The production of radiation tolerant vacuum phototriodes and their HV filters for the Compact Muon Solenoid endcap electromagnetic calorimeter

P.R. Hobson[a]*,

[a]School of Engineering & Design Brunel University,
Uxbridge, Middlesex UB8 3PH, UK

Particle detectors which will operate at the Large Hadron Collider face unprecedented challenges in both the number of active detector elements and in operating without maintenance in a high radiation environment for many years. In the Compact Muon Solenoid (CMS) detector the scintillating crystal electromagnetic calorimeter uses vacuum photodetectors in the endcap where the lifetime neutron and hadron fluence is too high for the silicon avalanche photodiodes used in the barrel. Over 15000 radiation tolerant vacuum phototriodes (VPT) have been now been produced by industry for the endcap calorimeter. The VPT have to operate in an environment which has both a significant lifetime dose (up to 50 kGy) from electrons and gamma rays and a high neutron fluence (up to nearly 10^{15} n.cm^{-2} for E > 100 keV). This paper discusses the steps taken during both the development and production of the VPT to ensure that the response to the scintillation light from the lead tungstate scintillator will not be significantly degraded during the operational lifetime of the experiment. Data from the quality assurance procedures and radiation induced degradation of complete VPT devices is presented. Other components of the endcap calorimeter are also exposed to a similarly intense radiation field. The quality assurance procedure used to select the passive components (resistors and capacitors) used in the high-voltage filter cards is described.

1. Introduction

The Compact Muon Solenoid (CMS) [1] detector currently under construction will operate at the Large Hadron Collider (LHC), CERN for a period of at least ten years. The radiation environment that both active and passive components will experience is not dissimilar to that found inside a nuclear reactor. Detector subsystems close to the beam line will receive a lifetime dose in the kGy to MGy range and hadron fluences of more than 10^{15} n.cm^{-2}. This extreme environment, coupled with the practical difficulties of affecting any repairs to the detector after it becomes operational, means that extensive evaluation and quality assurance has been required for all component parts.

In this paper we discuss the production of radiation tolerant vacuum phototriodes (VPT) and their HV filters which are used in the endcap electromagnetic calorimeter (EECAL) [2][3].

*On behalf of the CMS ECAL Group

2. Radiation Environment of the EECAL

The endcap region of the CMS detector will receive a high dose from electromagnetic particles and also a significant neutron fluence. We must thus fully evaluate the radiation tolerance of all components that will be used and test batches during the detector construction phase.

2.1. EM dose

The predicted lifetime dose, at the position of the photodetectors, in the EECAL is a function of pseudorapidity, with the dose rising to 20kGy at η of 2.6 and reaching 50 kGy at the inner edge of the endcap (η of 3.0).

2.2. Hadron fluence

At $\eta = 3$ the neutron fluence (E > 100 keV) at the VPT is predicted to be 7.5×10^{14}cm^{-2} and the charged hadron fluence is 5×10^{13}cm^{-2}. At $\eta = 2.6$ (limit for active electronics) the neutron fluence is about a factor of ten lower than at $\eta = 3$.

3. Vacuum Phototriodes

The vacuum phototriode (VPT) is a single gain stage photomultiplier which was chosen as the photodetector for the homogeneous lead tungstate endcap electromagnetic calorimeter beacuse of its extreme tolerance to hadrons.

Quartz is often chosen as a faceplate because of its high resistance to ionising radiation but the different thermal expansion of quartz compared to the borosilicate glass of the tube envelope requires graded seals in the construction. This approximately doubles the cost of each VPT and increases their overall length.

Following a search for alternative materials, UV transparent borosilicate glasses were identified as suitable candidates [4] and one, a Russian glass, was chosen. This glass was made in batches and as part of our quality assurance processes each batch of glass was evaluated before any VPT that would use it were made

From each batch a number of fully-finished faceplates, of nominal thickness 1.0 mm, were cut and polished. The absorbance of these were measured in a Hitachi U4100 spectrophotometer before and after being irradiated in the dark at room temperature with ^{60}Co gammas. Faceplates were given a dose of nominally 20 kGy at about 400 Gy per hour.

4. HV filter passive components

The HV filter components are located close to the VPT. The filter is composed of high-value resistors and high-voltage capacitors. Changes in value, breakdown, or increased leakage currents after irradiation will degrade the noise performance of the readout. We use commercial-off-the-shelf components (COTS) and batch test these before they are mounted on the filter cards. Capacitors and resistors are evaluated, at a number of frequencies, for component value change. Capacitors also have their leakage current measured at 1kV.

5. Results

5.1. VPT

5.1.1. Faceplates

Figure 1 shows the induced optical absorbance of a faceplate after a dose of 19.3 kGy. An induced absorption band, with a peak around 320 nm is seen in all our samples. The induced absorbance, weighted by the scintillation spectrum, for all the faceplate samples in a given batch was calculated. If any single faceplate had a weighted absorbance of more than 10% then the batch was rejected. For the batch shown in Figure 1 the average (n=4) weighted absorption was 7.5%.

