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Large area P-I-N image sensitive devices deposited on plastic substrates

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Large area p-i-n image sensors deposited on plastic substrates were produced at low temperatures (110 ^{o}C) by PE-CVD and compared with similar sensors deposited on glass substrates. The same sensing element structure ZnO:Al/p(SiC:H)/i(Si:H)/n(SiC:H)/Al was used for both devices. In this work, the efforts are focused mainly on the optimization of the output characteristics of the sensor when fabricated on plastic substrates. The role of the sensor configuration and readout parameters on the image acquisition process is analyzed. The opticaltoelectrical transfer characteristics show a reasonable quantum efficiency under a red light pattern, broad spectral response, and reciprocity between light and image signal. First results show that the sensors deposited on a flexible substrate present smaller light to dark sensitivity than those deposited on glass. In both, the non-ohmic behavior of the transparent conductive oxide front contact blocks the carrier collection and leads to a surprising linear dependence of the image signal with the applied voltage.

Keywords: Optical sensors; large area imagers; flexible electronic; stacked pinpin devices.

Sensores de imagen de gran área con estructuras p-i-n se han depositado en substratos de plástico a baja temperatura (110 ^{o}C) por PE-CVD y se han comparado con sensores semejantes depositados en substratos de vidrio. Se ha utilizado en ambos los dispositivos en el mismo elemento sensor con la estructura: ZnO:Al/p(SiC:H)/i(Si:H)/n(SiC:H)/Al. En este trabajo se intenta optimizar las características de salida del sensor fabricado en el substrato de plástico. Se analiza la configuración del sensor y de los parámetros de lectura en el proceso de adquisición. Las características de transferencia óptica-eléctrica revelan una eficiencia cuántica razonable cuando se utiliza un padrón de luz en la región roja del espectro, una respuesta espectral alargada, y buena reciprocidad entre la señal de la imagen óptica y eléctrica. Los primeros resultados muestran que los sensores depositados en substratos de plástico presentan una menor sensibilidad al claro-oscuro que los depositados sobre vidrio. En ambos, el comportamiento no óhmico del óxido conductor transparente que constituye el contacto frontal limita la colección de portadores y traduce en una sorprendente dependencia linear entre la señal de la imagen y la tensión aplicada.

Descriptores: Sensores ópticos; sensores de imagen de gran área; electrónica flexible.

PACS: 73.40 Lq; 73.40Ty; 73.40Vz; 73.40Cg

1. Introduction

Large area a-SiC:H imagers fabricated on plastic substrates are strong candidates for flexible electronic [1–3]. They can be manufactured, at low a cost, taking advantage of the amorphous silicon technology. In our group, large area silicon single and stacked p-i-n structures with low conductivity doped layers were deposited on glass covered substrates and proposed as image sensors [4–6]. These sensors are different from the conventional ones [7–9] as they are based on one single or stacked sensing element and use a modulated, low-power laser beam to scan and acquire the image directly.

This work evaluates the possibility of using a single p-i-n device deposited on plastic as an optically addressed read-write image-processing device. Efforts are focused mainly on the optimization of the sensor performance (contrast and resolution). A trade-off is established between sensor design and light pattern and scanner wavelengths.

2. Sensor operation

The imager is an optically addressed read-write device based on a large area sensing element and a scanning reader. Imaging is performed in a simultaneous write-read two-step process: the write exposure, which converts the optical image into packets of charge that remain confined at the illuminated regions and the optical readout, which performs the charge to current conversion by detecting the photocurrent generated by a moving scanner beam [5]. The output signal in each scanner position is amplified and recorded as an electronic image whose magnitude depends on the light pattern localization, wavelength and intensity. No charge transfer to move the packets of charge within the sensor is needed during the image acquisition process. This permits, a real-time optically addressed readout.

3. Experimental details

The optically addressed device consists of a single p(SiC:H)/i(Si:H)/n(SiC:H) photodiode and two contacts. Two sensors were produced in the same run. The sensing p-i-n structures were deposited by PECVD at low temperatures (110 °C) on Corning glass (#M0031212-G), or on Tektronix copying foil substrates (#M0031212-F), both covered with the same transparent aluminum doped ZnO acting as front contact. After the deposition of the amorphous layers, a back contact of aluminum was thermally evaporated and defines the active area of the sensor (2×2 cm^2). The intrinsic layers were optimized for optoelectronic applications (photosensitivity of the order of 7.1×10^{4}) while the doped layers are based on low conductivity and wide band gap a-SiC:H alloys. The optical gap and conductivity sequences for each p-i-n sensor are, respectively, 2.1/1.8/2.1 eV and 2.5×10^{-9}/7.6×10^{-11}/$1.9\times10^{-12}\Omega^{-1}\cdot$cm^{-1}. The devices were characterized through the analysis of the photocurrent and spectral response under different steady state optical bias and applied voltages.

