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Photocapacitance measurements in irradiated a-Si:H based detectors

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Abstract

Photocapacitance measurements were performed on amorphous silicon p–i–n detectors before and after particle irradiation with 1.5 MeV 4 He^{+} ions. The spatial resolution across a degraded spot is similar to the one obtained in photocurrent scans and is of the order of the diameter of the scanning laser beam. We monitored the transient capacitance after applying short laser pulses to deduce trap energies of 0.64 eV. Photocapacitance measurements as a function of the applied bias, the measurement frequency up to 1 MHz, and the wavelength of laser light are discussed. The reduction in photocapacitance signal and the shift of the cut-off frequency after ion bombardment are correlated with the change in transport properties.

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Keywords: Silicon; Sensors; Defects; Radiation

1. Introduction

When monitoring the degradation behaviour of elementary particle or X-ray detectors often the charge collection efficiency is taken as a figure of merit. Early work directed towards performance analysis of space solar cells used as power sources for satellites quotes the reduction of short-circuit current of such detectors after some exposure [1]. More detailed studies look for the changes in both the electron and hole transport properties, the creation mechanisms of defects, their energetic level and their density, internal electric field distributions, and recombination kinetics. A new way of measuring the density-of-states distribution in amorphous semiconductors was introduced through photocapacitance spectroscopy [2]. It is in some sense similar to the well-known constant photocurrent method, CPM, and to thermal deflection spectroscopy [3].

Recently, several defect levels were identified by temperature-dependent spectral photocapacitance measurements in single films of ZnO [4] and CdTe [5]. Other authors applied this technique to complete amorphous silicon based p–i–n solar cells and described a combination of photocapacitance measurements and solar cell parameter measurements, combined with a computer model to show that under strong illumination the photocharge increases inside the solar cell and causes field collapse and thus a decline in solar cell efficiency [6]. A more theoretical treatment was given in Ref. [7], where the authors considered the photocapacitance C_{ph} to be a measure of the density of photogenerated carriers in the space charge region of a pin detector structure. It follows that both the electric field and the transport properties of photogenerated charges determine to the photocapacitance signal. In particular, the mobility and recombination lifetime of the minority carriers, which are generally holes, are important.

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2. Sample structure and measurement procedure

In most of the presented experiments we address the characteristics of photocurrent and of photocapacitance using a 1.1 μm thick and 1.5 mm × 6.8 mm large p–i–n detector sample (sample B-201-U) prepared at the University of Waterloo. A portion of the wire-bonded chip that includes pixels of different size is shown in Fig. 1. For comparison, other p–i–n detectors, prepared at the University of Stuttgart and the Hahn-Meitner-Institut in Berlin (samples HMI-2 and HMI-3), with a large range of i-layer thickness and pixel size, were also studied.

The detectors were exposed to a 1.5 MeV helium beam reaching a fluence of $1.5 \times 10^{15}\ \mathrm{cm}^{-2}$ at the ITN accelerator in Lisbon. The effect of particle irradiation is easily discernable in Fig. 1. The detector (B-201-U) was irradiated at three locations, marked by the white dotted circles. The first degraded spot of about 1 mm diameter (particle beam size) is seen at the left side by the damage caused to the metal contacts.

Experimentally, there are different ways to measure C_{ph}. For time-resolved capacitance measurements we used lock-in detection of the out-of-phase current through the device. Typically, we applied a sinusoidal modulation signal of 100 mV at 16 kHz and HeNe laser light modulation at 63 Hz. A commercial capacitance bridge was used for the measurements as a function of bias voltage and modulation frequency (C–V–f plots).

3. Experimental results

We first studied the temporal behaviour of the photocapacitance signal in the ms range by applying HeNe laser pulses of 60 ms of duration and then monitoring the capacitance decay. Fig. 2 shows the result in sample HMI-3 which has an intermediate thickness of 2 μm. The illumination density was about 0.3 mW/cm^2 when using a neutral density filter of ND = 1.7. The increase is about 17 pF. After the light is turned off, the capacitance does not return immediately to its dark value, but shows an exponential decay as seen by the straight line in the semi-logarithmic plot.

