were observed in PVD method. On the other hand, the microstructures with many larger grains and less uniform surface were shown in CSS method. The films were polycrystalline structure with preferential (111) direction. The electrical properties such as the dark current as a function of applied bias, X-ray sensitivity and signal-to-noise ratio (SNR) of the fabricated films were measured and investigated under X-ray exposure condition. The obtained experimental results will be presented in detail.

Session8 / 94

Radiation hardness and slim edge studies of planar n-in-n ATLAS pixel sensors for HL-LHC upgrades

WITTIG, Tobias¹; ALTENHEINER, Silke¹; FADEYEV, Vitaliy²; GOESSLING, Claus¹; JENTZSCH, Jennifer¹; KLINGENBERG, Reiner¹; PLÜMER, Till; Mr. RUMMLER, Andre¹; SADROZINSKI, Hartmut³

¹ *Technische Universitaet Dortmund (DE)*

² *University of California, Santa Cruz (US)*

³ *SCIPP, UC santa Cruz*

Corresponding Author: tobias.wittig@cern.ch

ATLAS plans two major upgrades of its pixel detector on the path to HL-LHC: First, the insertion of a 4th pixel layer (Insertable B-Layer, IBL) is currently being prepared for 2013. This will enable the ATLAS tracker to cope with an increase of LHC's peak luminosity to about $3E34 \text{ cm}^{-2} \text{ s}^{-1}$ which requires a radiation hardness of the sensors of up to $5E15 \text{ n}_{\text{eq}} \text{ cm}^{-2}$. Towards the end of this decade, a full replacement of the inner tracker is foreseen to cope with luminosities of up to $1E35 \text{ cm}^{-2} \text{ s}^{-1}$ at HL-LHC. Here, the innermost pixel layer will have to withstand a radiation damage of $2E16 \text{ n}_{\text{eq}} \text{ cm}^{-2}$.

Because of an inactive safety margin around the active area, the sensor modules of the present ATLAS pixel detector have been shingled on top of each other's edge which limits the thermal performance and adds complexity. For the IBL and the HL-LHC upgrade of ATLAS, a flat arrangement of the sensors is foreseen. Therefore, it is essential to reduce the inactive edge to a minimum so the required level of detector hermeticity can be achieved.

N-in-n sensor assemblies based on the current ATLAS pixel read-out chip FE-I3 as well as on the new FE-I4 chip have been irradiated to IBL and HL-LHC fluences using thermal neutrons in Ljubljana as well as protons in Karlsruhe and at CERN PS. Magnetic-Czochralski bulk sensors were irradiated with neutrons and protons which models the expected scenario for the medium layers. Space resolved analysis results such as hit efficiencies from data taken in CERN SPS and DESY test beams are going to be shown. Further unirradiated and irradiated pixel sensors with a dedicated design were studied in test beams to investigate the efficiency performance in their edge region.

A promising method to reduce the inactive peripheral sensor region to a minimum is the scribe, cleave and passivate (SCP) technique. First results of such post processed planar n-in-n pixel sensors will be shown.

Session8 / 95

Planar pixel detector module development for the HL-LHC ATLAS pixel system

BATES, Richard ¹; BUTTAR, Craig ¹; TSURIN, Ilya ²; Dr. BROWN, Simon ³; PATER, Joleen ⁴; Mr. ASHBY, Joseph ⁵; Dr. BLUE, Andrew ⁵; STEWART, Andrew ⁶; DOONAN, Kate ¹; CASSE, Gianluigi ²; DERVAN, Paul ²; FORSHAW, Dean Charles ⁷

