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Preliminary radiation tests of 32 μm thick hydrogenated amorphous silicon films

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Abstract

Preliminary radiation tests of hydrogenated amorphous silicon n–i–p photodiodes deposited on a coated glass substrate are presented in this paper. These tests have been performed using a 24 GeV proton beam. We report results on the fluence dependence of the diode dark current and of the signal induced by a proton spill.

1. Introduction

A novel radiation detector for charged particles has been recently proposed [1]. It consists of a thick n–i–p hydrogenated amorphous silicon (a-Si:H) sensing layer deposited directly on top of the integrated readout circuit. This is the so-called Thin Film on ASIC technology (TFA) and is a potential candidate for applications in high-energy physics and medical imaging. It shows a high integration level of the detecting device and readout electronics, a system cost reduction and a possibility to build large-area imaging devices. Several studies and characterizations have recently been performed by our group and presented in [1–4]. The tests were performed with pixel detectors based on the TFA technology, and with n–i–p a-Si:H test structures deposited on a glass substrate.

Another attractive feature of a-Si:H sensor for applications in collider experiments is its high level of radiation hardness. Proton irradiations have been performed by several groups on thin film a-Si:H solar cells for space applications, and the results demonstrate its high radiation resistance [5–7]. Other irradiations with neutrons [8] and photons [9] have also been performed. All these tests have been done on thin films and mostly conducted for the photovoltaic effects of solar cells.

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In this paper, we present the preliminary results we have obtained with thick n–i–p a-Si:H photodiodes deposited on a glass substrate, with high-energy protons, in measuring the evolution of the radiation-induced current and leakage current with respect to the total fluencies. This study on a-Si:H test structure is carried out to characterize the radiation hardness of a 30 μm thick n–i–p a-Si:H film that is used as detecting sensor in the TFA technology.

2. Experimental setup

In order to study the radiation hardness of solid-state detectors based on the TFA technology, we have performed preliminary tests on n–i–p a-Si:H photodiodes (see Fig. 1) deposited on a coated glass substrate. Two samples have been tested under proton irradiation and the preliminary results are presented here.

For each sample, a 30 nm thick n-layer, a 32.6 μm thick i-layer, and a 30 nm thick p-layer of a-Si:H were deposited on chromium-coated glass. The depositions were made by very high-frequency plasma-enhanced chemical vapor deposition at the IMT of Neuchatel. ZnO structures are used as top contact, defining the geometry of the diodes. The samples under tests have a square active area of 2 mm × 2 mm. Measurements were made with a reverse bias of 300 V applied to the diode, which does not fully deplete the diodes (the full depletion voltage is estimated to be 415 V).

The tests were done at the CERN IRRAD 1 facility. The diodes have been exposed to a primary beam line of 24 GeV protons, with fluencies up to 3×10^{13} protons/cm^{-2}/h^{-1}, at room temperature and in dark conditions, to avoid any light degradation [9].

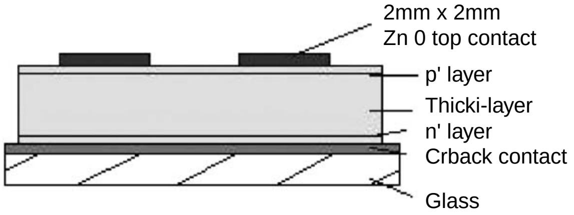

Fig. 1. Structure of an a-Si:H n–i–p photodiode used for the tests.

The beam fluencies were measured by a Secondary Emission Chamber (SEC), giving fluency measurement for each spill, corresponding to the whole beam spot size of 2 cm × 2 cm. It was also measured by activation of aluminium foil. During the irradiation period, several squares of 5 mm × 5 mm of Al have been successively placed in the beam, in alignment with the diode, to get a precise measurement.

For the first test, an a-Si:H sample was placed for 3 days in the beam. Each cycle of the beam presented three bunches of protons impinging onto one 2 mm × 2 mm a-Si:H diode. One spill was 120 ms long, with an average fluence of 1.6×10^{11} protons/cm^2. The accumulated fluencies during the whole irradiation were 3.5×10^{15} protons/cm^2. For the second test, another a-Si:H structure was placed for 2 days in the beam, with three bunches of protons, with an average fluence of 1×10^{11} protons/cm^2 per spill. The total fluencies reached onto the a-Si:H diode were 7×10^{14} protons/cm^2. We measured during the whole irradiation periods the signal induced by each proton spill in the test diode.

