Nuclear Instruments and Methods in Physics Research A 594 (2008) 389–394

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Radiation hardness tests of GaAs amplifiers operated in liquid argon in the ATLAS calorimeter

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ARTICLE INFO

Article history:
Received 19 March 2008
Received in revised form
26 June 2008
Accepted 30 June 2008
Available online 4 July 2008

Keywords:
LHC
Calorimeter
GaAs
Amplifier
Radiation damages

ABSTRACT

Highly integrated Gallium Arsenide (GaAs) chips of preamplifiers and summing amplifiers have been exposed to high fluence of fast neutrons and γ-dose at the IBR-2 reactor in Dubna. A stable performance of the electronics has been demonstrated up to a fluence of $5 \times 10^{14}\,\mathrm{n\,cm^{-2}}$ and a γ-dose of 55 kGy. The radiation hardness tests confirm the applicability of the preamplifiers for more than 10 years operation in the ATLAS hadronic end-cap calorimeter at LHC.

1. Introduction

The hadronic end-cap calorimeters (HEC) of the ATLAS detector [1] are read-out via preamplifiers and summation amplifiers (HEC-PAS) [2] mounted at the perimeter of the HEC inside the liquid argon. Eight preamplifiers and two drivers are integrated into one GaAs chip. Outputs of four preamplifiers are fed into the driver input. At the location of the cold electronics in the HECs of the ATLAS experiment a γ-dose of 0.3 kGy and a neutron fluence[5] of $0.2 \times 10^{14}\,\mathrm{n\,cm^{-2}}$ is expected after 10 years of LHC operation at maximum luminosity of $10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$. Comprehensive tests of the GaAs HEC-PAS prototypes exposed to photons and fast neutrons were carried out at the fast neutron pulsed reactors in Dubna [3] at a typical neutron flux of $10^{10}\,\mathrm{n\,cm^{-2}\,s^{-1}}$. No significant deterioration of the prototype performance was observed for the neutron fluence up to $\sim 3 \times 10^{14}\,\mathrm{n\,cm^{-2}}$ and up to 31 kGy, the highest γ-dose collected. The irradiation tests with a neutron flux smaller by two orders of magnitude also revealed no evidence for dose rate effects.

In this paper we present the results of radiation tests of the final design HEC-PAS [2] produced in the GaAs TriQuint QED-A 1 μm technology. Neutron irradiation was performed on a set of 7 GaAs chips. The preamplifiers were exposed to much higher total fluence of fast neutrons of $(1.1 \pm 0.2) \times 10^{15}\,\mathrm{n\,cm^{-2}}$ and accompanying γ-dose of (3.5 ± 0.3) kGy. Motherboards with the GaAs chips were kept in a cryostat filled with liquid nitrogen during the whole period of irradiation and measurements. Separate tests showed that the performance of HEC-PAS was the same whether the power was switched on or off during the periods of dose collection, so it was switched off in between the measurement runs. The γ-irradiation of 8 chips was carried out at cold conditions as well. A total γ-dose of (55 ± 8) kGy was collected with an accompanying fast neutron fluence of $(1.1 \pm 0.2) \times 10^{14}\,\mathrm{n\,cm^{-2}}$.

The results of these tests are presented in the paper after a brief description of the irradiation facility and the measurement setup.

2. Description of the experiment

A schematic layout of the irradiation facility is shown in Fig. 1. The mother-boards with GaAs chips were immersed into the

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[5] All fluence values are scaled to 1 MeV neutron equivalent.

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doi:10.1016/j.nima.2008.06.042

liquid nitrogen cryostat which was located in front of the movable platform not far from the beam shutter. The composition of the beam was determined by the beam filter. It was a 5 cm thick Pb absorber for the neutron beam replaced by a n/γ converter for exposure by γ's. The converter consisted of a paraffin moderator interleaved with cadmium foils. During the period of electronics measurements the beam was blocked and the signals were transferred via coaxial cables to the counting room at ~50 m distance.

The setup for electronics measurements is presented in Fig. 2a. Rectangular pulses from a pulse generator were converted into the triangular waveform and sent into the GaAs preamplifiers. Signals from various output channels were fed into the bipolar shaper system and then to the digital scope which was read out by a computer. The shaper allowed to vary the shaping time constants in the range from 10 ns to 10 μs. The GaAs chips were mounted on preamplifier and summing board (PSB) as shown in Fig. 2b. In order to simulate the detector capacitance, the capacitors (C_d) were mounted on the PSBs in parallel to the input channels. Each chip used the same capacitance value C_d for all its preamplifiers: the value could be either 10, 100, 220, or 330 pF. In this paper the results for the 220 pF case are shown in more detail, representing a typical detector capacitance in the HEC.

More information about the irradiation facility including the dosimetry aspects one may find in ref. [4]. It was shown that the neutron fluence is homogeneous within ±5% over the area of 20 cm × 10 cm (the size of PSB).

