Study of the long-term behavior of the sensitivity of amorphous silicon photo detectors under illumination [1]

Ludwig Eglseer, Sandra Horvat* and Hubert Kroha

Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 München, Germany

Abstract

The deterioration of the sensitivity of amorphous silicon strip photo detectors ('ALMY' sensors) under long-term illumination has been studied with collimated laser beams of different wavelengths and intensities. The high position sensitivity of the ALMY sensors allows for the precise localization of the illumination point and for monitoring of the local sensitivity degradation with respect to the rest of the non-illuminated sensor area.

Key words: silicon strip sensors, hydrogenated amorphous silicon, laser diodes, photo detectors, Staebler-Wronski effect, long-term illumination

[1] Proceedings of the 10th European Symposium on Semiconductor Detectors, June 12-16, 2005, Wildbad Kreuth, Germany, to be published in Nucl. Instrum. Methods Phys. Res., Sect. A.

* Corresponding author, e-mail: Sandra.Horvat@cern.ch

Study of the long-term behavior of the sensitivity of amorphous silicon photo detectors under illumination

Ludwig Eglseer, Sandra Horvat* and Hubert Kroha

Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 München, Germany

Abstract

The deterioration of the sensitivity of amorphous silicon strip photo detectors ('ALMY' sensors) under long-term illumination has been studied with collimated laser beams of different wavelengths and intensities. The high position sensitivity of the ALMY sensors allows for the precise localization of the illumination point and for monitoring of the local sensitivity degradation with respect to the rest of the non-illuminated sensor area.

Key words: silicon strip sensors, hydrogenated amorphous silicon, laser diodes, photo detectors, Staebler-Wronski effect, long-term illumination

1 Introduction

From the study of thin-film hydrogenated amorphous silicon (a-Si:H) solar cells, it is well known that the photo current response of a-Si:H deteriorates under illumination. This property, known as the Staebler-Wronski effect [1], has been studied intensively. However, it is still difficult to combine all experimental results in a consistent way which agree only qualitatively. The predominant explanation of the effect is that the illumination leads to the creation of additional meta-stable states in the band gap of the amorphous silicon, by breaking the weak bounds of the hydrogen atoms to the silicon, which decreases the lifetime of excess carriers and thus reduces the photoconductivity (see for example [2]). A local degradation of the sensitivity has

* Corresponding author, e-mail: Sandra.Horvat@cern.ch

been observed also for the ALMY amorphous silicon strip sensors [3] when they were continuously illuminated by a laser beam at a fixed position [4]. The position sensitivity of the ALMY sensors allows for detailed studies of the dependence of the degradation effect on the illumination time, laser intensity and wavelength. We compare the measurements to the quantitative predictions of the kinetic model of the evolution of the meta-stable states in a-Si:H created under illumination by Stutzmann et al.

2 ALMY Photo Detectors

The ALMY photo detectors consist of a thin layer of hydrogenated amorphous silicon (a-Si:H) of 0.3 μm thickness embedded between two transparent layers of indium-tin oxide (ITO) electrodes deposited at a temperature of 120°C on a 1 mm thick glass substrate. The hydrogen content of the a-Si:H film is estimated to be 15%. The two electrode layers are segmented into two orthogonal arrays of 64 strips with 312 μm pitch and a width of 300 μm covering the whole sensitive area of 20x20 mm^2. The centroids of the photo current distributions on the top and the bottom strips measure the position of a gaussian laser beam of a few mm diameter with a precision of 1 μm over the whole sensitive area. The ALMY sensors have been developed for high-precision optical alignment monitoring system for large high-energy particle tracking detector systems. The sensors studied here were fabricated at the Institute for Physical Electronics in Stuttgart, Germany, by chemical vapor deposition at low temperatures.