¹ *University of Glasgow (GB)*

² *University of Liverpool (GB)*

³ *University of Manchester (GB)*

⁴ *University of Manchester*

⁵ *University of Glasgow*

⁶ *U*

⁷ *University of Liverpool-Unknown-Unknown*

Corresponding Author: richard.bates@glasgow.ac.uk

The ATLAS pixel detector for the HL-LHC will require the development of large area pixel modules that can withstand does up to 2×10^{16} neq cm⁻³. The area of the pixel system will be over 5m² and as such low cost, large area modules are required. The development of a quad module based on 4 FE-I4 ROIC will be discussed. The FE-I4 ROIC is a large area chip and the yield of the flip-chip process on single chips and the quads is covered. The readout of the quad module for laboratory tests will be reported. To reduce mass of the system the assembly will be required to be as thin as possible and the insensitive edges of the sensors also need to be reduced to a minimum. The thin edge is achieved by reducing the physical edge of the sensor and by the use of through-silicon vias to move the wire bond pads from the edge of ROIC to its backside. Progresses in these areas are discussed.

Session2 / 96

Advances in the Development of Pixel Detector for the SuperB Silicon Vertex Tracker

Dr. PAOLONI, Eugenio ¹

¹ *INFN Pisa*

Corresponding Author: eugenio.paoloni@pi.infn.it

The latest advances in the design and characterization of several pixel sensors developed to satisfy the very demanding requirements of the innermost layer of the SuperB Silicon Vertex Tracker will be presented in this paper.

The SuperB machine is an electron positron collider operating at the Y_{4S} peak to be built in the very near future by the Cabibbo Lab consortium.

A pixel detector based on extremely thin, radiation hard devices able to cope with rate in the tens of MHz/cm² range will be the optimal solution for the upgrade of the inner layer of the SuperB tracking system.

At present several options with different levels of maturity are being investigated to understand advantages and potential issues of the different technologies:

thin hybrid pixels, Deep N-Well CMOS MAPS,

INMAPS CMOS MAPS featuring a quadruple well and high resistivity substrates and CMOS

MAPS realized with Vertically Integration technology.

The newest results from beam test, the outcomes of the radiation damage studies and the laboratory characterization of the latest prototypes will be reported.

Session2 / 97

The New PILATUS3 ASIC with Instant Retrigger Capability

Dr. BROENNIMANN, Christian ¹; Dr. DONATH, Clemens ¹; Dr. LOELIGER, Teddy ¹; Dr. SCHNEEBELI, Matthias ²; Mr. SCHNYDER, Roger ¹; Dr. SCHULZE-BRIESE, Clemens ¹; Dr. TRUEB, Peter ¹

¹ *Dectris Ltd.*

² *matthias.schneebeli@dectris.com*

Corresponding Author: clemens.schulzebriese@dectris.com

A novel photon counting method for non-paralyzable counting and its implementation in the new PILATUS3 ASIC are presented. Pulse pile-up significantly affects the observed count rate at high photon fluxes in single-photon counting x-ray detectors and can lead to complete paralyzation of the counting circuit. In PILATUS single-photon counting hybrid-pixel x-ray detectors, count rate correction is applied in order to compensate for the counting loss at high count rates. However, counter paralyzation limits the maximum usable count rate of the PILATUS2 ASIC to typically $2 \cdot 10^6$ photons per second and pixel. In order to overcome this limitation, instant retrigger capability is introduced as a new photon counting method that results in non-paralyzable counting and achieves improved high-rate counting performance. The instant retrigger capability re-evaluates the pulse signal after a predetermined dead time interval after each count and potentially retriggers the counting circuit in case of pulse pile-up. The respective dead time interval is adjustable and accounts for the width of a single photon pulse. As a result, the counting becomes non-paralyzable and enhanced count rate correction can be applied in order to achieve improved data quality at high count rates. The new PILATUS3 ASIC features instant retrigger capability with adjustable dead time. The implementation of this new approach and experimental results are presented. The new ASIC additionally features counter overflow handling, improved pixel uniformity, reduced crosstalk, reduced readout time, and compatibility with CdTe sensors. With the new design, higher count rates can be measured and better data quality is achieved up to rates of more than 10^7 photons per second and pixel.

