Institution: University of Glasgow

Unit of Assessment: B9: Physics

Title of case study: Medipix - High Energy Physics collaborators deliver technological breakthrough behind world's most advanced X-ray detector

1. Summary of the impact

Medipix-based detectors are the best pixelated X-ray detectors available on the market and are commercialised by PANalytical under the brand name PIXcel. At the core of PIXcel is the Medipix2 chip, which was developed around a photon counting breakthrough conceived by the Medipix collaboration and is unique in its adaptability, high spatial resolution, high dynamic range and low noise. This product is the direct result of an exclusive license and a collaboration agreement between PANalytical and the Medipix collaboration, coordinated by CERN and comprising a further sixteen leading physics research institutes in Europe. The University of Glasgow is the only UK institution to be one of the four founding members of the Medipix1 collaboration.

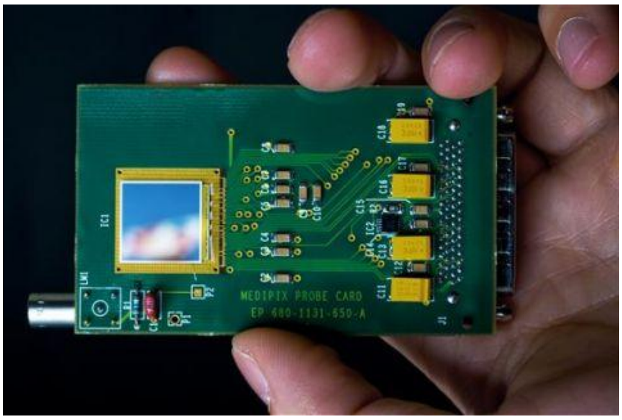
2. Underpinning research

In the 1990's, a University of Glasgow team led by Prof Kenway Smith FRSE was actively involved in the development of hybrid pixel detectors for the Large Hadron Collider (LHC). These hybrid pixel detectors combine a CMOS chip and an array of readout electronics channels, connected via micro bump bonds to an identically segmented sensor chip. The primary motivation was to develop a 2-D detector capable of time stamping high energy physics (HEP) events at the expected 40MHz collision rate of the LHC. In the course of this research, it became clear that such a technology could also be useful in medical imaging [1].

The Glasgow group identified the need for new technology in X-ray imaging as being particularly significant. In photon counting mode, the Medipix chip could deliver significant advances in the detection of X-ray diffraction patterns. The Glasgow team demonstrated this for the first time, using hybrid pixel detectors at a synchrotron X-ray source [2]. The Omega3 chip, a predecessor of Medipix, was used in this early work, and it was repeated with the Medipix chip when it became available.

However, to be useful for medical and other imaging applications, the electronics readout chip would have to be adapted to produce X-ray images which are high resolution and noise-free. From the starting point of this pioneering Medipix1 chip in 1997 grew the design brief of what was to become the Medipix2 chip produced in 2001 and now at the core of the PIXcel detector. This brief was outlined by the Glasgow research team including Dr R Bates (Research Associate 1999-2007 and Research Fellow 2007-present), Dr S D'Auria (Research Associate 1999-2010 and Research Fellow 2010-present) and Dr C Raine (Research Assistance 1980-98), along with teams from Freiburg, Pisa and the European Organization for Nuclear Research (CERN). The Glasgow group effort was led by Prof K Smith (Lecturer/Reader 1963-93, Professor 1993-2003) from 1991 until 2003 and since then by Prof V O'Shea (Research Associate 1992-2005, Lecturer 2005-2010, Professor 2010-present). Glasgow brought design engineering expertise to the Medipix ASIC design group and performed much of the initial characterisation of the Medipix1 chip.

As interest in medical imaging applications grew and the collaboration expanded, it became possible to consider a more advanced chip design involving simultaneously shrinking the pixel size, increasing its complexity and increasing the number of pixels, which resulted in the Medipix2 chip. Seventeen institutions contributed ideas to the Medipix2 readout chips, pixel sensors design, characterisation of the pixel modules and applications of the Medipix2 chips. The Glasgow team contributed to the chip design, including the features necessary to make it an efficient, high-resolution photon-counting device. The Glasgow team also tested and characterised the Medipix2 chip, studying novel sensor materials (GaAs, CdTe) and structures (3-D Si) for a variety of applications. As a consequence of these and other studies [3], further developments of the technology were made resulting in the Medipix3 chip. Today, the Medipix family of hybrid pixel detectors are used for medical imaging including computer tomography scans, material analysis including pharmaceuticals, nuclear power plant decommissioning and astronomical adaptive optics.