3 Photo Sensitivity Degradation under Illumination

To study the degradation of the photo current sensitivity, a fixed position on the ALMY sensor surface has been continuously illuminated with a laser beam with given wavelength and intensity. The different beam parameters are summarized in Table 1. The photo current response is monitored as a function of time by regular short scans of the sensor surface with a stepping motor using an additional laser probe. The laser illumination and scans are performed in darkness. The local sensitivity minimum is compared to the sensitivity on the rest of the sensor area. With this method, one does not have to rely on the precise calibration of the intensity of the probe laser. Figure 1 shows the local degradation of the sensitivity under illumination with a laser wavelength of 780 nm and intensity of 20 mW/cm^2 integrated over the beam profile. The shape of the sensitivity minimum is determined by the gaussian beam profile of 1.5 mm width. The decrease of the relative sensitivity as a

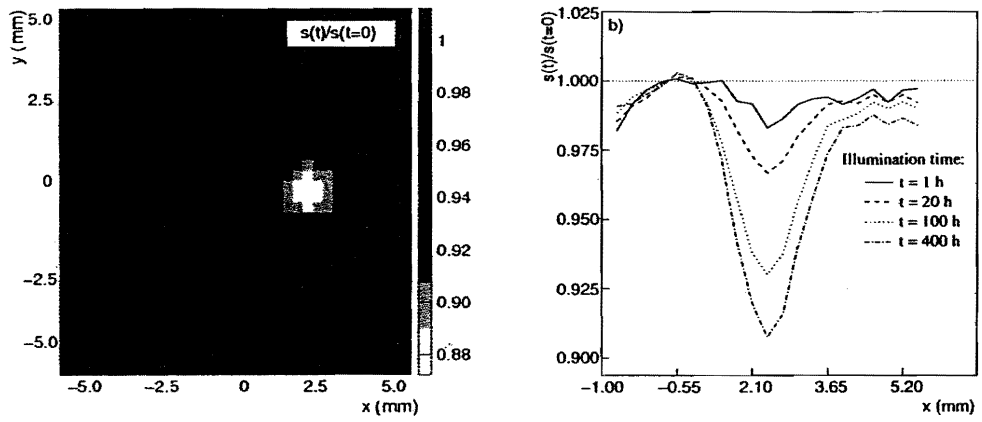

Fig. 1. Local degradation of the sensitivity from a scan of the sensor surface a) after 400 hours of illumination and b) at different illumination times. The sensitivity is normalized to the average sensitivity $s(t = 0)$ over the whole sensor surface before illumination.

function of illumination time is shown in Figure 2 for three different laser beam intensities and two different wavelengths. The laser beam intensities for the two different wavelengths are chosen such that the photo current responses at the start of the illumination are equal (0.6 mW/cm^2 at the wavelength of 690 nm, and 20 mW/cm^2 at 780 nm). We observe a strong dependence of the sensitivity degradation on the laser beam intensity and no dependence on the laser wavelength.

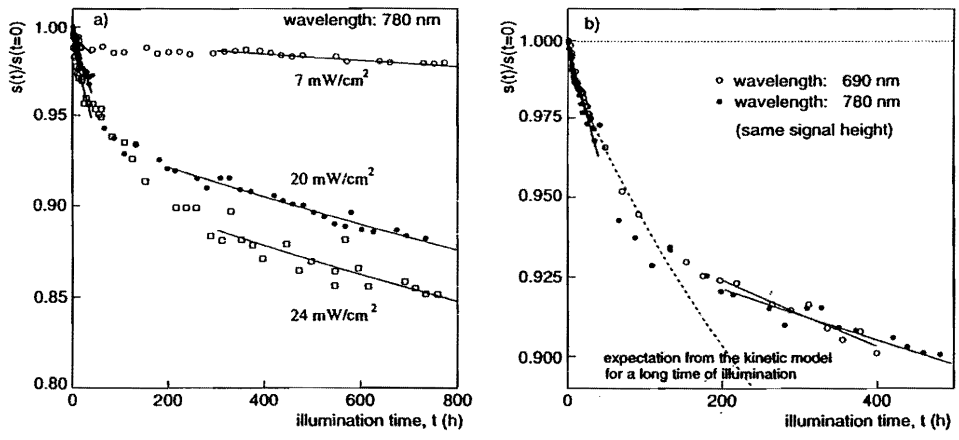

Fig. 2. Decrease of the relative sensitivity $s(t)/s(t = 0)$ with illumination time a) for three different laser beam intensities at 780 nm and b) for two different laser wavelengths and intensity leading to the same signal height. The full lines show the fit of the theoretical model to the data with the slope as a free parameter independently in two time intervals. The dashed line is the extrapolation from short to long illumination times based on the prediction of the kinetic model (see text).

