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Color sensing ability of an amorphous silicon position sensitive detector array system

Javier Contreras[a,b], Rodrigo Martins[a,b,*], Pawel Wojcik[a,b], Sergej Filonovich[a,b], Hugo Aguas[a,b], Luis Gomes[c,d], Elvira Fortunato[a,b], Isabel Ferreira[a,b,*]

[a] CENIMAT/I3N, Department of Materials Science, Faculty of Science and Technology of New University of Lisbon, Portugal
[b] CEMOP/UNINOVA Campus da Caparica, 2829-516 Caparica, Portugal
[c] Department of Electrical Engineering, Faculty of Science and Technology of New University of Lisbon, Portugal
[d] CTS/UNINOVA, Campus da Caparica, 2829-516 Caparica, Portugal

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ABSTRACT

The color sensing ability of a data acquisition prototype system integrating a 32 linear array of 1D amorphous silicon position sensitive detectors (PSD) was analyzed. Besides being used to reproduce a 3D profile of highly reflective surfaces, here we show that it can also differentiate primary red, green, blue (RGB) and derived colors. This was realized by using an incident beam with a RGB color combination and adequate integration times taking into account that a color surface mostly reflects its corresponding color. A mean colorimetric error of 25.7 was obtained. Overall, we show that color detection is possible via the use of this sensor array system, composed by a simpler amorphous silicon pin junction.

1. Introduction

Unlike detectors which are formed of discrete elements such as for example, charged coupled devices (CCD) that supply a discrete output signal, position sensitive detectors (PSD) are based on analog detection principles, providing continuous position information with a high position resolution and speed response. A wide spectral response range and high reliability are also offered by this device, plus bearing in mind the fact that it is able to detect simultaneously the intensity and the position of the center of gravity of a light spot.

PSDs made of amorphous silicon pin structures have already been reported [1] and their use has expanded significantly over the years. Issues such as linearity, spatial resolution and response times were analyzed and this and other literature discussed features [2] make pin amorphous silicon structures suitable for optical inspection and image processing applications especially where continuous detection is required. The working principle of one, two and three dimensional devices as well as their fabrication characteristics and structural design were described elsewhere [3–10], presenting good characteristics for continuous position detection of a direct incident laser beam with a linear resolution of 1 μm [7] in areas that can be as high as 10 cm^2 or as low as 1 cm^2.

These types of sensor arrays have also been used for the detection of the movement and dimensions of micro objects, based on reflecting light coming from those objects [8,9]. Research and development work in the field of PSDs has increased, as well as its application in various areas of optical measurement such as surface inspection and control [10–13]. Any application which requires low bulks of signal processing power or high speeds, in comparison to existing standard video frame rates, it is an ideal candidate for integrating on it PSDs. Most commercially available PSDs are developed using crystalline silicon [14] and the main areas of application where these devices are employed, are those where precision is crucial, such as, machine tool and remote optical alignment, medical instrumentation or robotic vision. Their principle of operation and relevant characteristics were already described in previous papers [15–18].

1.1. Position sensitive detector constitution and 1D operation principle

Position sensitive detectors (PSD) have the sandwich structure of nip photodiodes coated on one side with an ohmic contact

* Corresponding authors at: CEMOP/UNINOVA Campus da Caparica, 2829-516 Caparica, Portugal. Tel.: +351 21 294 8564; fax: +351 21 295 7810.
E-mail addresses: ja@uninova.pt (J. Contreras), rm@uninova.pt (R. Martins), imf@fct.unl.pt (I. Ferreira).

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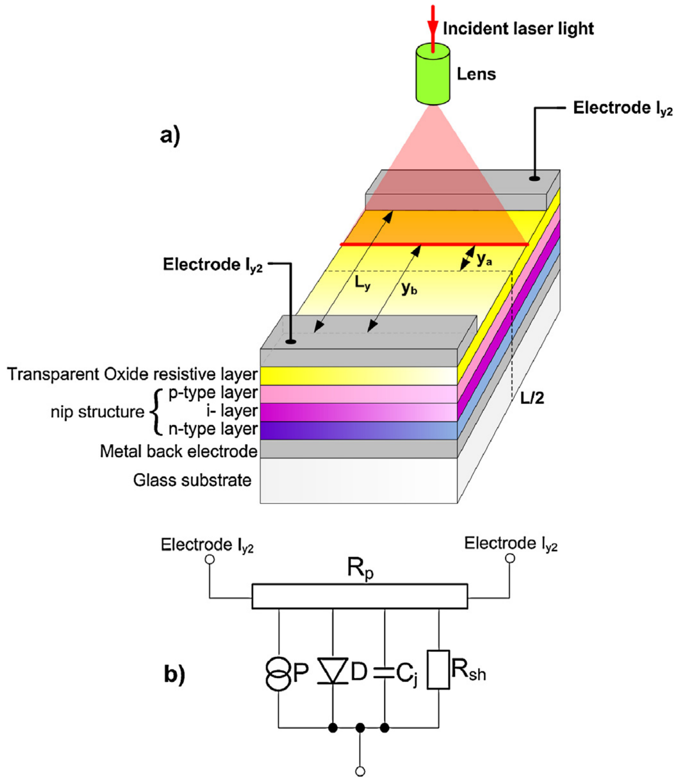

Fig. 1. (a) Sketch of a position sensitive detector, showing their constitutes, the terminal contacts, the incident light spot and the back ohmic contact. (b) The electrical equivalent circuit, where R_p is the series resistive layer; P is the equivalent power current source; D the ideal diode; C_j the pin junction capacitance; R_{sh} the shunt resistance.

