

Effect of the Load Resistance in the Linearity and Sensitivity of MIS Position Sensitive Detectors

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ABSTRACT

It is experimentally known that the linearity and sensitivity of the position sensitive detectors (PSD) are dependent on the resistance of the collecting layer and of the load resistance, mainly if the detection is based on the measurement of the photo-lateral voltage. To determine the value of the load resistance to be used in metal - insulator - semiconductor (MIS) PSDs structures that lead to the maximum value of sensitivity and linearity, we propose an electrical model through which it is able to simulate the proper sensor response and how the load resistance influence the results obtained. This model is valid for PSDs where the resistance of the collecting resistive layer is quite low ($\leq 500 \Omega$), leading to a low output impedance. Under these conditions we conclude that the value of the load resistance should be of about $1 \text{ k}\Omega$ in order to achieve a good compromise between the linearity and the sensitivity of the PSD. This result is in agreement with the set of experiments performed.

INTRODUCTION

Position Sensitive Detectors (PSD) are optoelectronic devices that allow the determination of the position of a striking light beam on the sensor surface. There are several types of PSD's based both on crystalline and amorphous silicon (a-Si:H) technology [1]. The a-Si:H technology presents several advantages, like low cost, easiness of device fabrication and higher sensitivity in the visible range of the spectrum [2,3]. Due to these advantages, several research works appeared in the last two decades [4-8]. The main goals in the PSD research are the increase in sensor length, its sensitivity and resolution, for which different types of device structures, ranging from the classical p-i-n to a multilayer system (MLS) of a-Si:H/Ti have been proposed. In the present work we investigate one dimensional PSD's fabricated with a Metal - Insulator - Semiconductor (MIS) structure similar to the one proposed by Arimoto et. al. [9] that reported a sensor with a length of 1 cm length. In this work we report sensors with an active linear length of 6 cm, exhibiting a high sensitivity and linearity. The objective of this study was to understand the role of the load resistance R_L on the final static PSD performances, function of the characteristics of the of the resistance of the top collecting layer that for the MIS sensors is several orders of magnitude lower than the one due to typical p-i-n sensors [1].

THEORETICAL MODEL

Figure 1 shows a scheme of the sensor where the width (W) and the length (L) of the active region are indicated. It is also shown the external connections, where the load resistances (R_L) and the voltmeter (V) used to measure the lateral photo-voltage is indicated. Figure 2 shows the equivalent electric circuit of the sensor. The generator in the middle represents the source of electron - hole charges in the position where the laser beam points the sensor. The left and right

sides of the circuit corresponds to the areas of the sensor at left and right sides of the laser beam position, which are diodes that establish the photo-generated voltage (V_G).

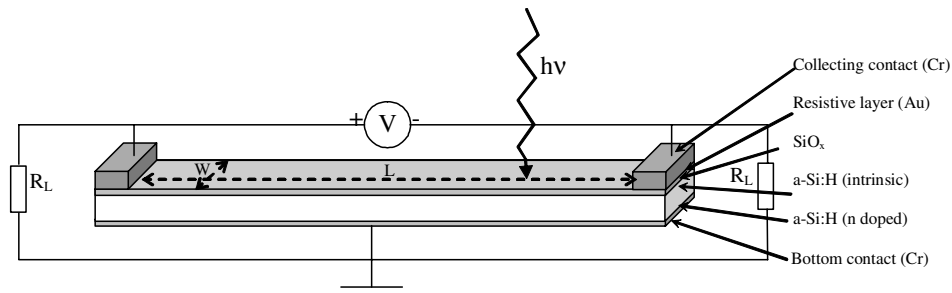


Figure 1. Scheme of the sensor structure, dimensions width (W) and length (L), and external connections.

The parallel resistance (R_P) represents the recombination paths along the sensor length. The series resistance (R_S) represents the path that the charges have to travel to reach the lateral contacts of the sensor. At each terminal contact it is connected a R_L , while the voltmeter is connected between the two terminal contacts. A more accurate model should have included a capacitor in parallel with R_P , which was omitted since it is not important for the static analysis of the circuit now performed.