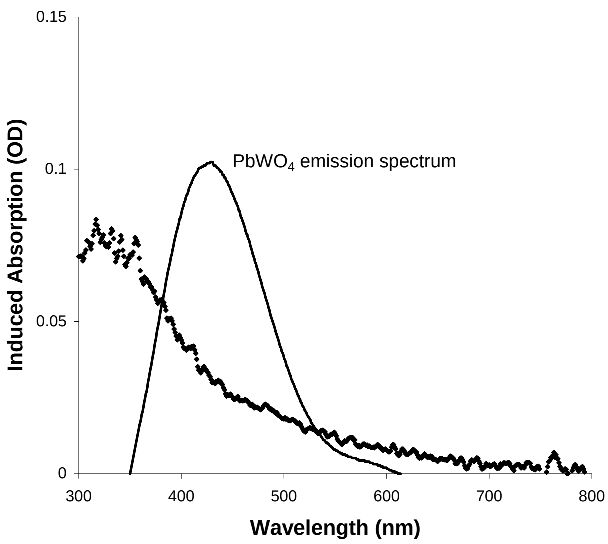

Figure 1. Induced optical absorbance of a faceplate after 19.3 kGy. The emission spectrum of a CMS lead tungstate crystal is shown for reference.

5.1.2. Complete devices

A number of complete VPT passing all of our acceptance tests were recently irradiated. Table 1 shows the relative change in response after a dose of 10 kGy. Due to differences in the measurement techniques the data obtained at magnetic fields of 0T and 1.8T show the combined effects of faceplate damage and any change in gain. Any change in the faceplate or photocathode is cancelled out in the 4T/0T ratio test, which should always produce a result close to unity.

Table 1
Response (relative to unirradiated data) after irradiation for five production VPT. The accuracy of these measurements is of the order of 2%

VPT	A	B	C	D	E
0 T response	0.94	0.81	0.90	0.84	0.96
1.8 T response	0.94	0.81	0.95	0.81	0.97
4T/0T ratio	0.98	0.98	1.01	0.99	1.00

The data show that, as anticipated, some reduction in response does occur, slightly more than might be predicted by considering the increased faceplate absorption alone for tubes B and D, and consistent with faceplate damage alone for the other three. No significant change in the gain ratio is seen at 4T for any tube.

5.2. HV filter components

Batches of 10 samples of each value of resistor (22 MΩ, 10 MΩ and 100 Ω) and 10 of each capacitor (1 nF and 470 pF, 2kV rating) were irradiated unbiased in the dark at room temperature with ^{60}Co gammas to a nominal dose of 135 kGy.

No significant change in any parameter measured was seen in any component. This is in contrast to earlier tests on similar COTS capacitors where we recorded a 10% decrease in capacitance after doses of 105 and 345 kGy in unbiased components. Complete recovery of capacitance over a period of three weeks was also seen for the capacitors irradiated to 345 kGy. This effect has been previously reported in the literature [5]. A number of 1 nF capacitors, previously irradiated with gammas were subjected to a neutron fluence of $1.1 \times 10^{14}\text{cm}^{-2}$. Following this an average reduction in capacitance of 1.2% was measured.

6. Conclusions

Faceplates, complete VPT, and HV filter components have been evaluated for radiation tolerance in the endcap calorimeter environment. Strict quality assurance procedures before production of VPT devices minimise the risk of significant loss of response even after ten years of operation at the LHC. COTS capacitors and resistors that can be used in the HV filter cards have been identified, and batch testing of all the lots used in the production of these filter cards is underway. A possible upgrade of the LHC to ten times the original design luminosity motivated the evaluation of some of the COTS components of the HV filter at a nominal dose of 350 kGy.

All 15000 production VPT have now been produced with batches of radiation tolerant faceplates which have passed our quality assurance tests.

Other passive components (cables, thermistors, thermal insulation, connectors etc.) that will operate in the radiation environment of the EECAL have also been selected on the basis of negliglible change under irradiation. Space limitations preclude any discussion of these components in this paper.

7. Acknowledgements

This work has been supported by funding from PPARC, UK. The VPT are produced by Central Scientific Research Institute, Electron, St. Petersburg, Russia.

REFERENCES

1. The Compact Muon Solenoid Technical Proposal, CERN/LHCC 94-38 (CMS TDR 1) 1994
2. CMS: The Electromagnetic Calorimeter Project TDR, CERN/LHCC 97-3 (CMS TDR 4) 1997
3. Apollonio M et al, *Nucl.Instrum. & Meth. in Phys.Res.* A532 (2004) 566-574
4. Bell K W et al, *Nucl.Instrum. & Meth. in Phys.Res.* A469 (2001) 29-46
5. Osmokrovic P et al, *Nucl.Instrum. & Meth. in Phys.Res.* B140 (1998) 143-151