(equipotential layer) and on the other side with a non-equipotential transparent resistive layer with two ohmic contacts at its terminals.

The typical nip photodiode structure [6] is composed by glass/Cr/a-Si:H(n)/a-Si:H(i)/a-Si:H(p)/ZnO(Ga). When these structures are illuminated through the transparent resistive layer by a spot or light line, carriers are generated and collected differently by the two longitudinal ohmic contacts placed along one direction of a strip as a function of the light position on the surface. The total collected photocurrent is given by:

$$I_{y1} + I_{y2} = I_{tph} \tag{1}$$

where, I_{tph} corresponds to the total photocurrent generated by the photodiode; I_{y1} and I_{y2} are the output currents collected at the ohmic contacts (electrodes) placed at the ends of each strip, as described by Wallmark [19] and Martins et al. [5] for different types of one, two or three dimensional configurations. The three dimensional configuration is effectively an array of 32/128 strips or amorphous silicon position sensitive detectors.

Fig. 1(a) illustrates the operating principle of a PSD while Fig. 1(b) shows its electrical equivalent circuit. Photoelectric conversion takes place in the active i-layer of the nip diode structure (D) and the charge collection is performed by the transparent resistive layer (R_p) placed on top of D with two collecting terminal contacts localized on the extreme ends of R_p. A common low resistive electrode (back electrode) that behaves as an equipotential which can be biased is placed on the glass (see Fig. 1).

An electric charge is generated (working like a current power source, P, whose charge accumulation depends on the value of the junction capacitance, C_j at the incident position of the light line. The current generated is proportional to the light intensity of the light line striking the PSD strip.

In order to calculate the incident position y_a of the light striking the PSD in relation to the middle point of the active area, the following formula is used:

$$\left(\frac{I_{y2} - I_{y1}}{I_{y2} + I_{y1}}\right)\frac{L_y}{2} = y_a \tag{2}$$

where y_a is the spot position according to one of the collecting electrodes considered as reference and L_y is the length of the active area or resistance length.

The position worked out from Eq. (2) is effectively the center of gravity of the projected beam of light.

1.2. Static and dynamic 3D PSD operation principle

The working operation principle of a PSD array is that an image line projected in the array induces photocurrents ($I_{\mathrm{ph}1}$ and $I_{\mathrm{ph}2}$) in the illuminated elements [5]. All elements are then scanned to determine the position of the image line. In this case the angle of incidence that the laser line makes with the surface to be inspected should be such that allows its detection along the length of the detector. That is, the maximum active length d_d of each element of the array has to be such that:

$$d_0(\max) \geq \frac{d_d(\max)}{\cos\ \phi} \tag{3}$$

where d_0 is the distance between the sensor and the surface to be scanned [5]. At each element ΔI_{ph} has an uncertainty related to the noise (n) and so, the measured position is given by [5]:

$$P(y_n) = \frac{(V_1 \pm n_1) - (V_2 \pm n_2)}{(V_1 \pm n_1) + (V_2 \pm n_2)} \cdot \frac{L}{2} \Rightarrow P_{\max}(y_n)$$
$$= \frac{V_1 - V_2}{V_1 + V_2 - 2n} \cdot \frac{L}{2}, \quad \text{for} \quad -n_1 = -n_2 = -n \tag{4}$$

where n_1 and n_2 are the absolute noise detected at each of the element terminals and L is the length of each line. Thus, the position of an image line projected in the plane z–y is determined by $P(y_n)$ obtained over the 32/128 stripes and related to the currents detected by both shift registers (SR) connected to the terminals of each line of the array.

The detection threshold limit will depend on the signal to noise ratio (S/N), which is given by:

$$\mathrm{S/N} = \frac{I_{ph_1} + I_{ph_2}}{\sqrt{2n}} \tag{5}$$

Thus, the positional resolution (dP) depends on the active length of each sensing element and on S/N [5]:

$$dP \approx \frac{L}{2\mathrm{S/N}} \tag{6}$$

Once established the proper S/N ratio, the performances of the PSD are mainly dependent on the maximum distance that a light spot from each of the collecting electrodes can be detected with a linear correlation between the spatial position and the lateral photocurrent measured. This will depend on the so-called fall-off parameter α given by [5]:

$$\alpha = \rho_s \sigma_0 \times \frac{2a}{W} \times \frac{2a}{W_r} \tag{7}$$

where ρ_s is the sheet resistance of the resistive layer (ZnO(Ga)), σ_0 the conductivity of the photosensitive i-layer, W the thickness of the photoconductive layer, W_r the thickness of the resistive layer (ZnO(Ga)) and a the radius of the light spot in the surface. These parameters for a typical nip detector are: $\rho_s \cong 100\ \Omega$/sq.; $W_r \cong 10$ nm; $W \cong 800$ nm; $a \cong 0.5$ mm; $\sigma_0 \cong 10^{-10}$ S cm^1, which gives $\alpha = 0.03$ cm^{-1}. This value is much lower than 1 cm^{-1}, the limit situation below which linearity appears, so it is expected that each