Microdosimetry and measurement of neutron fields in the context of the ARDENT project

G. D’Angelo¹, E. Aza², E. Frojdh², S. P. George², M. Magistris², F. Murtas², E. Sagia¹, M. Silari²

¹ POLIMI, Milan, Italy. ² CERN, Geneva, Switzerland.

INTRODUCTION

The ARDENT (Advanced Radiation Dosimetry European Network Training) is a Marie Curie Initial Training Network (ITN) funded by the European Commission under the 7th Framework Programme involving 14 partner institutes worldwide. The group that was involved in activities at the CN accelerator consists of researchers from the European Organization for Nuclear Research (CERN, Switzerland) and the Polytechnic of Milan (POLIMI, Italy).

In collaboration with worldwide institutes, over the last 10 years CERN has developed two detector technologies in the field of dosimetry, beam and plasma monitoring: the gas electron multiplier (GEM) and the silicon detector Medipix. The GEM technology has seen a number of applications including high-flux particle detection near accelerator beam pipes and detection of thermal and fast neutrons (n_TOF facility). CERN has also designed and tested several versions of the Medipix detector (e.g., Timepix), mainly for detection and imaging of neutrons and X-rays with high spatial resolution.

During the last decade, the POLIMI research group was involved in the design, construction and characterization of a silicon microdosimeter based on a monolithic silicon telescope detector and of its electronics (low-noise preamplifiers, data acquisition systems, etc.). Microdosimetric spectra were measured with the silicon detector across the Bragg peak in phantoms irradiated with 62 MeV/u protons and carbon ions.

ARDENT addresses the potential uses of a class of instruments based on the above technologies with the three main objectives:

- disentangle the various components of the radiation field and determine the dosimetric quantities due to each component;
- measure the radiation quality of the radiation field (microdosimetry);
- obtain information on the energy distribution of the various components of the radiation field (photon and neutron spectrometry).

More detailed information can be found on the ARDENT web site: www.cern.ch/ardent.

The ARDENT collaboration submitted an application for beam time in June 2013 and was assigned two shifts of two days each in December 2013 and January 2014, as well as an additional shift in June. The next section describes the general experiment on microdosimetry with the GEMPIX detector, which started in 2013 and was carried out throughout 2014. The last section of this paper provides details on the specific experiments that took place during the shift in June.

OVERVIEW OF DETECTORS

The Timepix is a hybrid pixel detector developed by the Medipix collaboration at CERN [1]. It consists of a sensor 256 by 256 pixels of pitch 55 µm bump bonded to the Timepix ASIC. The sensor is typically 300 µm thick silicon and each pixel is individually processed and read out by electronics in the ASIC. The Timepix can measure the time of arrival of particles, perform single photon counting or with an appropriate calibration measure the energy deposited by incoming particles [2]. Due to the pixel pitch being small compared to the range of many higher energy particles one can see tracks in silicon which can be characteristic of the radiation field [3], the detector effectively acts as a solid state nuclear emulsion.

The GEMPIX is a new detector developed by ARDENT consisting of three layers of gas electron multipliers (GEM) coupled to a 2x2 matrix of Timepix ASIC’s for readout. In such a detector, the ionizing charge is collected and read by a chip of 250,000 channels (Medipix). The total active area is 8 cm². The spatial resolution is of the order of 50 µm.

MEASUREMENT OF NEUTRON FIELDS WITH THE TIMEPIX AND GEMPIX DETECTORS

Timepix chips covered with polyethylene and boron converter layers were irradiated in order to measure fast and thermal neutrons respectively; three Timepix chips with and without converter layers are shown in figure 1. Slow hadronic particles produce characteristic blobs like clusters in the Timepix due to the charge sharing effect. Protons produced by the polyethylene were successfully detected by measuring their distinctive clusters. After producing a thermalized neutron field using a large block of polyethylene, thermal neutrons were measured with a boron converter layer using the reaction $^{10}$B + n → $^4$He + $^7$Li. Discrimination between the two hadron energies produced by the boron converter and residual protons is possible, based on a cut in deposited energy and the number of pixels in one cluster.
The neutron field generated in the CN accelerator was also measured with the GEMPIX. The GEMPIX is able to identify long curly tracks from high energy electrons, small blobs that correspond to photons and long characteristic tracks which appeared to originate from recoil protons produced by the neutron field as shown in figure 2. On insertion of a thin $^{10}$B target inside the detector it was possible to see the secondary particles emerging from the target. An integral over many different tracks with this detector is shown in figure 3, clearly showing the particles emitted from the target, including what seems to be an alpha or lithium nuclei from $^{10}$B neutron capture.

**MICRODOSIMETRY WITH THE GEMPIX DETECTOR**

The goal of this set of experiments performed at the CN accelerator was to test the GEMPIX detector as microdosimeter and as interaction analyser. Commonly, microdosimetry studies the stochastics of energy deposition in site sizes of 1 µm or 2 µm, which is comparable to the size of the nuclei of human cells. Here, to investigate the feasibility of a microdosimeter based on GEMPIX, the detector was supplied with a tissue-equivalent gas in order to measure the energy deposition in a material equivalent to approximately 1-2 human cells (from about 20 mm to 30 mm). Thanks to the detector spatial resolution of 50 µm, a reproduction of the specific energy deposited inside a cell like volume was obtained.

For the study of GEMPIX as interaction analyser, a sample of tissue equivalent material was inserted in the gas gap. The charged particles produced by the interaction of neutrons with the sample were reconstructed in 3D with a 50 µm resolution. The active volume of the detector was 27 cm$^3$.

**CONCLUSIONS**

An initial set of measurements was carried out, with a view to characterize Timepix and GEMPIX for dosimetric applications. The devices are able to detect clusters of different size (number of pixels) and length, which are related to the properties of secondary particles. Future work will focus on a better characterization of these clusters. The possibility to perform a quantitative comparison with other microdosimeters will also be investigated.

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**REFERENCES**