Session2 / 98

The Diamond Beam Monitor for Luminosity Upgrade of ATLAS

KAGAN, Harris ¹¹ O**Corresponding Author:** kagan.1@osu.edu

Luminosity monitors, beam monitors and tracking detectors of the experiments at the Large Hadron Collider and their upgrades must be able to operate in radiation environments several orders of magnitude harsher than those of any current detector. We have observed in ATLAS that as the environment becomes harsher, detectors not segmented, either spatially or in time, have difficulty handling the separation of signal from background. Once the charged particle multiplicity reaches the point where all segments of these detectors have a high probability of having a hit in every bunch crossing their sensitivity quickly vanishes. This is already happening in ATLAS to the MBTS luminosity counters that will be removed in the 2011 year-end shutdown and LUCID luminosity counters. Chemical Vapor Deposition (CVD) diamond has a number of properties that make it an attractive alternative for high energy physics detector applications. Its large band-gap (5.5 eV) and large displacement energy (42 eV/atom) make it a material that is inherently radiation tolerant with very low leakage currents and high thermal conductivity. CVD diamond is being investigated by the RD42 Collaboration for use very close to LHC interaction regions, where the most extreme radiation conditions are found. The ATLAS Diamond Beam Monitor project (DBM) is a highly spatially segmented diamond-based luminosity monitor to measure bunch-by-bunch luminosity in ATLAS. The DBM will complement the highly time-segmented ATLAS BCM so that when the other ATLAS luminosity monitors (MTBS and LUCID) have difficulty functioning the ATLAS luminosity measurement which is a key to most precision measurement is not compromised. The DBM will provide three orders of magnitude higher spatial segmentation (relative to the single BCM pads) at the expense of lower (25 ns vs sub-2 ns) time resolution. However these two systems will complement one and each other in our characterization of the beam backgrounds. The BCM will still use its exquisite timing resolution to localize beam background sources up (or down) stream of ATLAS, while the DBM will provide additional spatial information about the source(s) of background. To accomplish these goals, the DBM architecture is four 3-layer telescopes on each side of the interaction point with each layer having the size of one FE-I4 module, namely 20mm x 16.8mm active area. The first and last layers of the telescope are offset so that particles from both the ATLAS interaction point and beam halo background can be tracked. It is foreseen to install the DBM during the long shutdown of LHC in 2013/14 together with the ATLAS Insertable B-Layer (IBL) upgrade of the pixel detector. DBM shares a lot of parts with the IBL project mainly in off detector area. The development of the DBM components are well advanced and the project enters now the production phase to be ready for integration in 2013. Several DBM modules made of a FE-I4 readout chip bump bonded to a CVD diamond have been built and tested in laboratory and test beams. The results from these prototype detectors and status of other project components like mechanics and readout will be presented.

Session6 / 99

Design and manufacturing of a Monolithic Active Pixel Sensor in a CMOS Image Sensor (CIS) 180 nm technology

TURCHETTA, renato ¹; BEVAN, Adrian ²; KOLYA, Scott ³; MYLROIE-SMITH, James Edwin ⁴

¹ *ral-stfc*

² *Queen Mary University of London*

³ *Univ of Bristol*

⁴ *University of Liverpool (GB)*

Corresponding Author: renato.turchetta@stfc.ac.uk

The Arachnid collaboration has been set up in the UK to develop CMOS Monolithic Active Pixel Sensors. The first device of this collaboration is named Cherwell. The Cherwell device consists of several arrays of pixel optimised either for vertexing or for calorimetry. For the former, two subarrays were designed. The first one has 96x48 pixels on a 25 um pitch. Each pixel consists of a low-noise 4T pixel, lifted from the previously tested sensor FORTIS. The readout is on a rolling shutter basis with a fine resolution 10-bit, single-slope column parallel ADC. The second array has a similar structure but the column-parallel ADC was folded back into the array, to generate strixels. The use of the INMAPS process allows the PMOS transistors for the ADC to be isolated into deep P-wells islands, thus preserving the 100% fill factor of the pixel. The pixels for calorimetry are arranged into 2 arrays: one of 96x48 pixels on a 25um pitch and the one of 48x24 pixels on a 50 um pitch. Readout is done through column-parallel ADC as the ones used for the tracking array. The pixel architecture is built around the same 4T pixel mentioned above, but has additional devices to provide snapshot and in-pixel correlated double sampling (CDS) capability. At the periphery of the 25um pixel array, additional circuitry is added to provide charge summing of 2x2 pixels during readout. The Cherwell sensor was manufactured on a standard resistivity as well as on high (>1kOhm cm) epitaxial wafers. This latter would allow the charge collection to be helped by an electric drift field. The sensor is currently being characterised with different sources of radiation and experimental results will be presented at the conference.