The readout process relies on the same principle as the LSP image sensor [4]. A low power solid state green laser (λ_{S}g $=$ g50 nm;g Φ_S=200 μW/cm^2) is used as a scanner, and red (λ_{L}g $=$ g50 nm) optical images with different intensities are acquired. The line-scan frequency was close to 1 kHz and no algorithms where used during the image restoration process. If one considers a 100 line image then the reported images, correspond to a frame rate of 10 Hz.

4. Results and discussion

The current as a function of the applied voltage is displayed in Fig. 1, in dark and under different optical biases.

The analysis of the current/voltage characteristics shows that the current of the sensor deposited on a plastic substrate are systematically lower (one order of magnitude) than those deposited on a glass/TCO substrate. For both sensors, the reverse and the forward currents are of the same order although open circuit voltages around 0.5 V could be found. From the above data, it was seen that the resistance of the analyzed sensors is extraordinarily high. This high resistance may be attributed to either defects at the TCO-p interface or to the defective ZnO:Al layer, especially when it is deposited on the plastic substrate. To further improve the I-V characteristics of the devices, it seems that a suitable texturing of the plastic substrate should be tried and a high conductive ZnO:Al

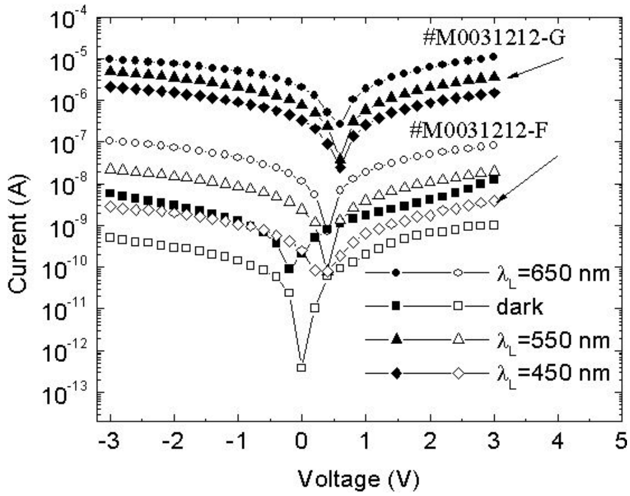

FIGURE 1. I-V characteristic under different illumination conditions for the sensor deposited on plastic.