3. Results

The first 32.6 μm thick n–i–p a-Si:H diode was irradiated up to 3.5×10^{15} protons/cm^2. The extremely high flux of the beam and the readout system of the diode do not permit a single proton measurement, so that the online measurement consists of measuring the current signal induced by one spill, and recording the average value of the proton-spill-induced current (PSIC). The fluence per spill was assumed to be stable around 1.6×10^{11} protons/cm^2 during the irradiation period. Fig. 2 shows the fluence dependence of the proton-spill-induced current.

From a fluence of 6×10^{13} protons/cm^2 (corresponding to the first data recorded) up to 1.5×10^{15} protons/cm^2, the PSIC drops rapidly from 8 μA down to 3 μA and seems to stabilize for higher fluencies around 2 μA. The drop in

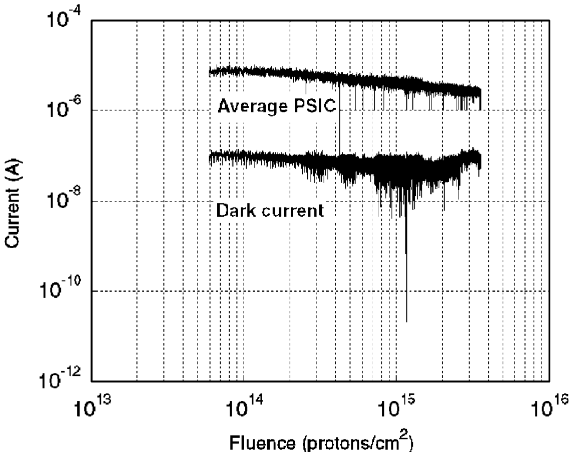

Fig. 2. Fluence dependence of the PSIC (current in μA range) and the dark current (curve with lower currents) measured for each spill during the radiation to 24 GeV protons, in a 2 × 2 mm^2 diode.

current can be attributed to a radiation-induced creation of dangling bonds, acting as recombination centres for the electron–hole pairs created by the protons through the a-Si:H-depleted i-layer. Fig. 2 shows the fluence dependence of the dark current measured between spills and after each spill. Results show a stable dark current characteristic up to 3.5×10^{15} protons/cm^2. The noise observed in the leakage current characteristic and in the PSIC characteristic is due to the noise introduced by the readout system of the signal, which is constant in the experiment, and to the noise introduced by the fluctuations of the fluence of each proton spill around the average value, which can change during the experiment.

The second 32.6 μm thick n–i–p a-Si:H diode was irradiated up to 7×10^{14} protons/cm^2. The fluence per spill is assumed to be stable around 1×10^{11} protons/cm^2. Fig. 3 shows the fluencies measured by activation of aluminium foils with respect to the corresponding number of spills.

The *I–V* characteristics of the diode under test have been measured before radiation and after several steps of irradiation. It shows a slight increase in leakage current (Fig. 4).

Fig. 5 shows the fluence dependence of the PSIC measured with the same method as for the first sample. We observe an increase in the PSIC for fluencies up to 5×10^{13} protons/cm^2, and for higher fluencies we observe the same degradation as was observed during the first test. After fluencies of 4.5×10^{14} protons/cm^2 the PSIC corresponds to 50% of the initial PSIC. At this stage, as it is indicated in Fig. 4, the sample was placed out of the beam for 20 h at room temperature and still under bias. It was then placed back into the

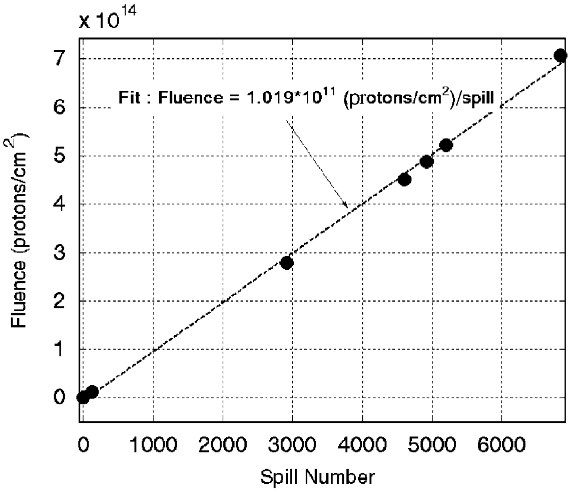

Fig. 3. Beam characteristics. Fluence with respect to the spill number.