Session6 / 100

Design and characterisation of a Highly Miniaturised Radiation Monitor

GUERRINI, Nicola Carlo ¹

¹ STFC - RAL

Corresponding Author: nicola.guerrini@stfc.ac.uk

Reliable data on the ionising radiation environment are regarded as very important to ensure an efficient design and operation of spacecraft. Engineering such sensors, and their cost, anyway, still represents a limitation to their widespread adoption. Here we present a Highly Miniaturised Radiation Monitor (HMRM), developed by the Science and Technology Facilities Council and Imperial College London within the framework of a European Space Agency technology development contract. Its aim is to greatly reducing costs and complexity of radiation detectors.

At the core of the current design is a CMOS Image Sensor. Size and mass are considerably reduced thanks to this approach and there is also scope for a reduction in power consumption. This makes the HMRM much easier to integrate on a spacecraft.

The image sensor is based on a 50 by 51 pixel array. The selected pixel is a 4T, to reduce the noise. The array is readout in snapshot mode at a frame-rate of 10,000 fps.

Biasing currents and voltages are generated on-chip to reduce the number of signals required to control the sensor. The sensor is designed to work on a large range of temperatures, from -40°C to +80°C, hence a temperature sensor has been integrated.

The digital output data are obtained with a three bits column parallel ADC with programmable thresholds. An analogue readout has been also designed to characterise and debug the ASIC.

In this following paper we want to present also the results obtained from the measurements on the prototype. Preliminary PTC plots show a gain of 60uV/e⁻ with CDS and a noise of 16e⁻ rms, which include the noise from the external board.

The sensor was manufactured on standard (low) and high resistivity epitaxial substrates, the former being the baseline for the technology and the latter the one which will be used in the instrument. The high-resistivity allows the charge to be collected by drift and not diffusion, thus reducing the overall cross-talk. In both substrates, the epitaxial layer is 12 um thick.

Poster session / 101

Design and Fabrication of Endoscope-Type Compton Camera

TAKAHASHI, Hiroyuki ¹; NAKAMURA, Yasuaki ¹

¹ Univ. of Tokyo

Corresponding Author: yasuaki.nakamura@me.com

We are constructing an endoscope coupled with radiation detector, and its real time radiation imaging system. The imaging system is based on Compton camera composed of a digital signal-processing unit with ASIC and FPGA and reconstruction algorithm using spherical harmonics that can compute in real time. Acquired data are immediately transferred to a host PC and computed by a reconstruction algorithm, and reconstructed image is displayed one after another. In this paper, we show some simulation results on the performance of the system using EGS5, Monte Carlo simulation code. We have also fabricated a prototype Compton camera using two array-type semiconductor detectors, a Si array and a CdTe array, whose sizes are less than 10mm x 10mm.

Session6 / 102

Monolithic pixel detectors

SNOEYS, Walter ¹

¹ CERN

Corresponding Author: walter.snoeys@cern.ch

Monolithic detectors integrate sensor and readout in one piece of silicon and therefore present advantages compared with hybrid detectors in terms of detector assembly, production cost and detector capacitance. Despite years of intensive research they have not yet been widely adopted for high energy physics. Several functional devices on high resistivity silicon have been developed but often require fabrication steps incompatible with high volume manufacturing in standard semiconductor foundries. Recently devices have been manufactured in more standard CMOS technologies, with several improvements, but preserving the low capacitance and efficiency over the full surface for more complex readout circuitry has remained a challenge. An overview will be presented of different approaches to realize monolithic detectors, including developments using monolithic active pixel sensors (MAPS), deep well implants, silicon on insulator (SOI) and high resistivity substrates. Their performance in terms of particle detection and radiation tolerance will be discussed as well as power consumption which is a key parameter. An effort will be made to point out the challenges that need to be overcome for monolithic detectors to be adopted more widely in high energy physics.