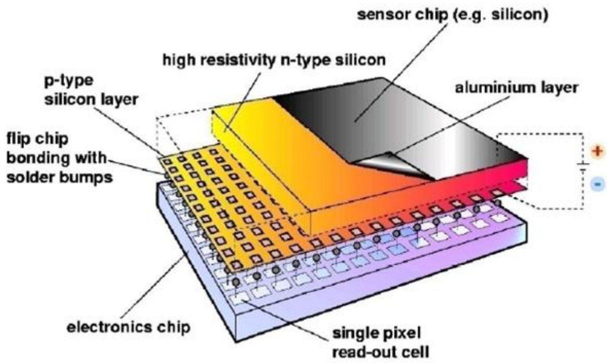


Figure 1: A picture and schematic diagram of the high-sensitivity, low-noise Medipix2 chip.

3. References to the research

[1] C Da Via, et al, "Gallium arsenide pixel detectors for medical imaging", * Nuclear Instruments and Methods A, Volume 395 (1997) 148-151.
DOI: 10.1016/S0168-9002(97)00631-1
Glasgow Authors: C Da Via, R Bates, C Raine, V O'Shea, KM Smith
Description: This paper is one of the first papers to use a hybrid pixel detector assembly for non-HEP applications using the fore-runner LHC1/Omega3 chip. It demonstrates that such devices can be used for a variety of applications, from medical imaging to DNA sequencing.
Glasgow contribution: These were in the specification of the chip and the design, evaluation and analysis of the device characterisation. Chip characterisation is a vital part of the design phase, proving that the device works as expected and feeding back to the design.

[2] **S Manolopoulos, et al,** "X-ray powder diffraction with hybrid semiconductor pixel detectors", * Journal of Synchrotron Radiation, Volume 6 (1999), 112-115.
DOI: 10.1107/S0909049599001107
Glasgow Authors: S Manolopoulos, R Bates, V O'Shea, C Raine, KM Smith
Description: This paper demonstrates the first use of a hybrid pixel detector in a Synchrotron beam line. The detector is the Omega3 chip. The experiment was repeated with the Medipix1 chip when this became available.
Glasgow Contribution: The Glasgow group defined the experiment, performed the experiment with help from the beam line scientists, and performed the data analysis.

[3] **K Mathieson, et al**, "Charge sharing in silicon pixel detectors", *
Nuclear Instruments and Methods A, Volume 487 (2002), 113-122.
DOI: 10.1016/S0168-9002(02)00954-3
Glasgow authors: K Mathieson, MS Passmore, V O'Shea, RL Bates, KM Smith, M Rahman
Description: This paper models charge sharing in hybrid pixel detectors. The models are developed and benchmarked against an analogue pixel sensor with large pixel size. The consequences of charge sharing are then developed for the smaller 55µm x 55µm sized pixels of the Medipix2 chip. The results of this paper directed the attention of the Medipix collaboration towards the need for the Medipix3 architecture with attempts to mitigate charge sharing effects.
Glasgow contribution: The simulations and experimental work was all performed in Glasgow. The non-Glasgow authors developed and produced the analogue pixel detector.

4. Details of the impact

Physicists at Glasgow first recognised the potential medical applications of the hybrid particle detector in the 1990's. In the years that followed, the Medipix collaboration developed an innovative new microchip, and then brought the technology to market through a commercialisation deal with leading X-ray equipment manufacturer PANalytical. The resulting PIXcel range is the most advanced technology of its kind on the market, offering a cost-effective, accessible, but highly adaptable machine producing images of unrivalled quality.

The Head of the Knowledge Transfer Group at CERN said: "At CERN we assess the impact of knowledge transfer projects in terms of the number of people benefitting, project visibility, and wider dissemination as well as financial return. In these terms Medipix2 and its relationship with Panalytical is one of the projects with highest impact that CERN has been involved with."

