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Characterization of 13 and 30 μm thick hydrogenated amorphous silicon diodes deposited over CMOS integrated circuits for particle detection application

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Abstract

We present the experimental results obtained with a novel monolithic silicon pixel detector which consists in depositing a n–i–p hydrogenated amorphous silicon (a-Si:H) diode straight above the readout ASIC (this technology is called Thin Film on ASIC, TFA). The characterization has been performed on 13 and 30 μm thick a-Si:H films deposited on top of an ASIC containing a linear array of high-speed low-noise transimpedance amplifiers designed in a 0.25 μm CMOS technology. Experimental results presented have been obtained with a 600 nm pulsed laser. The results of charge collection efficiency and charge collection speed of these structures are discussed.

1. Introduction

A radiation sensor for charged particles based on the deposition of hydrogenated amorphous silicon (a-Si:H) n–i–p films on ASIC [1,2] has been recently proposed. The charge collection of the a-Si:H films has been studied with an ASIC containing 32 channels of Active Feedback Preamplifiers (AFP) designed in a 0.25 μm CMOS technology [3] (Fig. 1).

The AFP is a transimpedance amplifier which uses a PMOS transistor as feedback element, making the circuit fast and low-noise, two characteristics which are crucial to measure a-Si:H films charge collections. The feedback current controls the noise, the gain and the speed of the amplifier. A 13 μm thick and a 30 μm thick n–i–p a-Si:H diodes have been deposited on two ASIC samples.

2. Leakage current

A negative voltage is applied to the ITO electrode (Fig. 2) connected to the p-layer which reverse biases the n–i–p diode and depletes it. The intrinsic i-layer is in fact slightly n-doped, thus the depleted layer extends increasing the voltage from the p–i interface down to the i–n interface. The dark current of thick a-Si:H n–i–p structures has been measured at low bias voltage elsewhere [2],

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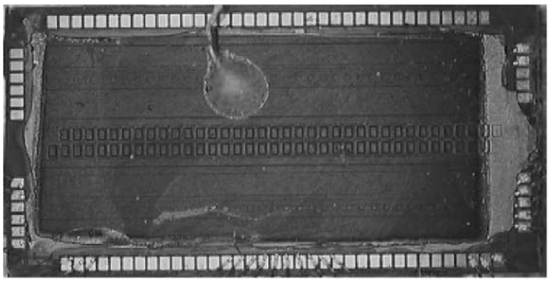

Fig. 1. Photography of a 30 µm n–i–p a-Si:H film deposited on the 32-channels AFP amplifier integrated circuit, the size is 2 mm × 4 mm.

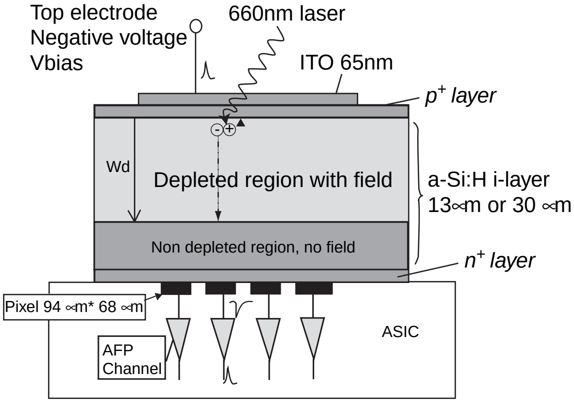

Fig. 2. Schematic of the n.i.p layers deposited on top of the ASIC.

and values of 6 pA/cm^2 for an applied voltage of 1 V/µm have been obtained. Above 130 V for the 30 µm thick a-Si:H sample and 50 V for the 13 µm thick a-Si:H sample, the dark current increases very rapidly (Figs. 3 and 4). A previous work [4] has shown that this effect at room temperature can be attributed to a leakage through the p-layer, by a mechanism of field-enhanced generation at the p/i interface.

