Nuclear Instruments and Methods in Physics Research A ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Upgrade to the Birmingham Irradiation Facility

Q1 P. Dervan [a], R. French [b], P. Hodgson [b], H. Marin-Reyes [b], K. Parker [b], J. Wilson [c], M. Baca [c]

[a] The University of Liverpool, Department of Physics, United Kingdom

Q2 [b] The University of Sheffield, Department of Physics and Astronomy, United Kingdom

[c] The University of Birmingham, School of Physics and Astronomy, United Kingdom

ARTICLE INFO

Keywords:
Cyclotron
Q3 Irradiation
Silicon sensors
Thermal enclosure
Scanning system
Robot
High intensity
Cooling
Upgrade

ABSTRACT

The Birmingham Irradiation Facility was developed in 2013 at the University of Birmingham using the Medical Physics MC40 cyclotron. It can achieve High Luminosity LHC (HL-LHC) fluences of 10^{15} (1 MeV neutron equivalent (n_{eq})) cm^{-2} in 80 s with proton beam currents of 1 μA and so can evaluate effectively the performance and durability of detector technologies and new components to be used for the HL-LHC. Irradiations of silicon sensors and passive materials can be carried out in a temperature controlled cold box which moves continuously through the homogenous beamspot. This movement is provided by a pre-configured *XY*-axis Cartesian robot scanning system. In 2014 the cooling system and cold box were upgraded from a recirculating glycol chiller system to a liquid nitrogen evaporative system. The new cooling system achieves a stable temperature of $-50\,^{\circ}C$ in 30 min and aims to maintain sub-0 °C temperatures on the sensors during irradiations. This paper reviews the design, development, commissioning and performance of the new cooling system.

1. Introduction

In approximately 2024, the Large Hadron Collider (LHC) will be upgraded to the HL-LHC. The upgrade is foreseen to increase the LHC design luminosity by a factor 10. This planned increase in luminosity results in significantly higher levels of radiation inside the planned ATLAS Upgrade detector [1]. This means existing detector technologies together with new components and materials need to be re-examined to evaluate their performance and durability within this enhanced radiation field. Of particular interest is the effect of radiation on the upgraded ATLAS tracker. To study these effects an ATLAS irradiation scanning facility using the Medical Physics Cyclotron at the University of Birmingham was built in 2013 [2]. A 1 μA beam of 27 MeV protons allows irradiated samples to receive in 80 s, fluences corresponding to 10 years of operation at the HL-LHC, 10^{15} (1 MeV neutron equivalent (n_{eq})) cm^{-2}. Since commissioning in early 2013 this facility has been used to irradiate silicon sensors, optical components and carbon fibre sandwiches for the ATLAS upgrade programme [2] and up to September 2014, 211 samples have been irradiated. Irradiations of silicon sensors and passive materials are carried out in a temperature controlled cold box which moves continuously through the homogenous $1\times1\ cm^2$ beamspot. This movement is provided by the scanning system, Fig. 1, which can move at speeds from $1\ mm\,s^{-1}$ to $10\ mm\,s^{-1}$ in the horizontal direction and up to $25\ mm\,s^{-1}$ in the vertical direction [2]. In 2014, upgrades have been made to the cooling system, moving from a recirculating glycol chiller system to a liquid nitrogen (LN_2) evaporative system, as well as upgrades to the cold box to increase the window size to allow irradiations of larger samples. These upgrades were motivated by the limitations of the glycol system which resulted in overheating of sensors during irradiations, causing annealing, as discussed in Section 3. The new system was developed with the specification to maintain sub-0 °C within the samples during irradiations. Initial tests of the LN_2 system were performed [3] and results showed that temperatures of $-50\,^{\circ}C$ could be achieved, an ideal base temperature for irradiating silicon sensors. These upgrades have been installed and commissioned in the Birmingham Irradiation Facility.

2. The scanning system and initial cold box

The scanning system is controlled using a NI RIO Real-Time programmable controller with a LabView GUI [4]. This also monitors the temperature and humidity within the cold box. However the temperature of the sensors during irradiations could not be measured directly due to the adverse effect of the beam on the PT1000 sensors. Instead the temperature of a sensor, in a test setup simulating beam conditions, was measured and also other in-beam checks of temperature were made. These are described in Section 5. The initial cold box was based on the CERN-PS irradiation setup [5] using recirculating glycol and the box is purged with dry N_2 to prevent condensation forming. The cold

http://dx.doi.org/10.1016/j.nima.2015.02.005
0168-9002/© 2015 Published by Elsevier B.V.

Fig. 1. The scanning system and cold box in the Birmingham Irradiation Facility.