Session1 / 103

Vertex detectors for the future linear colliders

BENOIT, Mathieu ¹

¹ CERN LCD

Corresponding Author: mathieu.benoit@cern.ch

The Linear Collider's vertex detectors present a new challenge in terms of requirements for material budget (0.2% X₀. 200 um of Si), cooling system (air cooling) and temporal (~10 ns) and spatial resolution (3 um) [1] with regard to LHC and ILC experiments. The hybrid planar pixel sensor technology, due to its robustness, low noise and fast timing properties, is currently studied using TCAD, GEANT4 and experimental measurements to determine its viability as the main building block of CLIC vertex detectors. We present plans for production of ultra-thin hybrid sensor devices and fine pitch fast readout electronics (SmallPix, CLICPix), using Through-Silicon-Via (TSV), to be used for test beam analysis of their characteristics. First results on power pulsing of Timepix type pixel sensors [2] using the Timepix Telescope in CERN SPS test beam campaign will be presented. Comparison and validation of a TCAD driven GEANT4 [3] digitization methods with test beam data to be used in full detector simulation of CLIC vertex detectors is also be discussed.

Session1 / 104

Accident at TEPCO's Fukushima-Daiichi nuclear power plant - What went wrong and what lessons are universal -

OMOTO, akira¹

¹ T

Corresponding Author: akira.omoto@mac.com

The speech on the recent nuclear accident focuses on “what went wrong” and “what lessons are universal”.

As is well recognized in the nuclear safety regime, prevention of radiological impact to human and environment as a consequence of nuclear reactor accident follows the basic philosophy of defense-in-depth consisting of five layers of defense, of which the first three by design, the 4th by prevention and mitigation of beyond design basis (severe accident) conditions, and the 5th by offsite emergency plan.

Breach of defense layers was particularly significant in protection a) against natural disaster (1st layer of defense) as well as b) against severe conditions, specifically in this case, a complete loss of all AC/DC power and isolation from Ultimate Heat Sink (4th layer of defense). Confusion in crisis management by the Government and insufficient implementation of offsite emergency plan revealed issues such as delineation of responsibility in the 5th layer of defense.

Deliberation of lessons learned should not stop at analysis of causal chain of events but also touch upon underlying factors such as cooperate risk management strategy, organizational culture, interface among operator, regulator and society etc., all of which influences key decisions on safety. This deliberation here is based on a) analysis of what led to breach of layers of defense-in-depth, b) UT (University of Tokyo) study on “why nuclear community failed to prevent this accident”, and c) Accident Investigation Committees' reports. Details are discussed such as a) preparedness to residual risk by assuming “what if the assumed condition was wrong” under high uncertainties, b) not sufficient continuous safety improvement by learning from global good practices, c) basic assumptions in the most basic level of safety culture hierarchy.

In conclusion, personal view on universal lessons comes to the very basics of the use of technology;

a) Resilience: There is a need to enhance organizational capability to Respond, Monitor, Anticipate, Learn in varying conditions to lead to success. As for design, expected are reduced system interactions, enhanced reliability by “diversity” & “passive” in safety system,

b) Responsibility: Operator is primarily responsible for safety (responsible use), and the Government has to fulfill the responsibility to protect public health and environment.

For both, their capability is supported by competence, knowledge and understanding of the technology,

c) LPHC (Low Probability High Consequence) risk: Consequence matters, rather than voicing low probability. There is a need to avoid, as much as possible regardless its probability of occurrence, the reasonably anticipated environmental impact (spill, land contamination etc.), and

d) Interface with society: Importance of risk communication and communication with safety experts in other disciplines was recognized. Further, post-Fukushima situation indicates “no production without trust from the society”.

