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The Birmingham Irradiation Facility ☆

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ABSTRACT

At the end of 2012 the proton irradiation facility at the CERN PS [1] will shut down for two years. With this in mind, we have been developing a new ATLAS scanning facility at the University of Birmingham Medical Physics cyclotron. With proton beams of energy approximately 30 MeV, fluences corresponding to those of the upgraded Large Hadron Collider (HL-LHC) can be reached conveniently. The facility can be used to irradiate silicon sensors, optical components and mechanical structures (e.g. carbon fibre sandwiches) for the LHC upgrade programme. Irradiations of silicon sensors can be carried out in a temperature controlled cold box that can be scanned through the beam. The facility is described in detail along with the first tests carried out with mini ($1 \times 1\ cm^2$) silicon sensors.

1. Introduction

The irradiation facility work can be broken down into three major areas of effort. Firstly there is the installation of the necessary infrastructure at the Birmingham cyclotron, a new beamline to a dedicated high intensity irradiation area with additional shielding to allow higher beam currents and the installation and commissioning of the chiller unit and the associated control systems for the scanning table. Secondly the development of a remotely controlled scanning robot that allows precision scanning of samples through the incident beam and thirdly the design and construction of a fully environmentally controlled cool box in which samples are monitored as they are exposed to the beam. The sections below describe in detail each of these areas.

2. The Birmingham cyclotron

The irradiations were performed at the Medical Physics MC40 cyclotron in the School of Physics and Astronomy at the University of Birmingham. To date, most irradiations to qualify sensors and materials for the LHC have taken place with 27 GeV protons at the CERN PS Irradiation facility. For the upgraded LHC, fluences of approximately 1.0×10^{15} 1 MeV $N_{eq}\ cm^{-2}$ are required at the inner layer of the strip detector. Such high fluences are more easily obtained with high current cyclotrons especially as 27 MeV protons have a Non-Ionising Energy Loss (NIEL) enhancement factor ≈2 while the equivalent factor is ≈0.5 for 27 GeV protons. However the lower energy cyclotron protons do suffer a significant energy loss in traversing material e.g. 1.1 MeV in 1 mm of silicon.

Although the cyclotron has the capability of running at energies up to 40 MeV with various ion beams, our irradiations were performed exclusively using protons of 27 MeV kinetic energy. The cyclotron supplied an almost DC beam current whose magnitude makes irradiation to upgrade LHC levels an attractive proposition. For example, a beam current of 1 μA passing for 3 min corresponds to a proton fluence of $\approx 10^{15}\ cm^{-2}$. In practice, the beam current was limited to 0.2 μA to avoid excessive background radiation levels.

The layout of the experiment in the beam is shown schematically in Fig. 1. Four ATLAS mini-sensors were irradiated to LHC upgrade fluences. (A BPW34F pin diode was also irradiated in order to determine whether as found at CERN [2], these devices could be used for auxiliary measurements of fluence.) The beam is collimated into an area of $1\ cm^{-2}$ using pairs of vertical and horizontal plates, each insulated from the other (see Fig. 2). By measuring charges accumulating on each plate, the horizontal and vertical asymmetries of the beam can be determined. The uniformity of the beam was checked at the start of each run by exposing Grafchromic film to the beam. Measurement of the film showed that the beam was uniform horizontally and vertically to better than 20%. Beam fluence is determined online using a Faraday Cup which measures the charge of the beam incident on the samples. An offline cross-check is made by measuring the

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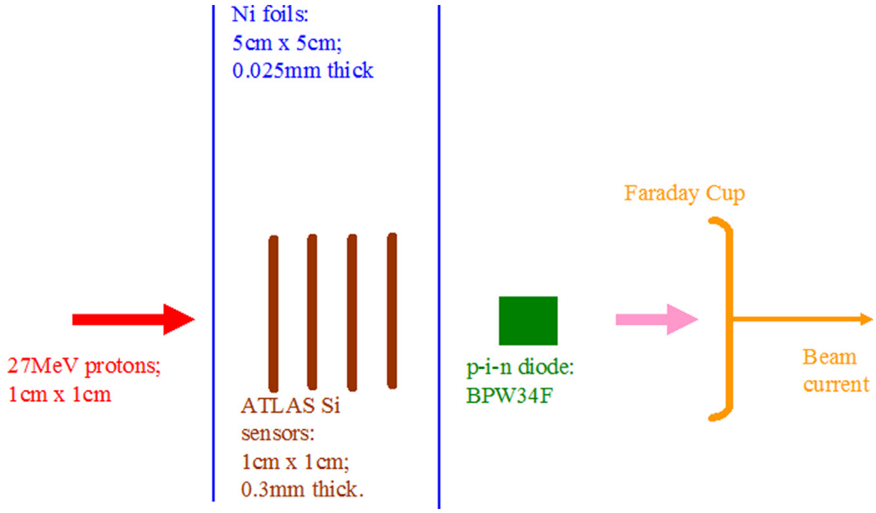

Fig. 1. A schematic view of the beam layout used for irradiation tests.

