Characteristics of a Ce-Doped Silica Fiber Irradiated by 0 - 400 MeV Neutrons

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***Abstract*—A 200 μm and 600 μm diameter Ce^{3+} doped silica fiber, part of the UniBEaM charged-particle beam profiler system from D-Pace, were tested with 0 - 400 MeV neutrons at the TNF facility at TRIUMF, Canada. The detector's response to neutrons as a function of fiber length exposure was found to be linear, and the fiber was used to measure this neutron beam along its horizontal axis. This demonstrates the potential of the UniBEaM to measure neutron beam profiles.**

I. Introduction

Physicists in the field of accelerators have interest in profiling the particle beams used in their experiments. Rare-earth doped silica fiber detectors can be used due to their small size and therefore high spatial resolution, fast fluorescence decay time [1] for real-time measurements, and radiation hardness compared to organic scintillators [2]. In contrast to other profiler diagnostics, doped fiber detectors also have the advantage of being able to measure radiation in the form of photons [1], [3], and have the potential to measure mean beam energy for protons and other ions [4]

The UniBEaM beam profiler system [5] from D-Pace Inc. uses a Cerium doped silica fiber which is typically used to profile charged particle beams in the transverse plane. These fibers operate through the process of scintillation, in which charged-particle beams deposit their energy into the fiber material by ionizing bound electrons, which can then combine with activators (or dopants) within the material to create metastable (higher energy, low lifetime) atomic states. Subsequently, these atoms relax back into the ground state through the emission of fluorescent light. This system has primarily been used for ion beam profiling [6], [7], but the fiber has potential to be used for photons and electrons as well.

It is of interest to determine if such a fiber can produce signals due to neutron irradiation, making it a fully multipurpose beam profiler for nearly any particle beam. In this paper, we looked at the response of a cerium-doped fiber used by the UniBEaM when irradiated by thermal to 400 MeV neutrons at the Neutron Irradiation Facility (TNF) at TRIUMF.

II. Materials and Methods

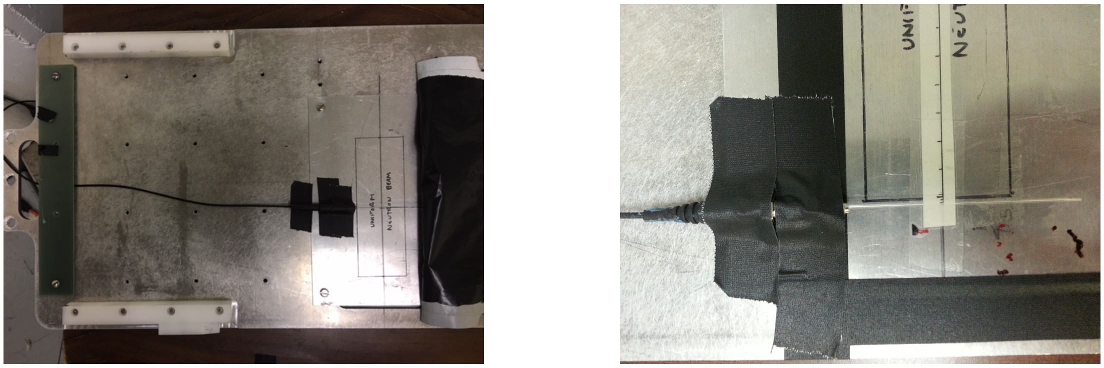
The studied detector is part of the UniBEaM system licensed by D-Pace from AEC-LHEP University of Bern. The D-Pace fibers here used are 200, and 600 μm in diameter. The 200 μm fiber has a length of 3 cm. The 600μm fiber is 8 cm long. The fiber is cerium doped silica glass and does not have an optical cladding. Due to the high sensitivity required for reading out neutron irradiations, the fiber was coupled to a MPPC module from Hamamatsu (model C13366-3050GU) set at 100 ms gate time. To reduce the background light contaminating the signal, the front-end of the MPPC was covered in black plastic. A 1mm core diameter plastic optical fiber, terminated with SMA 905 connectors, was used to couple the sensor fiber to the light sensor. A built-in software was used to read out the signal as a function of irradiated time.

TRIUMF operates a large cyclotron to produce up to 500 MeV protons for its research programs. The TNF (TRIUMF Neutron Facility) utilizes a beam dump at the end of one of the beam lines (beam line 1A). The final beam stop on this beam line generates neutrons from the spallation reaction on an aluminum plate absorber surrounded by a water moderator. The beam is actively monitored via a neutron detector. Over the course of these experiments, the neutron flux measured from this monitor was (3.47 $\pm$ 0.06) $\times$ $10^6 \frac{n}{cm^2 \cdot s}$ where n is the number of neutrons. This corresponds to a dose rate of 3.16 $\times$ 10^4 Gy/s.