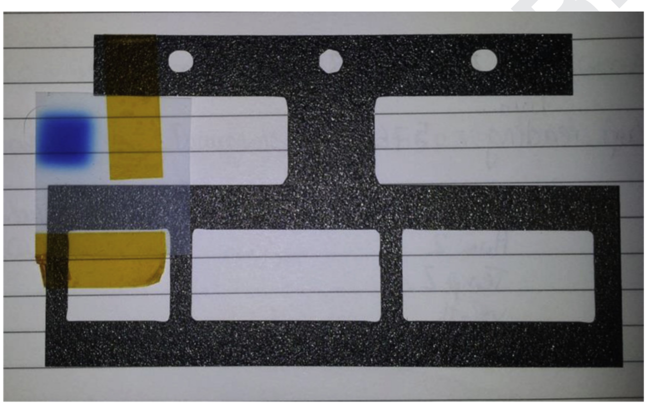

Fig. 2. Carbon fibre pixel frame with gafchromic film [6] after exposure to beam.

box reaches $-15\,^{\circ}$C with approximately a 2 h cooling time. Fans within the box are also used to ensure good air circulation. The scan time depends on the size of the sample, the required fluence and the beam current. For reference, a 1 cm^2 sample can be irradiated to 10^{15} n$_{eq}$ cm^{-2} in 80 s using a 1 μA beam, and the scan time scales linearly with current. Two types of carbon fibre frames, see Fig. 2, are used for sensor irradiations:

1. Pixel frame: 3 slots, 2 for double pixel sensors ($4.2\ \times 1.9$ cm^2) and 1 for single pixel sensors (2.2×1.9 cm^2).
2. Mini frame: 3×3 slots for 1×1 cm^2 sensors.

Kapton tape is used to attach samples to the frame which then clips into a mount on the underside of the cold box lid. The sample position is measured relative to a reference point, 'Home position'

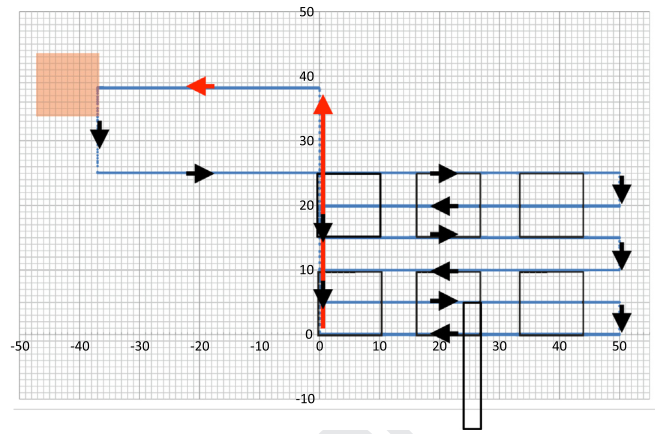

Fig. 3. Scan path starting from Home position (red square), scanning over 6 1 cm^2 sensors and returning to Home position. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this paper.) Q6

to ensure the precise location of the samples, which is essential to calculate the scan path and ensure uniform irradiation. The scan path requires several input parameters from the user: the offset *x* (horizontal) and *y* (vertical) positions of the sample with respect to 'Home', the area to be scanned, the speed of the scan in the *x*-axis, and the beam current which is used to calculate the number of scans to achieve the required fluence. Each run starts and ends with the 'Home' position and scans horizontally over the area with 0.5 cm vertical displacement between horizontal scans, see Fig. 3.

3. Irradiated samples

I–V and charge collection measurements were performed on a mini sensor irradiated at Birmingham to 10^{15} n$_{eq}$ cm^{-2} at 1 μA which indicated that the sensor had overheated [3]. In order to cross-check these results, the charge collection measurements were compared to results from other facilities. The same type of sensors were used for the comparison so that the behaviour of the sensors irradiated to the same fluence, should be equivalent. The results from Birmingham are compared to charge collection measurements from two other facilities: KEK and Los Alamos. KEK uses a 70 MeV proton beam with currents up to 1 μA [7]. Los Alamos uses a pulsed 200 MeV proton beam with beam current of 80 nA (unshielded) or up to 1 μA shielded [8]. While the other facilities can also irradiate to high fluences, the Birmingham facility is able to attain a target fluence in a shorter time (for the same beam current) due to a larger damage factor caused by 27 MeV protons [9].

In Fig. 4, the charge collection measurements are shown. KEK and Los Alamos measure a similar charge collection on the sensor, whilst Birmingham collects more charge, indicating that the sensor has received less radiation damage. To investigate further, the KEK and Los Alamos sensors were deliberately annealed by heating to 80 °C for 60 min. Charge collection measurements of the annealed sensors were made and compared to the Birmingham sensor, which had not been heated. The similarity of the charge collected in all three sensors in Fig. 5 suggests that the Birmingham sensor had also been annealed and it is likely that this occurred during the irradiation, due to overheating. The overheating takes the form of brief but large temperature increases during the period that the sensor is moving through the beam spot. This is due to the 27 MeV protons depositing energy in the sensors at a rate of 1.1 W, causing significant temperature

Please cite this article as: P. Dervan, et al., Nuclear Instruments & Methods in Physics Research A (2015), http://dx.doi.org/10.1016/j.nima.2015.02.005