The measurement results are compared to the quantitative predictions from the kinetic model of the behavior of meta-stable states in a-Si:H by Stutzmann et al. [2]. This model predicts the following dependence of the sensitivity

degradation on the illumination time t:

$$\frac{s(t)}{s(t=0)} = (1 + G_{s(l)} \cdot t)^{C_{s(l)}} \tag{1}$$

where G_s (G_l) is a constant depending on the material and the laser beam intensity for short (long) illumination time intervals, with $G_l = 3G_s$, which can be expressed as

$$G_{s(l)} = A_{s(l)} \cdot I^{B_{s(l)}}, \tag{2}$$

where I is the laser beam intensity, $A_{s(l)}$ a material constant and $B_{s(l)}$=2. For long illumination times the exponent C_l is predicted to be $-1/3$. In the limit of short illumination time or small intensities, the exponent becomes $C_s = -1$. We fit the theoretical model to the measured data independently for short and long illumination time intervals using G_s and G_l as free parameters while keeping the exponents C_s and C_l constant at the predicted values, since the fit becomes unstable otherwise. The results are shown in Figure 2 and are summarized in Table 1.

		Model			Empirical fit
		Short illum. times, $t \leq 30\ h$	Long illum. times, $100\ h \leq t \leq 900\ h$		
Laser beam parameters		G_s ($\cdot 10^{-3}$/s)	G_l ($\cdot 10^{-3}$/s)	G_l/G_s	g $\cdot(10^{-3})$
690 nm, 0.6 mW/cm^2		0.96(3)	0.37(1)	0.38(2)	2.98(5)
780 nm, 7 mW/cm^2		0.41(1)	0.05(1)	0.12(2)	0.31(2)
780 nm, 20 mW/cm^2		1.00(3)	0.27(1)	0.27(1)	2.86(5)
780 nm, 24 mW/cm^2		1.19(5)	0.32(1)	0.27(1)	3.6(1)
Coefficients using	$A_{s(l)}$	0.9(3)$\cdot 10^{-4}$	2.0(4)$\cdot 10^{-6}$		
equations (1), (2)	$B_{s(l)}$	0.8(3)	1.7(3)		
Coefficients using	$A_{s(l)}$	1.4(2)$\cdot 10^{-4}$	3.0(6)$\cdot 10^{-6}$		
equation (3)	$B_{s(l)}$	0.8(2)	1.9(2)		

Table 1. Parameters obtained from the fit of the theoretical model (equations (1) and (2) or equation (3)) and of the empirical formula (equation (4)) to the data. The error on the last digit of each parameter is shown in parentheses.

For large illumination times, the photo current response decreases slower than expected from the initial degradation rate, i.e. we observe $G_l \approx 0.3 \cdot G_s$ in disagreement with the model. From the fit of the relation (2) to the coefficients

$G_{s(l)}$, we obtain $B_s = 0.8 \pm 0.3$ for short and $B_l = 1.7 \pm 0.3$ for long illumination times (compare Table 1 and Figure 3a). The observed intensity dependence is in good agreement with the prediction of the kinetic model for long but not for short illumination times.