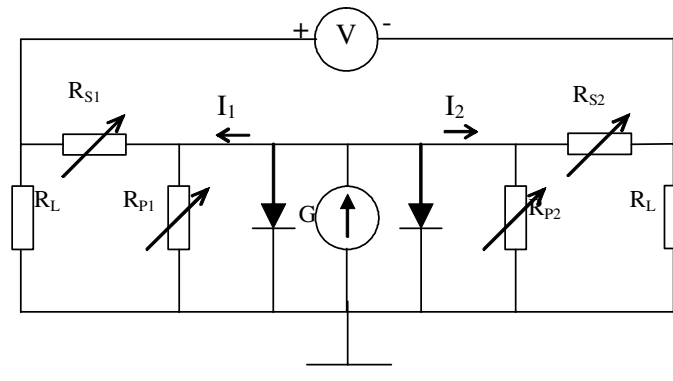


Figure 2. Equivalent electric circuit of the sensor, showing also the external connections.

It is important to note that $R_{S1} + R_{S2} = R_S$ corresponds to the total resistance of the Au top collecting layer, measured between the extremes of the device terminals. This means that when R_{S1} decreases by ΔR , R_{S2} increases by ΔR .

From the circuit we have that:

$$V = I_{RS1} R_{S1} - I_{RS2} R_{S2} \quad (1)$$

Since the input resistance of the voltmeter resistance (typically 10 to 100 $M\Omega$) is much larger than R_L , we can say that $I_{RS} = I_{RL}$, in each branch of the circuit.

Also, if we choose R_L so that:

$$(R_L + R_{S1}) \ll R_{P1} \quad (2)$$

we can neglect the current that passes through R_P and so equation (2) becomes:

$$V = I_1 R_{S1} - I_2 R_{S2} \quad (3)$$

Taking into account those approximations we also have that:

$$I_1 = \frac{V_G}{R_{S1} + R_L}; \quad I_2 = \frac{V_G}{R_{S2} + R_L} \quad (4)$$

Substituting equation (4) in to equation (3) and rearranging we have:

$$\frac{V}{V_G} = \frac{R_{S2}}{R_{S2} + R_L} - \frac{R_{S1}}{R_{S1} + R_L} \quad (5)$$

Assuming that V_G is constant in all the sensor area, the signal measured (V) depends only of R_{S1} , R_{S2} and R_L . The values of R_{S1} and R_{S2} are related with the position of the light beam and so, they are strictly related to the beam position. Nevertheless, from equation (5) it is seen that there is a value of R_L that maximizes the sensitivity of the measure. That value of R_L is obtained by the derivation of equation (5) in order to R_L and finding the zero of the function. Doing so, the maximum of sensitivity is obtained when:

$$R_L = \sqrt{\frac{R_{S2} R_{S1}^2 - R_{S1} R_{S2}^2}{R_{S1} - R_{S2}}} \quad (6)$$

This result shows that the ideal value of R_L is not constant but depends on the values of R_{S1} and R_{S2} for any given position of the light beam. Figure 3 shows the simulation of equation 6 for an arbitrary variation of R_{S1} from 0 to 1000, which is the equivalent for the variation of the light beam position from one extreme of the sensor to the other.

The simulated curve shows that the ideal value of R_L is not constant, but depends on the beam position. The maximum value of R_L that gives higher sensitivity corresponds to half of R_S (matching of the circuit) but it is only valid when the light beam strikes the sensor area in the middle position. This means that values of R_L lower than $R_S/2$ will result in poor linearity. To verify this result we simulate equation (5) substituting various values of R_L . The results are shown in figure 4. There we notice that as previewed, the maximum sensitivity in the centre of the sensor is obtained for $R_L = 0.5R_S$. For values of R_L lower than this the sensitivity in the extremes of the sensor increase but decrease in the centre and the overall linearity strongly decreases. For values of R_L higher than $0.5 R_S$ the linearity improves, but the sensitivity decreases as R_L increases. So, as it is shown in figure 4, values of R_L higher than $3.0R_S$ will not result in an improvement of the linearity but will only result in a decrease of the sensitivity. This means that in theory there is a compromise for the value of R_L , which should be higher than $0.5R_S$ but lower than $3.0R_S$.