The beam is accessible by a vertical shaft about 5 m below the local monitoring room. To get the fiber within the beamline, it was mounted onto a plate which could be lowered on a cable into the beam. The plate is marked with a box outlining the approximate profile of the beam from previous experiments at TRIUMF. The box is 15.2 cm in the horizontal and 5.1 cm in the vertical direction.

Figure 1 shows two general examples of the setup of the fiber detector on the plate. Figure 1a shows the general setup of the fiber taped on the plate. A dark plastic bag was used to cover the fiber before placing it in the beamline to reduce background ambient light. Figure 1b shows a closeup of the fiber when used for beam profiling. In these cases, a makeshift ruler is placed along the beamline to mark the position of the fiber along the beam, with each mark 1 cm apart. The uncertainty in position is estimated to be about $\pm$ 0.05 cm for each position.

For each measurement, the procedure is as follows: The fiber is lowered to about 0.5 m above the beam. A measurement is taken at this position to measure the background signal. The the plate is then lowered into the beam while



(a) General Setup (b) Close Up

Fig. 1. Examples of the fiber setup. Case a) shows the setup of the doped fiber coupled to the optical fiber taped along the beam (rectangular outline). Case b) shows a close-up used in the profiling experiments, with fiber positions marked along the beam. The 600 μm fiber is shown.

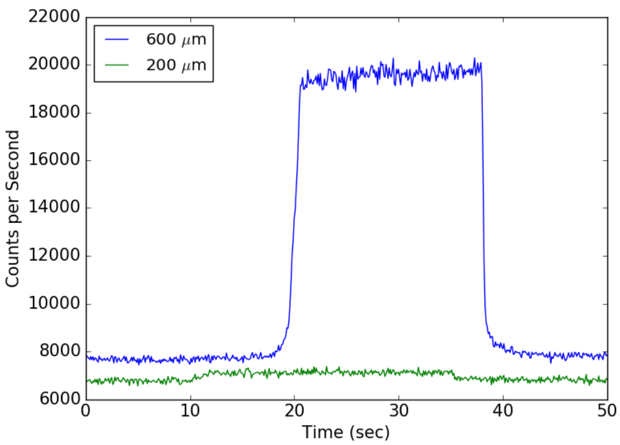


Fig. 2. An example measurement taken for the 200 and 600 μm fibers in the horizontal center of the beam profile. Both fibers reach only 3 cm into the beam vertically).

data aquisition is ongoing. The plate was removed from the neutron beam after about 10-20 seconds of irradiation, and allowed to reach background levels again. Before and after each measurement, the neutron flux from the monitor was recorded for normalization.

Measurements were made using both 200 μm and 600 μm fibers at various positions within the beam. For each measurement, the middle 50% of the plateau signal was used, and a mean and standard deviation calculated. The background was found by taking the mean and standard deviation of the signal before the plateau. This were subtracted by the plateau to get the signal from the beam. The noise after the plateau was not used, as there may be phosphorescence contaminating the background.

III. Results and Discussion

A. Fiber Diameter

Fig. 2 shows the different response due to the fiber diameter. The fibers were placed so that only 3 cm were within the marked box, in order to irradiate the same length of fiber. The background corrected signal height for the 600 μm fiber is 11900 counts per second while for the 200 μm it is 340. This is an unexpectedly large difference, as we'd expect the signal to rise by factor 9 due to the increase in volume. It is likely that the rest of the thicker fiber, which is 8 cm overall, is still irradiated outside of the marked beam profile given, though the relative signals are still much larger than expected when taking this into account. The reason for this is still unknown. As the signal of the 200 μm fiber is rather small, subsequent experiments were only carried out with the 600 μm fiber.

B. Linear Dose Response

A series of tests were performed irradiating the fiber with different lengths exposed to the beam, in the vertical direction. The fiber length within the beam was varied from 5 to 0 cm, in increments of 1 cm. The fiber was placed horizontally in the center of the beam for each data point. The neutron flux should cut off drastically at the boundaries of the rectangular profile, making the signal as a function of fiber length linear.

Figure 3 shows the results of the signal dependent on neutron irradiated fiber length. A non-linear least squares fit for a linear function results in R^2 = 0.995. The non-linearity is likely due to the neutron flux not having a sharp drop-off in the upper region of the beam profile, which is clearly the case as we receive a non-zero signal when the fiber is outside the beam at 0 cm.