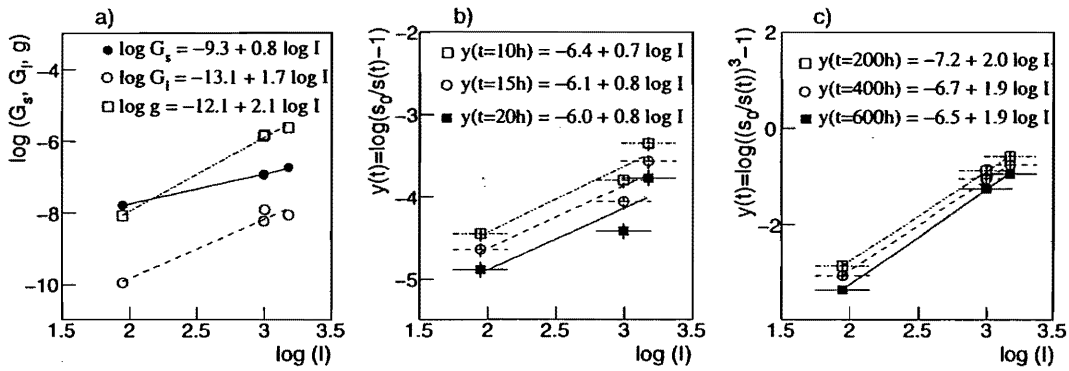

Fig. 3. Dependence on the laser beam intensity I obtained (a) from the coefficients G_s, G_l and g in equations (1) and (4) and from a fit to the the sensitivity $s(t)$ at fixed short (b) and long (c) illumination times t respectively, normalized to the initial sensitivity $s_0 = s(t = 0)$ (compare equation 3).

Alternatively, the intensity dependence can be determined by fitting the relation

$$\log \left[\left(\frac{s(t)}{s(t=0)} \right)^{1/C_{s(l)}} - 1 \right] = \log \left[A_{s(l)} \cdot t \right] + B_{s(l)} \log I \tag{3}$$

derived from equations (1) and (2) to the measured sensitivity $s(t)$ at fixed illumination time t normalized to the initial sensitivity $s_0 = s(t = 0)$ with $A_{s(l)}$ and $B_{s(l)}$ as free parameters. The results of the fit are shown in Figure 3b (3c) for different short (long) illumination times. The average of the parameters for different illumination times are given in Table 1. The parameters $A_{s(l)}$ and $B_{s(l)}$ obtained with the two methods agree well with each other (see Table 1). While the model agrees with the measurements for long illumination times, the data for short illumination times cannot be described by the short illumination limit of the model.

It is interesting to observe that the measured time dependence of the sensitivity degradation can be described very well by the empirical formula

$$\frac{s(t)}{s(t=0)} = c \cdot t^{g \cdot \log t} \tag{4}$$

over the full range of illumination times t. The fitted values of the parameter g are summarized in Table 1 for all data sets, where the parameter

$c = 1.00 \pm 0.01$. We also observe a quadratic dependence of the coefficient g on the laser beam intensity (compare Figure 3a).

4 Conclusions

The study of the photo current degradation under a long-term illumination of a-Si:H photo detectors shows a good qualitative agreement with theoretical predictions. The expected functional dependence on the laser beam intensity is observed for long illumination times. The results for different wavelengths support the concept that the degradation rate depends on the amount of absorbed light intensity in the amorphous silicon, where the sensitivity depends on the wavelength, rather than just on the illumination intensity. In contrast to the model prediction, however, we observe a faster initial degradation rate at short illumination times compared to the expectation from the degradation rate for long illumination times. The laser illumination intensity of the ALMY sensors can be made low enough (<10 mW/cm^2 at 780 nm) such that the sensitivity degradation over long illumination times (>800 hours) stop within the fluctuations of the sensitivity over the sensor surface (<2%, see Figure 1a).

References

[1] D.L.Staebler, C.R.Wronski, Appl.Phys.Lett. 31 (1977) 292

[2] M.Stutzmann, W.B.Jackson, C.C.Tsai, Phys.Rev. B 32 (1985) 23-47

[3] W.Blum, H.Kroha, P.Widmann, Nucl.Instrum.Meth. A 367 (1995) 413-417

[4] F.Bauer, M.F.Garcia, S.Horvat, H.Kroha, A.Ostapchuk, S.Schael, IEEE Trans.Nucl.Sci., vol.48, no.3, (2001) 262-267