Session1 / 105

Distribution of radioactive cesium measured by aerial radiation monitoring

Dr. SANADA, Yukihisa ¹

¹ *Japan Atomic Energy Agency*

Corresponding Author: toyokawa@spring8.or.jp

We measured the ambient dose-rate and the deposition amount of radioactive cesium by using four helicopters in the whole area of Japan to investigate the influence of the radioactivity that released in the atmosphere due to the disaster of the Fukushima Daiichi NPP (Nuclear Power Plant), Tokyo Electric Power Company (TEPCO), occurred by Tohoku-Pacific Ocean Earthquake and tsunami on March 11, 2011. A massive radioactive materials emitted from the NPP was released in the atmosphere due to the disaster and contaminated soils in the wide area in Japan. Therefore, we have carried out the airborne radiation monitoring (ARM) in the whole area of Japan, and investigated the influence of the radioactive cesium of the deposition to the ground level. It reports on the measurement technique and the result.

Session4 / 106

Achievement, Issues, and next steps of CMOS image sensors

SUGAWA, Shigetoshi ¹

¹ *Tohoku University*

Corresponding Author: yoshinobu.unno@kek.jp

CMOS image sensors have been widely applied to various fields in this decade by the great improvements of basic performances such as sensitivity, noise and resolution. Recent CMOS image sensors have achieved the pixel pitch of about 1 μ m, the number of pixels of 40 million or more and the input conversion noise of about 1 electron. CMOS image sensor has come to exceed CCD image sensor greatly in the shipment amount. In this paper, the achievement technologies, current issues and next steps for high sensitivity, low noise, wide dynamic range and high speed in CMOS image sensors are discussed.

Poster session / 108

Robust in hardware mapping of hot pixels and hot pixel data reconstruction

DELLEY, Bernard ¹

¹ *Paul Scherrer Institut*

Corresponding Author: bernard.delley@psi.ch

While originally aimed at imaging applications, robust in hardware mapping of hot pixels and hot pixel data reconstruction may also provide a starting point for algorithmic cluster reduction in future detector system. The method addresses issues with radiation defects and mitigation of radiation effects while establishing the hot pixel map or list.

Session2 / 109

Pixel detector developments for synchrotron radiation

SCHMITT, Bernd ¹

¹ P

Corresponding Author: bernd.schmitt@psi.ch

Currently there are many interesting developments going on in the area of pixel detectors for synchrotrons and XFELs. Many developments done for XFELs also open new measurement capabilities at synchrotrons and overcome limitations of single photon counting detectors. In the presentation I will give an overview of the current developments with a focus on hybrid detector systems.

Session2 / 110

Progress of SOI Pixel Process

ARAI, Yasuo ¹

¹ High Energy Accelerator Research Organization (JP)

Corresponding Author: yasuo.arai@kek.jp

TBD

Session3 / 111

Flat x-ray detectors and their applications

SPAHN, Martin

Corresponding Author: martin.spahn@siemens.com

The applications of x-ray imaging in the medical field are manifold and range from computer tomography (CT), radiography, angiography to mammography. Depending on the application, the x-ray systems support diagnostic and/or interventional procedures and generate 2D (projection) or 3D (volumetric) data sets. The performance requirements for the different application can vary strongly with respect to pixel size, frame rates, x-ray flux and detector size.

Healthcare trends such as the change of the demographic structure, outcome orientation of procedures or higher efficiency influence the design of new systems and their components such as the x-ray detector. High dose efficiency, support of new applications and cost efficiency reflect these demands.

Today's predominant x-ray detector technologies are integrating detectors and are based on scintillators, in particular CsI, and photodiodes of amorphous silicon (radiography, angiography) or crystalline silicon (CT) or on the direct converting material selenium (mammography).

Future developments will include the optimization of current technologies but may also bring new technologies such as CMOS and counting pixel devices in order to further increase performance characteristics or allow new applications.