Above the reverse bias voltages of 280 V for the 30 µm sample and 80 V for the 13 µm sample, large leakage currents prevent precise measurements and full depletion operation of the a-Si:H diode. Leakage currents of individual pixels have been measured by monitoring the leakage current flowing in the electronic channel (Fig. 4).

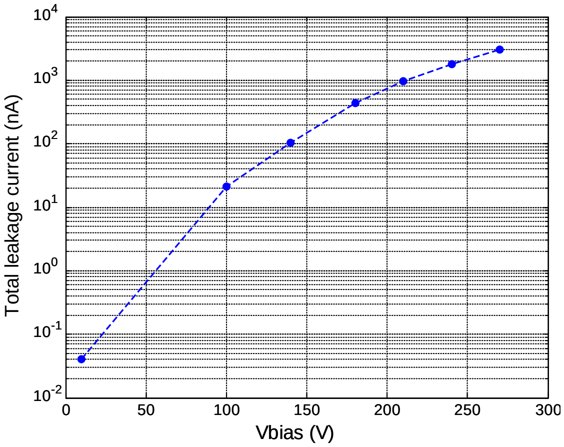

Fig. 3. I–V characteristic of the entire 30 µm chip.

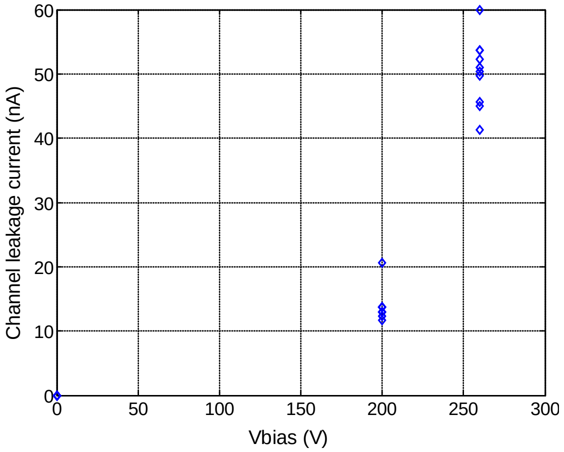

Fig. 4. I–V characteristic per pixel (AFP channel).

The leakage current flows through the AFP in puts and induces variations of the feedback current that are readout at the output of the AFP amplifier as DC variations. This current varies up to 50 nA/pixel for 260 V of bias that is sufficiently small compared to the AFP feedback current of 1.2 µA, and does not induce variations in the amplifier transfer function.

3. Charge collection

Charge collection of the 13 and 30 µm structures have been characterized using a 660 nm pulsed laser (2 ns pulse width) [1,2], having a 1 μm mean free path in a-Si:H.

The peaks (Figs. 5 and 6) correspond to the electron drift in the depleted region. We observe the peaks showing a rising time of 6 ns for both samples, and a falling time of 16 ns (30 μm sample) to 20 ns (13 μm sample) are constant while varying the detector bias voltage (the electron collection time is independent of the detector bias such that the i-layer is not fully depleted). By considering a linear variation of the electric field with the depth of the i-layer depleted zone, we can extract the electrons collection time constant $\tau_{\mathrm{coll,n}}$ [1]

$$\tau_{\mathrm{coll,n}} = (\varepsilon_0\ \varepsilon_{\mathrm{Si}})/(\mu_{\mathrm{e}}\ q\ N_{\mathrm{d}}) \tag{1}$$

$\tau_{\mathrm{coll,n}}$ varies from 10 to 1 ns for an electron mobility of 10 to 1 $\mathrm{cm^2/V\,s}$. After 3 $\tau_{\mathrm{coll,n}}$, 95% of the collection is achieved. This model can be applied to the non-dispersive electron transport occurring at room temperature in a-Si:H (standard transport model, by conduction in extended states).