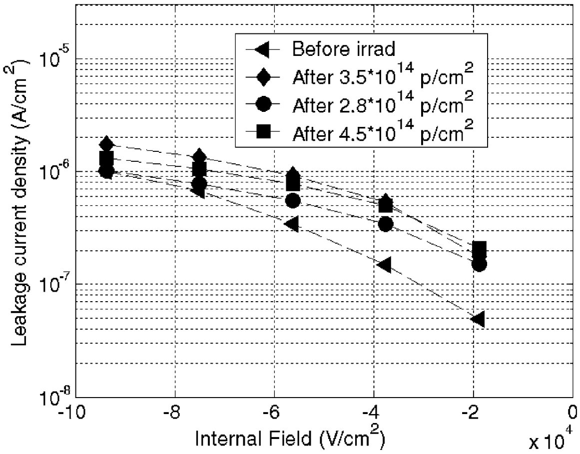

Fig. 4. Leakage current density characteristics measured on the diode, before irradiation and after several steps of irradiation.

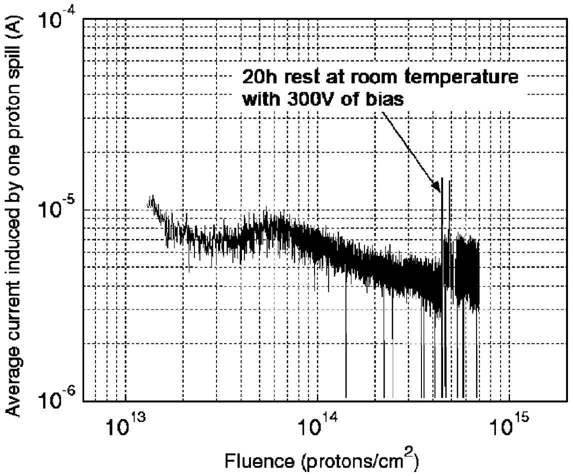

Fig. 5. Fluency dependence of the PSIC measured for each spill during the radiation to 24 GeV protons, in a 2 × 2 mm^2 diode.

beam with a similar fluency per spill. We observe that the PSIC is back to 66% of the initial PSIC. The slight increase at the beginning of the radiation and the first annealing effect observed can come from a recombination of deep centres and dangling bonds, leading to a smaller amount of trapped charge, and to an increase in the PSIC.

4. Discussion

A previous study [7] suggested that the structural metastability of the a-Si:H, enhanced by the protons irradiation, could be the cause of the excellent radiation resistance. Structural rearrangements in the a-Si:H random network could allow a recombination of the displaced atoms by the proton irradiation, disabling the creation of deep defects. The energy necessary to activate the atomic rearrangement could be provided by the electronic excitation generated by the incident protons. This theory could solve the paradox that a photon irradiation creates more damages than a proton irradiation [9], because photons do not provide sufficient activation energy. Other studies have also stated that the degradation could come mainly from ionization defects [6]. The degradation of our n–i–p a-Si:H photodiodes can come from both ionization and displacement damages. The observation of an increase with fluence of the PSIC for the second test could be explained by a structural rearrangement in the a-Si:H structure, activated by the proton electronic excitation, leading to a passivation of pre-existing dangling bonds. The degradation observed can be caused by generation of new dangling bonds. The process looks reversible, and dangling bonds could be regenerated, as we have observed in the second test, when the diode was placed out of the beam for 20 h at room temperature. The annealing properties have to be studied in more details in order to prove the reversibility of the damages mechanisms. The mechanism of radiation-induced generation and passivation of defects could explain the results we have obtained. These results are preliminary and other diodes are under test, mainly to study the annealing possibilities and to evaluate the radiation resistance to photons.

5. Conclusion

Some preliminary radiation tests with 24 GeV protons have been carried out on 32 μm thick n–i–p hydrogenated amorphous silicon photodiodes deposited on coated glass substrate. We have observed a global stable leakage current characteristic with respect to the fluencies, for a test up to 3.5×10^{15} protons/cm^2. A degradation attributed to a radiation-induced creation of dangling bonds has been observed in the current signal induced by a packet of protons. PSIC was reduced by a factor of 4 after fluencies of 3.5×10^{15} protons/cm^2. An increase in PSIC during the irradiation has been observed, as well as an increase after an annealing of 20 h at room temperature, both attributed to a passivation of defects.

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