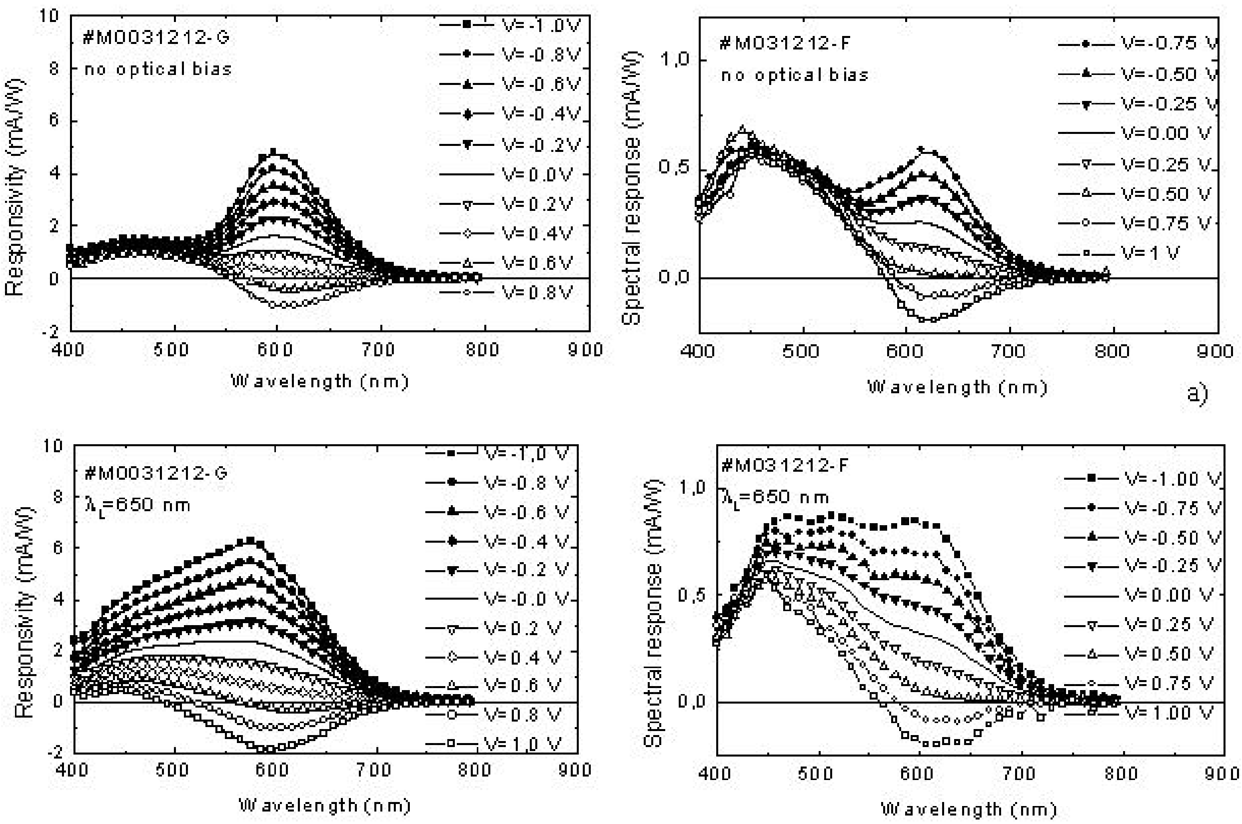

FIGURE 2. Sensor responsivity without (top figure) and with (bottom figure) red optical bias for the sensors deposited on: (a) glass; (b) plastic.

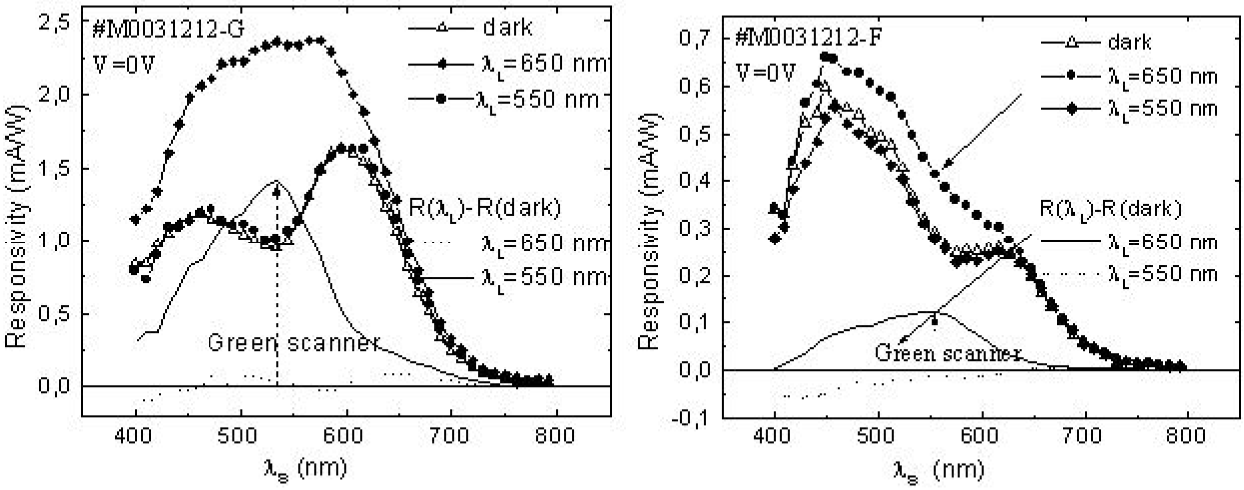

FIGURE 3. Sensor responsivity (symbol) without (open) and (solid) with red and green optical bias for the sensors deposited on: (a) glass; (b) plastic. The corresponding difference between the responsivity with and without optical bias (image signal) are displayed (lines).