When electron collection is achieved, a long decay tail (Fig. 7) represents the hole collection (holes mobility is about 0.01 $\mathrm{cm^2/V\,s}$ in a-Si:H). Increasing the bias, we observe an increase of the collection speed (1.6 μs for 70 V to 1 μs for 220 V). Holes are created in the vicinity of the p/i interface and drift up to the top electrode, on a short length.

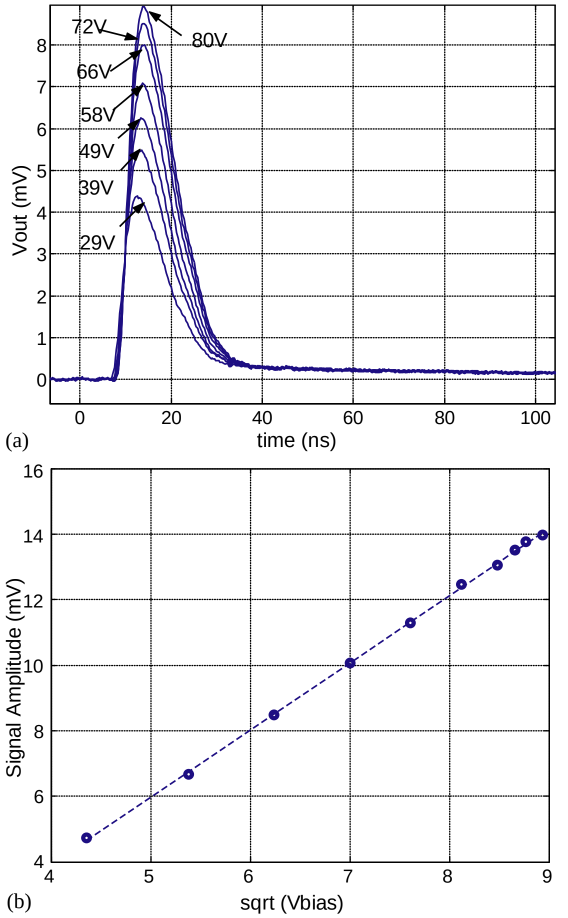

Fig. 5. (a) 13 μm sample, AFP output pulses for different detector bias voltages. (b) The signal amplitude versus the square root of the detector bias is displayed in the corner.

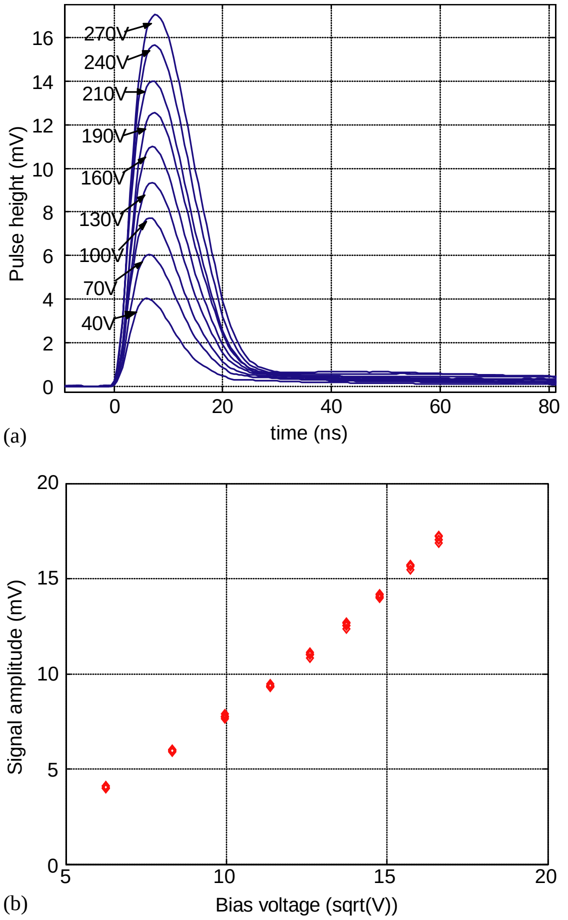

Fig. 6. (a) 30 μm sample, AFP output pulses for different detector bias voltages. (b) The signal amplitude versus the square root of the detector bias is displayed in the corner.