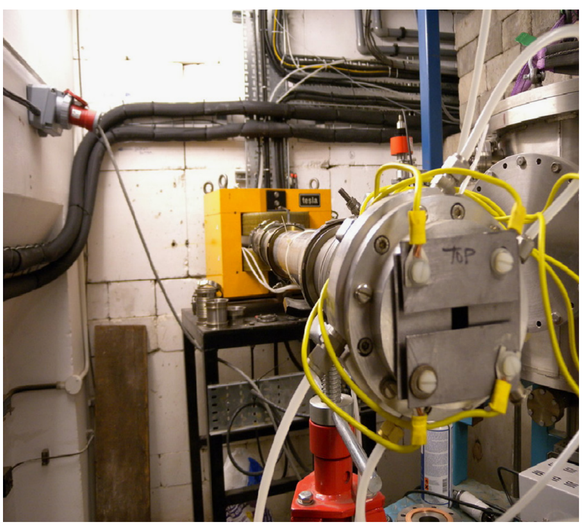

Fig. 2. The high intensity irradiation area at Birmingham University. The beam is collimated to a 10×10 mm area at the end of the beam pipe.

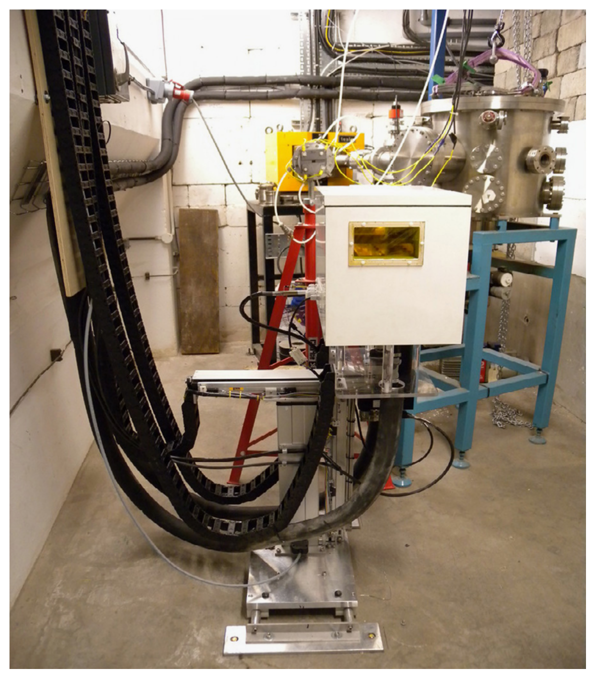

Fig. 3. The scanning robot with the Styrofoam thermal box attached. Note for scale the coolbox is 383 mm high and 309 mm in width.

activity of nickel foils, irradiated by the beam. A sheet of natural nickel 25 μm thick is exposed to the beam. The incident protons interact with the natural nickel to produce the unstable isotope 57Ni, which decays with a lifetime of 35.7 h to 57Co, emitting a gamma ray of energy 1377 keV. By measuring the intensity of 1377 keV gamma rays and knowing the cross-section for production of 57Ni the number of incident protons can be determined. Good agreement was found between the two methods.

3. The scanning system

The pre-configured *XY*-axis Cartesian robot system (see Fig. 5) is capable of handling loads of up to 60 kg with velocities as low as 0.5 mm s^{1} and up to 20.0 mm s^{-1} with accelerations of up to 20.0 ms^{-2}. The positional accuracy in the horizontal *x*-axis is ± 50 μm and ± 200 μm in the vertical *y*-axis. The robot can execute strokes up to 450 mm in the *x*-axis and 400 mm in the *y*-axis. However the scanning area is limited by the window dimensions of the prototype cold box to 140 (horizontal) $\times$ 80 (vertical) mm.

The scanning system is controlled using a National Instruments CompactRIO Real-Time programmable controller to drive the *x*-axis motor with the *y*-axis driven by a third party servo drive. A custom LabView graphical user interface is used to set up and program the controllers and also to control data acquisition. PT100 sensors are placed within the cool box and connected to a 800 W recirculating chiller to ensure constant temperature. Humidity and temperature are then controlled at the PT100 positions. A data acquisition (DAQ) is then used to monitor and control these parameters.

In order to irradiate samples whose areas exceed the cross-section of the beam, the samples are scanned through the beam. By scanning each part of the samples horizontally through the whole width of the beam any effects due to horizontal inhomogenities in the beam are avoided. By taking a large number of horizontal passes per scan as illustrated in Fig. 4 it is possible to reduce the sensitivity to vertical non-uniformities in the beam caused by either beam irregularities or more importantly the inherent *y*-axis inaccuracy.

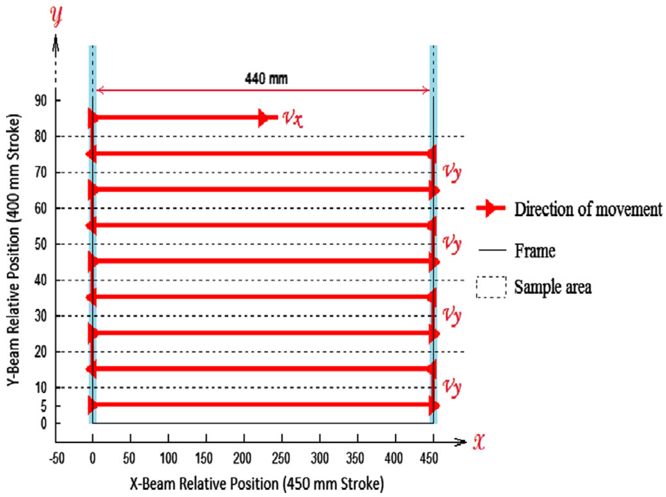

Fig. 4. The irradiation profile.