Session3 / 112

Development and Deployment Status of X-ray 2D Detector for SACLA

HATSUI, Takaki ¹

¹ RIKEN

Corresponding Author: hatsui@spring8.or.jp

TBD

Session3 / 114

History and prospect of the low-noise CMOS sensor

KAWAHITO, Shoji ¹

¹ *Shizuoka University*

Corresponding Author: yoshinobu.unno@kek.jp

This paper reviews the device and circuit technologies for low-noise CMOS image sensors(CISs) and discusses their future prospect. The first innovation in the low-noise CISs has been done by the CMOS active pixel sensor (APS) using an amplifier and a pinned photodiode in each pixel. The in-pixel amplifier eliminates a large stray capacitance in the signal detection and increases the charge-to-voltage conversion gain. The pinned photodiode and the technique of in-pixel charge transfer allow us to greatly reduce dark current noise and cancel kTC noise. In global shutter CISs, the two-stage charge transfer using pinned diodes has solved their noise problems. In the past 10 years, efforts are devoted to the reduction of noises due to the in-pixel transistor and peripheral readout circuits. The introduction of low-noise transistors as the in-pixel amplifier and high-gain noise reduction techniques used in the column readout circuits has effectively reduced the thermal, 1/f and RTS (random telegraph signal) noises of transistors and a sub-electron noise level has been attained. This paper also discusses the possibility of true photon counting by further reduction of readout noise and very high charge-to-voltage conversion gain.

Poster session / 115

Scribe-Cleave-Passivate (SCP) Slim Edge Technology for Silicon Sensors

FADEYEV, Vitaliy ¹; SADROZINSKI, Hartmut ²; ELI, Scott ³; CHRISTOPHERSEN, Marc ⁴; PHILIPS, Bernard F. ⁵

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

² *SCIPP, UC santa Cruz*

³ *SCIPP, Univ. of California, Santa Cruz*

⁴ *US Naval Research Laboratory*

⁵ *U.S. Naval Research Laboratory*

Corresponding Author: yoshinobu.unno@kek.jp

We are pursuing scribe-cleave-passivate (SCP) technology of making “slim edge” sensors. Such sensors have only a minimal amount of inactive peripheral region, which benefits construction of large-area tracker and imaging systems. Key application steps of this method are surface scribing, cleaving, and passivation of the resulting sidewall. We are working on developing both the technology and physical understanding of the processed devices performance. Our recent advances include: a) further investigation of scribing technologies, b) new methods of sidewall passivation, c) investigation of automated processing machines for scribing and cleaving, d) investigation of the charge collection near the edge, e) radiation hardness of the processed devices. We will also report on the status of devices processed at the request of the RD50 collaborators.

Poster session / 116

Construction of SPring-8 Experimental Data Repository

HISANOBU, Sakai ¹; OHATA, Toru ¹; FURUKAWA, Yukito ¹

¹ *Japan Synchrotron Radiation Research Institute*

Corresponding Author: saki@spring8.or.jp

SPring-8 experimental Data Repository system (SP8DR) has been developed to support the handling of the experimental data. High brilliant x-ray at the SPring-8 produces large quantities of data with a high data rate in a short time. It is difficult to manage experimental data conjunction with the experimental conditions without data management system. SP8DR manages a lot of experimental conditions as meta-data of experimental data for various x-ray experimental fields with same manner. SP8DR was built on the open source digital repository system, DSpace. In this presentation, we show an overview of the SP8DR and present status. An application to high-bandwidth data acquisition system for 2-dimentional detector is also discussed.

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TBD

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Opening address

Corresponding Author: yoshinobu.unno@kek.jp

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Closing remarks

Corresponding Author: bernd.schmitt@psi.ch

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Welcome party

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Dinner (BBQ)

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Excursion

Sazae-do, Tsukuga-jo Castle, Restaurant "Takino". This event is supported by Dectris.

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Conference dinner "Japanese cuisine"

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Farewell

Corresponding Author: yoshinobu.unno@kek.jp