C. Horizontal Profile

A horizontal profile was taken by placing the fiber at different positions along the horizontal axis of the neutron beam, covering the beam opening vertically. The fiber was positioned so that the same section of fiber was irradiated each time along the vertical axis. Unfortunately, the size of the plate did not allow for measurements far beyond the ends of the beam width. The measurements are shown in Figure 4 with 0 cm being along the left edge of beam opening as marked on the plate in Figure 1a, whereas the right edge is at 15.2 cm. Each point is normalized to the monitor counts,

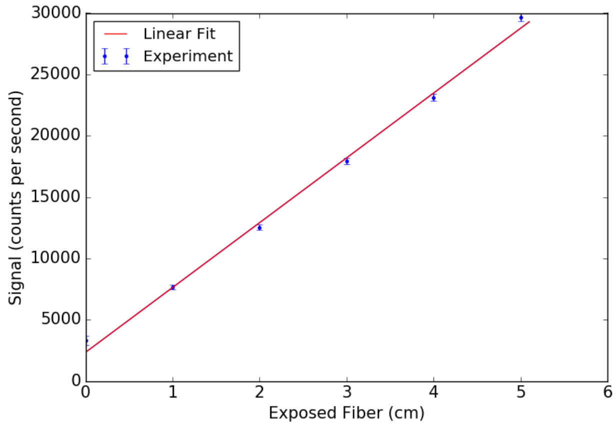


Fig. 3. Signal from the 600 μm fiber as a function of neutron irradiated fiber length. The linear fit parameters are slope = 3540±80 and intercept = 1500±200, with the fit having a R^2 = 0.998.

or neutron flux, and the profile peak is normalized to 1 in the center of the distribution. The fiber clearly shows a rise and fall on the edges of the beam with a plateau in the beam center. This measurement is compared to results taken with a SRAM dosimeter [8], normalized to the plateau values from the D-Pace fiber. The agreement between the two detectors is very good.

IV. Conclusion

The basic requirements for any detector used to profile beams are a signal proportional to its irradiated length, and proportional to the beam intensity. The 600 μm D-Pace cerium doped fiber shows a linear trend when different lengths of the fiber are irradiated in the neutron beam. To further show its potential as a profiler, this D-Pace fiber was placed in different positions along the beam with the same irradiated length at each position. The results are a profile of a neutron beam which is in good agreement with that of a SRAM detector used for neutron measurements. Therefore, the D-Pace fiber has good potential as a beam profiler for neutrons. Future work would include measuring the fiber response as a function of neutron kinetic energy.

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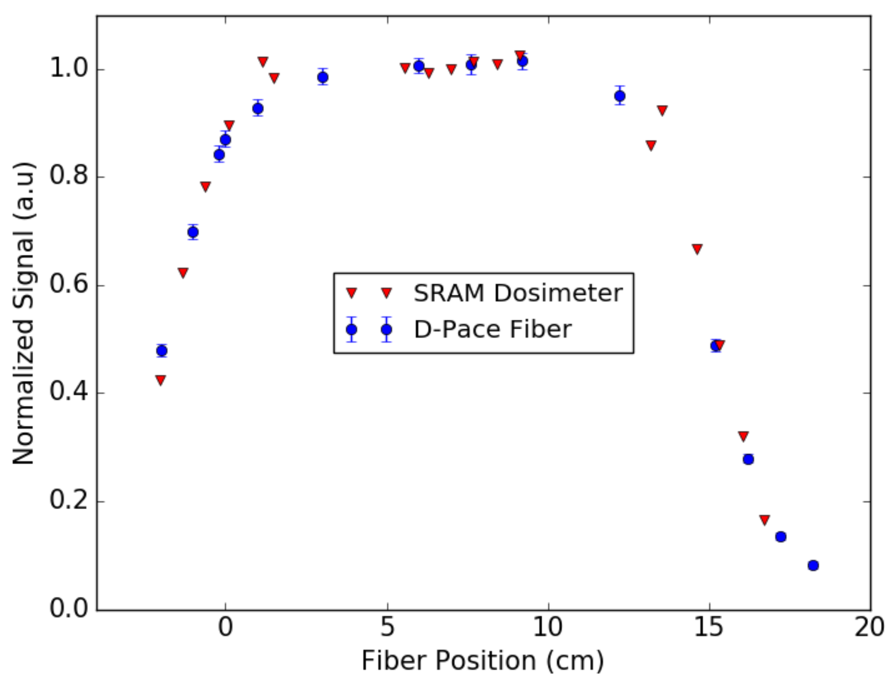

Fig. 4. Signal from fiber irradiated with neutrons as a function of horizontal placement along beam. Also shown are results of a similar scan from an SRAM detector.

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