For the maximum linearity it is necessary that the voltage measured by the voltmeter to be proportional to the beam position, represented by the variation of R_{S1} . This condition is theoretically achieved for an $R_L \gg R_S$, resulting in a current I which tends to zero, and so the sensitivity will also tend to zero. This results, as our experimental results have shown, in a

decrease of the linearity, since in these conditions R_P can no longer be ignored and the signal measured will be small.

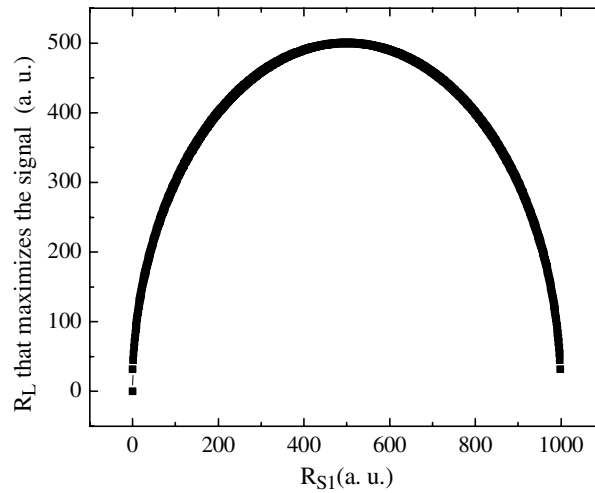


Figure 3. Value of R_L that maximizes the sensitivity as function of R_{S1} , considering an arbitrary variation from 0 to 1000, along the sensor length.

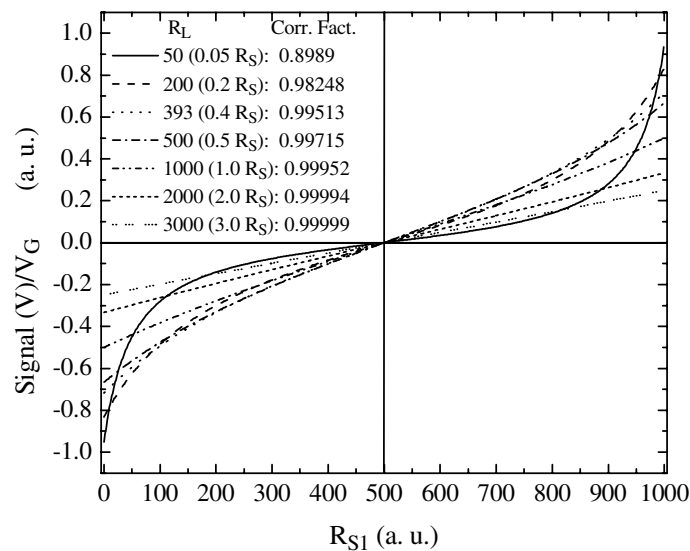


Figure 4. Simulation of equation (5), which gives the signal (V/V_G) as function of the beam position (R_{S1}) for different values of R_L presented in relation to R_S . The linear correlation factor obtained is also shown.