PANalytical, formerly known as Philips Analytical, is one of the leading suppliers of X-ray materials analysis equipment. The company offers a range of X-Ray Diffraction (XRD) instruments, which are sold to customers worldwide both in academia and industry. XRD is a non-destructive analytical technique used to determine the crystalline structure and elemental composition of materials. Its applications range from pharmaceuticals and petrochemical to semiconductor, electronics, and nanotechnology. XRD is a particularly versatile technique as it can provide information on the chemical and physical characteristics of a range of materials including powders, thin films or bulk materials.

The Medipix2 collaboration secured a Collaboration Agreement with PANalytical in 2001, and the company supported the development of the Medipix2 chip in return for exclusive rights to commercialise the resulting technology in its new Empyrean product line. The company successfully launched the first PIXcel product in 2007. Today, PANalytical sells three different products based on the Medipix2 pixelated detector. The introduction of a series of PIXcel detectors (PIXcel^{1D}, PIXcel^{3D} and PIXcel^{3D} 2x2) has added new dimensions to XRD analysis. With this complete series of detectors users can obtain the best available data quality. This technology breakthrough required sustained input for approximately 8 years from the Medipix collaboration before yielding mature, marketable products.

PANalytical's PIXcel, offers a number of distinct advantages over its competitors. First, it is uniquely adaptable, being the only detector on the market that can operate as a point-, linear-, 2-D or 3-D detector, all in one. This adaptability is complemented by its high spatial resolution, high dynamic range and low noise, which make PIXcel the most advanced photon counting detector in the world.

The PIXcel^{3D} X-ray detector offers flexibility and performance that sets it apart from all competing systems, which use separate detectors to cover the same range, thus increasing the cost. PIXcel's all-in-one capabilities are more cost-effective, allowing modes that were so far only available at large synchrotron facilities. In 2011, Empyrean, the product line of XRD systems incorporating PIXcel, won an award for the best technology innovation from R&D Magazine. It continues to be a very successful product line that is well received by customers.

In 2013, PANalytical introduced a further innovation to its Empyrean product line: the ability to perform grazing incidence small-angle X-ray scattering (GISAXS). GISAXS is a technique that is used to investigate the physical and chemical properties of nanostructured thin films. However, as an advanced analytical technique, it is traditionally restricted to users of synchrotron beam lines.

Thanks to the high efficiency and low noise of the Medipix2 detector, high quality images can be obtained even using laboratory sources with intensity orders of magnitude lower than that from a synchrotron beam. As nanomaterials become more widespread in a number of applications, affordable and convenient access to this technology is of great advantage to users both in academia and industry.

The PANalytical XRD Product Marketing Manager said: "We are very proud to be a commercial partner in Medipix2. PANalytical has a track record of innovation and this association will keep us at the forefront of detector technology for many years to come. We are determined to continue developing the best, and most innovative, detectors for all our future XRD customers. Empyrean is PANalytical's answer to the challenges of modern materials research. While today's research themes are nanomaterials, life sciences and renewable energy, tomorrow's science may move in a totally different direction. The lifetime of a PANalytical diffractometer stretches further than the typical horizon of a single research program and for many scientists, an ability to accommodate change is a 'must-have' feature in their decision to invest in an XRD system."

5. Sources to corroborate the impact

Medipix Knowledge Transfer
http://knowledgetransfer.web.cern.ch/life-sciences/from-physics-to-medicine/medipix

PANalytical Website Pixcel description
http://www.panalytical.com/Empyrean/Features/PIXcel.htm

PANalytial Empyrean brochure
Multi-Purpose X-Ray Diffractometer (XRD) and Computer Tomography (CT) with the PANalytical Empyrean
http://www.azom.com/materials-video-details.aspx?VidID=657

X-ray measures in multiple dimensions
http://www.rdmag.com/Awards/Rd-100-Awards/2011/08/X-ray-measures-in-multiple-dimensions/

Innovations in Pharmaceutical Technology
http://www.iptonline.com/newproduct.asp?id=1123

PANalytical - New GISAXS option on Empyrean
http://www.panalytical.com/News/New-GISAXS-option-on-Empyrean.htm

Newswire & PR - PANalytical Demonstrates New GISAXS Option on Empyrean
http://www.prnewswire.com/news-releases/panalyticals-empyrean-to-be-featured-at-intersolar-north-america---the-world-of-xrd-analysis-is-no-longer-flat-97929394.html

Head of the Knowledge Transfer Group, CERN, European Organization for Nuclear Research, can provide corroboration of the impact of the commercial relationship with PANalytical for CERN and the broader importance of the impact of the Medipix project.