3. Experimental results

A standard set of characteristics like transfer function, peaking time (t_p), linearity and equivalent noise current (ENI) of the preamplifiers were measured during the tests. The transfer function was measured as the preamplifier's output voltage for different values of the input current. The peaking time was defined as the time between the signal level at 5% of maximum and the peak. The r.m.s. voltage on the shaper output with no input signal was used to determine the noise value. All measurements were done for different values of the shaping time constant of 10, 20, 50, 100, 200 and 500 ns, and 1, 2, 5 and 10 μs. The linearity of the preamplifiers was measured for different channels by injecting triangular current pulses with maxima in the range of 0−0.5 mA. All these characteristics were measured before the irradiation and after each step of the total dose collection.

One has to note that the measurement setup was sensitive to the low frequency pickup noise in the experimental hall which was most visible for channels with high C_d values. The affected data were not used in the analysis and the measured values for transfer function, peaking time and noise were averaged over the group of channels with the same detector capacitance.

3.1. Transfer function and peaking time

The transfer function measurement monitors the gain stability of the preamplifiers during the irradiation. The results of the measurements are presented in Fig. 3 for the neutron irradiation and in Fig. 4 for the γ-run. The data for various shaper time constants 10, 20, 50 and 100 ns were normalised to those obtained before the irradiation. Typical values in the HEC are a peaking time of 50 ns and a detector capacitance of 220 pF.

A degradation of the transfer function by 20% of its initial value is observed at a neutron fluence level of $(5-6) \times 10^{14}\,\mathrm{n\,cm^{-2}}$ for different shaper time constants and detector capacitance values. In the previous tests [3] of the prototype chips such decrease of the transfer function was found at lower fluence of $1 \times 10^{14}\,\mathrm{n\,cm^{-2}}$. The transfer function is more stable for the γ-irradiation. A small degradation observed at the highest γ-dose is at the same level as one would expect for the integrated underlying neutron fluence of $\sim 1.1 \times 10^{14}\,\mathrm{n\,cm^{-2}}$.

Similar conclusions may be drawn for the peaking time behaviour with neutron fluence and γ-dose.

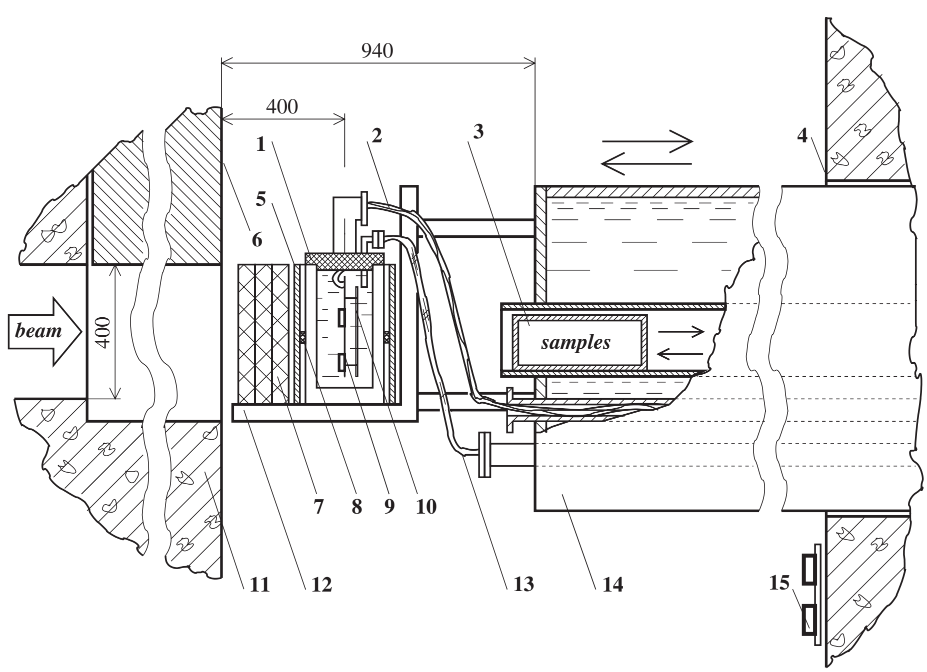

Fig. 1. Schematic layout of the irradiation facility: (1) cryostat; (2) signal cables; (3) transporting tube used for simultaneous irradiation of various samples; (4) outer reactor shields; (5) boron carbide layer; (6) beam shutter; (7) beam filter; (8) neutron and γ dosimeters; (9) motherboard with the electronics; (10) nickel foil; (11) inner reactor shields; (12) support frame; (13) cryogenic lines; (14) movable shielding platform; (15) electronics location for low dose irradiation. The fast neutron flux at the beam axis was up to $10^{10}\,\mathrm{n\,cm^{-2}\,s^{-1}}$, depending on the beam filter.