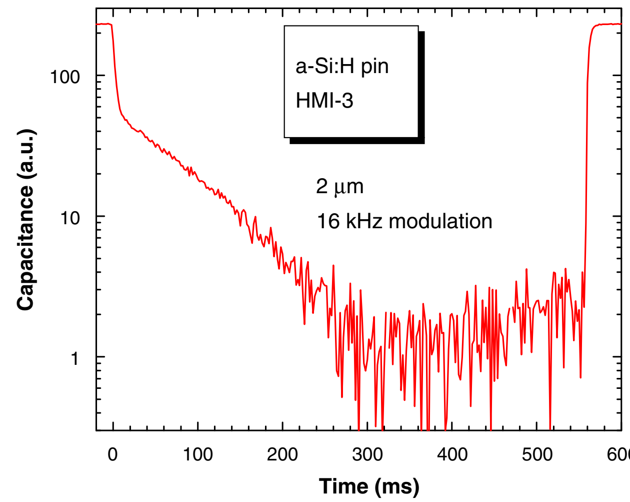

Fig. 2. Photocapacitance transients in the 2 μm thick p–i–n detector HMI-3 under HeNe laser pulses of 60 ms duration. The semi-logarithmic representation of the photocapacitance decay after switching off the HeNe laser shows a characteristic decay time of 96 ms at room temperature.

The same test with the 5 μm thick HMI-2 detector did not lead to conclusive results. The capacitance was much lower. One reason could have been that, at least for zero bias and for reverse bias operation, the capacitance change is too low for our set-up.

The remaining measurements are all done with the 1.1 μm thick B-201-U detector sample that had a number of different pixel sizes. We employed at that stage the commercial capacitance bridge which has a much higher resolution, even though time-resolved measurements were not possible.

Fig. 3 shows a photocapacitance scan along the 6.8 mm long and 1.6 mm wide center pixel of the detector B-201-U

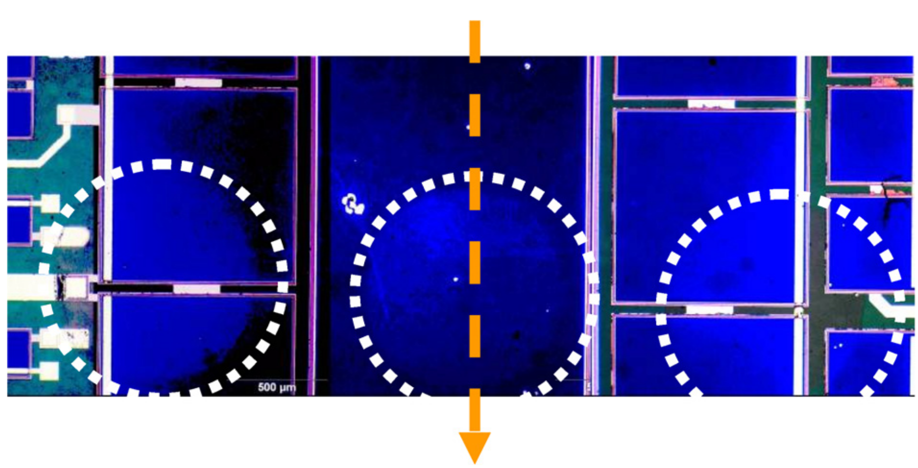

Fig. 1. Optical micrograph of the 1.1 μm thick detector (B-202-U) irradiated at three locations, marked by the white dotted circles. The first spot on the left of about 1 mm diameter is easily seen by the damage caused to the metal contacts. The vertical arrow indicates the scan direction of the laser beam. The width of the squares is 1.6 mm.