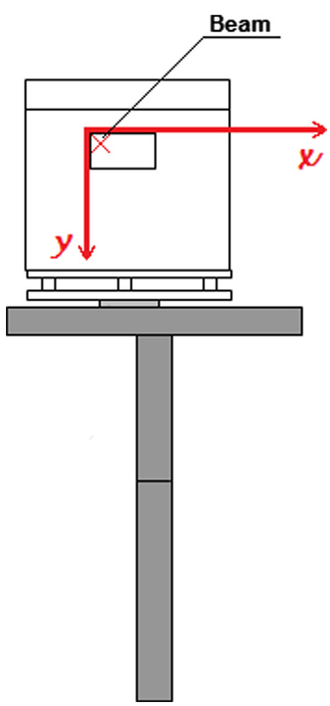

Fig. 5. The *XY*-axis Cartesian robot system.

4. The thermal chamber or cold box

Keeping detectors at a constant temperature during irradiation is vital as radiation damage is temperature dependent. The thermal chamber must allow accurate control of temperature, humidity, light tightness and electrical shielding whilst being radiation hard. A Styrofoam box structure (see Fig. 3) clad with Aluminium foil and Formica was prototyped. A thin double skinned Polyamide window is used to allow beam entry and exit. The thermal box is cooled using the principle of forced convection using an external 800 W recirculating glycol chiller system with insulating transfer lines connected to an internal heat exchanger unit. Two electric fans circulate air through the heat exchanger and the cooled air is directed via baffles to the active upper area of the box. Humidity is reduced and controlled with a nitrogen gas feed

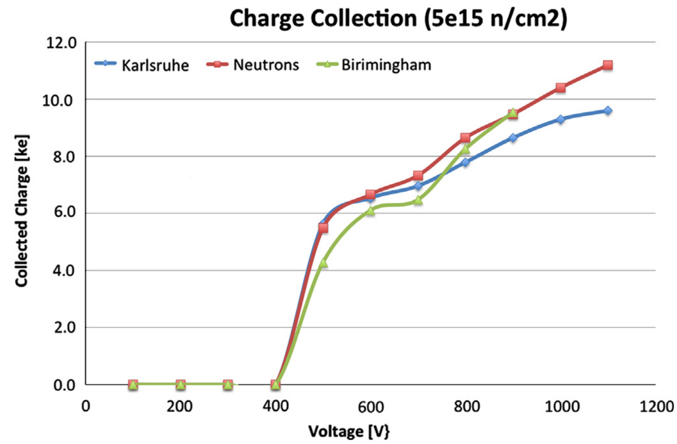

Fig. 6. Charge collection measurements for sensors irradiated at different facilities.

controlled via a flow meter. The temperature and relative humidity within the box, in both active and passive areas, is monitored via commercially available sensors. The sensor data are used by the control system to provide feedback to the chiller, fan and nitrogen systems which are automatically adjusted to maintain specified set points for temperature and relative humidity.

Detector samples and other passive materials can be mounted via a detachable rail system fixed to the underside of the lid of the thermal box. The positioning of these rails allows samples to be mounted on G10 or FR4 frames behind the polyamide window and directly in the beam path. The polyamide rails are designed to be disposable after irradiation. Multiple box lids have been manufactured to allow rapid “hot swapping” of samples.

5. Measurements

Before the installation of the scanning system and cold box described above, an ATLAS07 [3] mini sensor ($1.0 \times 1.0 \times 0.03$ cm^3) has been irradiated to 5×10^{15} N_{eq}. The irradiation was performed simply by placing the sensor directly in the path of the incident beam such that the entire sensor was irradiated. After the irradiation, charge collection measurements were performed using an Alibava [4] readout system with a ^{90}Sr source. These measurements were then compared with sensors irradiated to approximately the same fluence at other facilities. The results are shown in Fig. 6. The agreement of the charge collection between irradiations carried out with neutrons from a reactor and 26 MeV protons in Karlsruhe is very good [5]. This gives us confidence that, as expected from the NIEL hypothesis, irradiation at cyclotron energies is equivalent to irradiation at PS energies (despite their energies being different by three orders of magnitude).

6. Conclusion

A high intensity irradiation facility has been set up at the Birmingham University Medical Physics cyclotron. A pre-configured *XY*-axis Cartesian robot stager has been designed and built in order to allow the irradiation of material samples larger than the cyclotron beam. A thermal enclosure has also been designed constructed to fit on the stager robot to allow environmentally controlled irradiations of silicon sensor samples at the facility. The above systems have been installed and successfully tested at the facility and it is fully operational since early 2013.

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