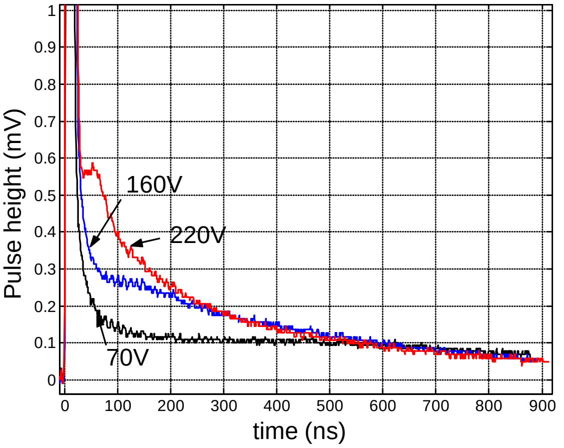

Fig. 7. AFP output pulses long tail for the 30 μm sample for 3 different biases.

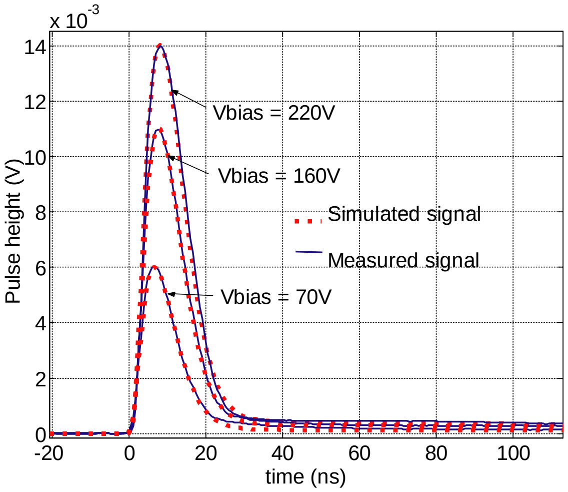

Fig. 8. Fits obtained between signals measured on 30 μm sample and signals simulated using a sum of 2 exponential as diode current transient.

Increasing the bias voltage, one increases the electric field so the holes speed. The drift length is not changing for holes, resulting in a global decrease of the collection time.

Due to the high speed of the current transient, the AFP pre-amplifier is shaping the signal. A deconvolution of the signals for biases of 70, 160 and 220 V have been carried out using the HSPICE model of the pre-amplifier AFP. We used a sum of two exponentials for the current transient $i(t)$ of the photodiode layer.

A fast exponential (Fig. 8) corresponds to the electrons transport (considering the standard transport model, the collection time constant is τ_1). A slow exponential (Fig. 8) corresponds to an approximation of the holes transport, the collection time constant is τ_2. Actually holes have a non-dispersive transport, and are subjected to trapping in deep states, making hole mobility a time dependent parameter. Though simplifying the complex electronic transport in a-Si:H, we performed good fits between simulated and observed signals (Fig. 9).

We extracted an electron collection time constant of $\tau_1 = 4.5$ ns (not varying with bias) for the 30 μm sample, corresponding to a $\mu \cdot N_\mathrm{d}$ of 1.45 $\mathrm{cm}^{-1}\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$; and a $\tau_2 = 4$ ns (not varying with bias) for the 13 μm sample, corresponding to a $\mu \cdot N_\mathrm{d}$ of 1.64 $\mathrm{cm}^{-1}\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$. The holes collection time constant τ_2 is varying with bias, from 600 ns at 70 V to 300 ns at 220 V. The charge collection speed of the 30 μm sample has been characterized (Fig. 10) for 3 different biases. It shows a collection of 50% of the total charge in 15 ns (electrons collection in $3 \times \tau_1$), and a long tail corresponding to the holes collection.