EXPERIMENTAL

The sensor structure consists of 5 layers deposited over a glass substrate (2 mm thick): Cr (3000 Å) / a-Si:H [n] (370 Å) / a-Si:H [i] (6000 Å) / SiO_x (15 Å) / Au (70 Å). The active area is 60 mm × 2mm. The metals were deposited by electron gun evaporation. The active a-Si:H [i] layer was deposited by a Modified Triode Plasma Enhanced Chemical Vapour Deposition (MTPECVD) [10] which allows de deposition of highly electronic grade material with a low defect density of states ($\approx 1 \times 10^{15} \text{ cm}^{-3}$), inferred by CPM. The a-Si:H [n] was deposited by standard PECVD. The SiO_x layer was grown over the a-Si:H by thermal oxidation, heating the

sample for 3h at 160°C. This process forms a native oxide with 15 Å of thickness, as measured by spectroscopic ellipsometry.

The linearity measurements were performed in the dark, using a step motor to move the laser over the sensor length. This system has a position precision of 0.05 mm. The laser has a spot size of 1 mm and emits a wavelength of 532 nm with a power of 5 mW. The sensor sensitivity is determined by dividing the full scale of the signal (F) by the sensor length (W). The linearity error (σ_e) is obtained by [11]:

$$\sigma_e = \frac{2S}{F}, \quad (7)$$

where S represents the standard mean deviation. In practical terms it is considered that an acceptable device has an $\sigma_e < 15\%$ [12].

RESULTS

Figure 5 shows the linearity measurements performed on a MIS position sensor. The different curves correspond to different values of R_L used.

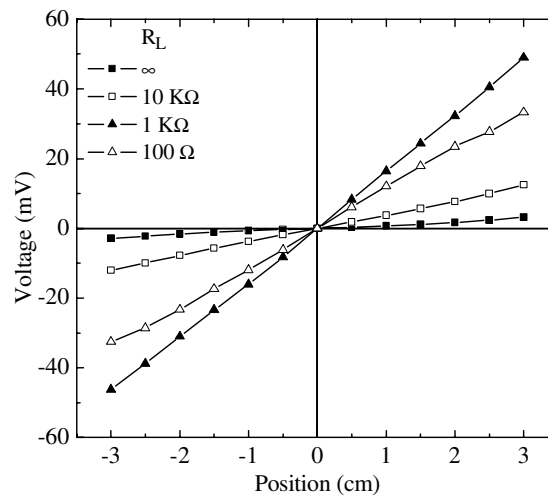


Figure 5. Lateral photovoltage measured between the lateral contacts of the sensor, function of the laser beam position for different values of R_L .

It is observed that the curves present a good linearity over all the 6 cm of the active length of the sensor and that the sensitivity and linearity of the sensor are maximized for $R_L = 1\text{ k}\Omega$. For values of R_L one order of magnitude higher (10 kΩ) or lower (100 Ω), the sensitivity and linearity decreases. The values of the sensitivity and linearity error are presented in table I. These results show that the linearity and sensitivity are higher when an R_L of 1 kΩ is used and that the worst result is obtained for the situation where $R_L = \infty$, since in this condition the sensitivity strongly decreases, affecting the sensor linearity. The value of R_S measured for this sensor was 380 Ω, which means that these results agree quite well with the model proposed, showing the importance of using the correct load resistance for the MIS position sensors. The ideal value found experimentally for R_L was about $2 \times R_S$, agreeing with the model proposed. The model proposed for the role of R_L also agrees with the work of Fortunato et al. [11], which used a different approach to determine the role of R_L on p-i-n PSD's.

Table I. Sensitivity and linearity error of the measures performed in the MIS position sensor, for different values of R_L .

R_L	Sensitivity	Linearity error
∞	0,909 mV/cm	7,42 %
10 k Ω	3,969 mV/cm	2,07 %
1 k Ω	15,891 mV/cm	1,16 %
100 Ω	11,314 mV/cm	2,28 %

CONCLUSIONS

The electrical model proposed in this paper help us to show the importance of R_L to the sensitivity and linearity of MIS position sensor, where the collecting resistive layer has a value below the typical one of the p-i-n structures, usually of several k Ω . The simulation performed allowed us to see that an R_L two to tree times larger than R_S should be used in MIS positions sensors, in order to achieve the best linearity and sensitivity, as confirmed by the experimental data.

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