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Radiation-hardness studies of high OH^- content quartz fibres irradiated with 24 GeV protons^{a)}

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Abstract

We investigated the darkening of two high OH^- content quartz fibres irradiated with 24 GeV protons at the CERN PS facility IRRAD. The two fibers, 0.6 mm quartz core diameter, one with hard plastic cladding (qp), the other with quartz cladding (qq), are both supplied by the US firm Polymicro Tech. Inc. (PT). These fibres were exposed at more than 1 Grad in 3 weeks. The fibres became opaque below 380 nm, and in the range 580-650 nm. Darkening under irradiation has variation versus dose similar to what we observed with electrons.

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1 Introduction

For a few years the University of Iowa group, in the frame of the Forward Hadronic calorimeter (HF) of the Compact Muon Solenoid experiment (CMS) at LHC, investigated the radiation hardness of different types of fibers, in association with Turkish Particle Physics laboratories. The results of darkening measurements of quartz fibres (0.3 and 0.4 mm core diameter) irradiated with 500 MeV electrons up to 100 Mrad have been already published [1].

To complete our knowledge of radiation damage of the HF quartz fibres (qp 0.6 mm core diameter) and to investigate the possible use of quartz fibers at SLHC we initiated a high level irradiation with 24 GeV protons at CERN. About $4.6 \cdot 10^{16} \text{ protons/cm}^2$ corresponding to a dose of 1.2 Grad (i.e. about 12 years of HF operation in the hottest tower) have been sent onto 1.20 m of quartz fibers. The fibre radiation damage induced by protons exhibits the same well known behaviour as with electrons : high light attenuation below 380 nm and in the band 550-680 nm. Moderate attenuation in the band 400-520 nm, no attenuation above 700 nm. With a constant dose rate, the damage has an exponential variation versus time (Fig. 3), fast in the first hours and slow after. Above 0.5 Grad the radiation damage is no more recoverable in the range 580-650 nm and below 380 nm.

2 Experimental set-up and data acquisition

2.1 Experimental set-up

The fibres were installed, with their light support, on a remote controlled table (Fig. 1) of the CERN facility IRRAD [2].

Figure 1: Experimental set-up

Three loops of qq and qp fibers (40 cm long) are wrapped together and placed along the beam with a 2.5% slope. The total irradiated length (L) is about 1.2 m. No material was inserted in front of the fibers.

The 24 GeV proton beam at IRRAD was delivered as 3-4 sub-cycles in a $(19.6 \pm 3.0)s$ long supercycle. This beam delivers $10^{11} p/cm^2$ /burst in a spot of $2 \times 2 \text{ cm}^2$. Some of these parameters were changed during the irradiation. The number of protons delivered was recorded and the dose calibration was done using a thin Al sample. We checked regularly the proton beam stability in size and time but it was not as stable as the LIL electron beam [1].

The optical setup uses Ocean Optics components. The two-channels spectrometer (SD 200) is the same as in electron measurements [1]. The deuterium halogen light source (d+h) generates a wide range spectrum (200-1000 nm). The spectrometer is sensitive in the range 350-850 nm only. The attenuation measurements were performed in-situ, the irradiated fibres being linked to the spectrometer and source with 25 m long fibers. The light is injected in a Y fibre splitter and then in the qq and qp fibres.

2.2 Data acquisition

The time interval between two successive light injections and data acquisition corresponds to one cycle (19.6 s) at the beginning of irradiation to 40 or 80 cycles (13 or 26 min) at the end, according to the damage variation versus time.

The two SD200 channels were read and registered at the same time using the Ocean Optics ADC1000 card. A PC Dell registers the spectra data as well as the time and the number of protons.

The intensity of the light source (d+h) was quite low for the SD2000 and we used an integration time of 1 sec inducing a noticeable background (Fig. 2). In the range of interest (350-750 nm wavelength, dose < 1 Grad) the signal strength in the SD2000 was significant. The qp channel was less sensitive than the qq one.

Figure 2: Evolution of the spectra versus increasing dose at 455 nm for the qq fibre.

Figure 3: Evolution of the ratio of spectra with and without irradiation at 455 nm for the qq fibre.

3 Analysis and results

As the PS cycling was changing, some runs included Cherenkov light generated by protons. These runs were discarded.

Then, the data are histogrammed in 10 nm wavelength bins. Runs are arranged in groups covering a few minutes of irradiation at the beginning and hours after 100 Mrad dose.

At a given dose D , the starting point, $c(\lambda, D)$, of the raw signal distribution $S(\lambda)$, in each bin are determined and the distribution $[S - c](\lambda, D)$, is summed over all the wavelengths and then fitted to a Moyal (Landau) distribution. The maximum of this distribution $d(D)$, characterises the spectrum. The same is done for the background to get the parameter b independent of dose and wavelength.

We assume that $I(\lambda, D) = c(\lambda, D) + d(D) - b$, and then calculate the ratios $I(\lambda, D)/I(\lambda, 0)$. The light attenuation in the fiber, is well represented by the function

$$A(\lambda, D) = \alpha(\lambda)[D/D_s]^{\beta(\lambda)}$$

α and β parameters for qq and qp fibres are then determined by fitting the ratios as a function of wavelength and dose.

$$I(\lambda, D)/I(\lambda, 0) = \exp[-(L/4.343)\alpha(\lambda)(D/D_s)^{\beta(\lambda)}].$$

Choosing a scale factor $D_s = 100$ Mrad, α is the attenuation at 100 Mrad, in dB/m, L being expressed in m.

The results are shown in Figure 3:

4 Summary

The radiation damage due to protons are in agreement with our published results on the radiation damage due to electrons. This is significant because the two types of irradiation are very different:

- 24 GeV protons compared to 0.5 GeV electrons with very different mode of interaction

Figure 4: α parameters for qq and qp fibres versus wavelength, where α is the attenuation in dB/m at 100 Mrad.

Figure 5: β parameters for qq and qp fibres versus wavelength.

- Higher dose: 1 Grad with protons compared 0.1 Grad
- Different set-up and different fiber sizes (all supplied by Polymicro)

As with electrons up to 0.8 Grad we don't observed a significant difference in attenuations versus dose between qq and qp fibers (Fig. 4).

Above 0.5 Grad there is no recovery of damage below 380nm and in the range of 580-650 nm, the quartz becomes opaque. The recovery was watched over 4 months.

The decrease of signal (Fig. 2) in fibres is very fast at the beginning: 30% loss after 20 Mrad at 455 nm, i.e., after about 2 months of operation of a detector at pseudo rapidity $\eta = 5$ (tower 12 of the CMS-HF).

The complete results of this analysis up to 1.2 Grad with a recovery study in qq fiber will be published soon.

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References

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