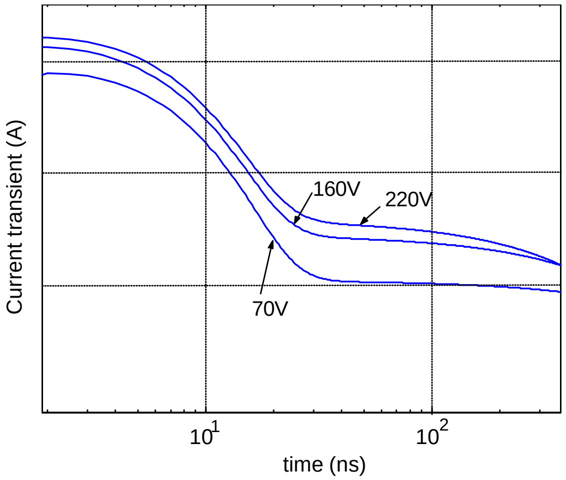

Fig. 9. Extracted current transient for the 30 μm sample.

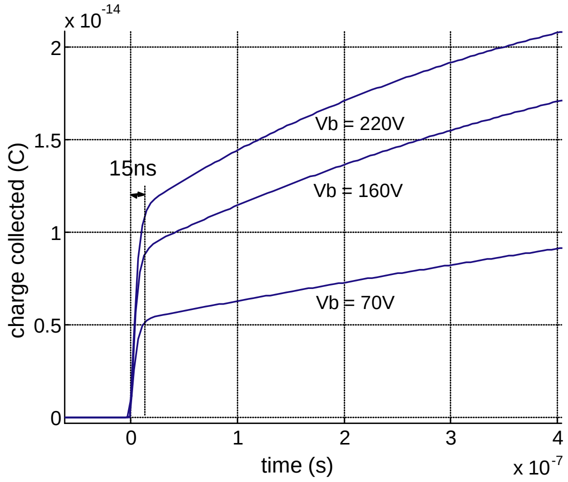

Fig. 10. Charge collection for the 30 μm sample for 3 different biases.

4. Conclusion

We have characterized the charge collection speed of 13 and 30 μm thick a-Si:H diodes directly deposited on the ASIC containing the readout electronics. We have used a 660 nm pulsed laser. Our measurements have shown that there are two components in the response of the detector: a fast one attributed to the electrons transport and a much slower one attributed to the holes transport. For both the 13 and the 30 μm thick detectors the fast component varies from 16 to 20 ns, whereas the slow component varies from 0.9 to 1.5 μs. The fast component does not depend on the bias voltage, the slow one decreases increasing the bias voltage. The high leakage current observed increasing the bias voltage prevents full depletion of the detectors: the expected bias voltage for a full depletion of 30 μm of a-Si:H is 415 V, and the maximum voltage we can apply to the 30 μm thick, a-Si:H film is 280 V.

References

[1] P. Jarron, G. Anelli, S. Commichau, M. Despeisse, G. Dissertori, C. Miazza, A. Shah, N. Wyrsch, G. Viertel, New concept of monolithic silicon pixel detectors: hydrogenated amorphous silicon on ASIC, presented at the 9th Pisa Meeting on Advanced Detectors, La Biodola, Isola d'Elba, Italy, May 25–31, 2003.

[2] N. Wyrsch, C. Miazza, S. Dunand, A. Shah, N. Blanc, R. Kaufmann, L. Cavalier, G. Anelli, M. Despeisse, P. Jarron, D. Moraes, A.G. Sirvent, G. Dissertori, G. Viertel, Development of vertically integrated imaging and particle sensors, Presented to the Mathematics Research Society, Spring Symposium 2003, San Francisco, MRS Proceedings, to be published.

[3] G. Anelli, K. Borer, L. Casagrande, M. Despeisse, P. Jarron, N. Pelloux, S. Saramad, Nucl. Instr. and Meth. A 512 (2003) 117.

[4] J.B. Chevrier, B. Equer, J. Appl. Phys. 76 (11) (1994).