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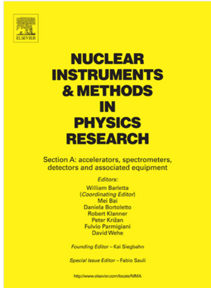

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Measurement and analysis of the conversion gain degradation of the CIS detectors in harsh radiation environments

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Abstract

The conversion gain of the CMOS image sensor (CIS) is one of the most important key parameters to the CIS detector. The conversion gain degradation induced by radiation damage will seriously affect the performances of the CIS detector. The experiments of the CISs irradiated by protons, neutrons, and gamma rays are presented. The CISs have 4 Megapixels and pinned photodiode (PPD) pixel architecture with a standard 0.18 μm CMOS technology. The conversion gains versus the proton fluence (including the proton ionizing dose), neutron fluence and gamma total ionizing dose are presented, respectively. The mechanisms of the conversion gain degradation induced by radiation damage are analyzed in details. The investigations will help to improve the PPD CIS detector design, reliability and applicability for applications in the harsh radiation environments such as space and nuclear environments.

Keywords—CMOS image sensor; Proton radiation; Neutron radiation; Gamma radiation; Conversion gain; Radiation damage

1. Introduction

CMOS image sensors (CISs) have been widely used as the detector [1-5], and the reliability and applicability are one of the key issues to the CIS detector design. However, the CIS detectors are sensitive to the radiation damage for applications in the harsh radiation environments such as space and nuclear environments [6-7]. Though many papers have been published on the radiation damages in pinned photodiode (PPD) CISs [8-10], fewer papers have focused on the conversion gain degradation of the PPD CIS detector induced by radiation damage.

In order to help the designers to improve the CIS detector performances for applications in the harsh radiation environments, the paper reported herein examines the conversion gain degradation induced by radiation damage. The CISs are irradiated with protons, neutrons and gamma rays, and the conversion gains before and after irradiation are compared. The conversion gain is correlated with the source followers of the pixels, the signal charge transfer loss of transfer gate (TG), and the on-chip analogue to digital converters (ADCs) of the CISs. The conversion gains versus the proton fluence (including the proton ionizing dose), neutron fluence, and gamma total ionizing dose (TID) are presented to compare the influences induced by the different radiation particles. The mechanisms of the conversion gain degradation induced by radiation damage are also analyzed in detail.

2. Experimental Details and Measurement Methods

The experiments of the PPD CISs utilized protons, neutrons and gamma rays respectively. The samples are unbiased with all pins grounded during radiation. The gamma radiation experiments are performed at ^{60}Co γ ray facility (at the Northwest Institute of Nuclear Technology, Xi'an, CHN). One sample was exposed to gamma rays at the TID of 50, 100, 150, 200 krad(Si) during radiation test and the dose rate is 50.0 rad(Si)/s. The neutron radiation experiments are performed at Xi'an pulse reactor (XAPR) facility (at the Northwest Institute of Nuclear Technology, Xi'an, CHN). One sample was exposed to 1MeV neutron-equivalent fluences of 1×10^{11} and 2×10^{11} n/cm^2. The flux of neutron beams is about 1.33×10^{8} n/(cm^{2}s), and the ratio of neutrons and the TID induced by γ rays (usually named n/γ) is 4.19×10^{9} n/(cm^{2}rad(Si)). The proton radiation experiments are performed at the EN Tandem Van De Graaff accelerator (at Peking University, Beijing, CHN) with energy of 3 MeV. One sample was exposed to proton fluences of 1×10^{10}, 5×10^{10}, and 1×10^{11} p/cm^2.

The samples used in these experiments are manufactured with PPD pixel architecture using a standard 0.18 μm CMOS

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