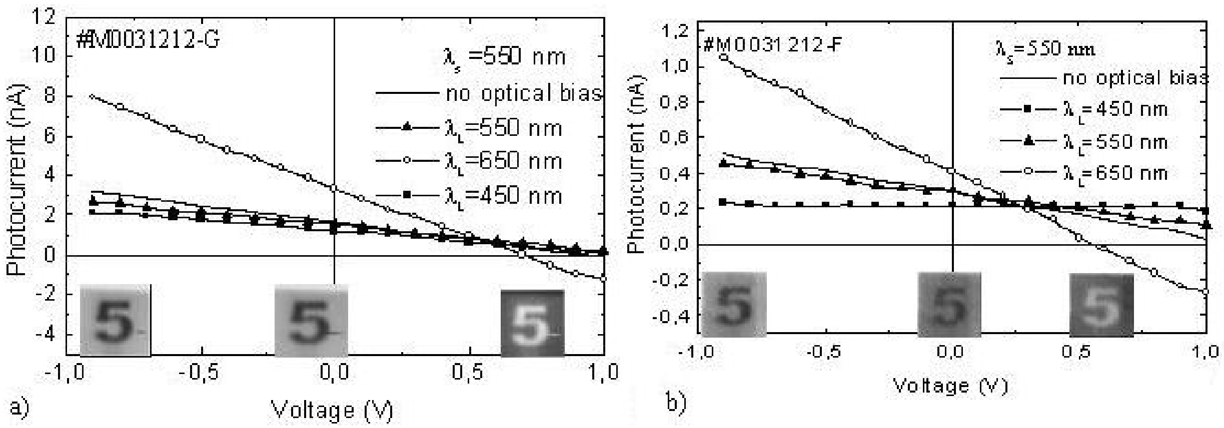

FIGURE 4. Photocurrent generated by a green read beam as a function of the applied bias without and under red, green and blue light exposures. The inserts show the acquired electrical images at +1V, short circuit and -1 V.

front contact used to assure an ohmic front contact. Two back diodes have to be considered. Under negative bias, the TCO-semiconductor junction is forward bias and the carriers are injected into the intrinsic layer where they recombine or are collected, giving rise to currents higher than expected for a p-i-n diode under reverse bias. Under positive bias, the TCO-semiconductor junction becomes reverse bias and bocks the flow of the forward current across the p-i-n diode.

In Fig. 2, the responsivity of the sensor as deposited, on glass (a) and on plastic (b), are displayed in dark (Φ_L=0) and under red optical bias (Φ_L=2mWcm^{-2}, λ_L=650 nm).

In both sensors, the results show that the spectral sensitivity is optical and electrical bias dependent and much lower in the sensor deposited on plastic. The responsivity is enhanced in the presence of the optical bias, and it decreases in the red region almost linearly as the applied voltage changes from negative to positive: in the blue/green spectral region, mainly in the absence of the optical bias, it remains almost independent of the electrical bias.

In Fig. 3, the responsivities with and without red and green optical bias and its differences are depicted, under short circuit conditions, showing sensor light to dark sensitivity under red illumination, and also an increased collection in the green spectral range under red optical bias.

Since light to dark sensitivity to a red light pattern was achieved and an increased collection was obtained in the green spectral region, these preliminary results prove the ability to use this non-optimized sensor, even deposited on plastic substrates, as an image sensor if a green scanner is used to read out a red light pattern.

In order to evaluate the sensor's responsivity to different light pattern wavelengths, the photocurrent generated by the scanner (λ_S=550nm) was measured under green, red and blue (λ_S) steady-state illumination conditions as depicted in Fig. 4. The inserts show the acquired images (difference between the photocurrents with and without a light pattern). Here the same red picture (**5**) where projected on sensor and acquired, using a green scanner.

Results show that it is possible to acquire a black and white image with a sensor deposited on plastic, though with lower light to dark sensitivity, than those deposited on glass substrates. In both sensors, the photocurrent presents a surprising linear–like dependence on the applied voltage due to rectifying front contact (Fig. 1). They behave as phototransistor-like devices that operate in common-emitter configuration. Under red steady-state illumination, the incoming light is absorbed uniformly into i-layer (the base), decreasing the internal electrical field inside the bulk and enhancing it at the p-i interface, which becomes depleted due to charge accumulation at the p(a-SiC:H)-i (a-Si:H) junction. Under green or blue illumination, an opposite behavior is observed due to the smaller light depth penetration [5,6] responsible for an electric field enhancement, mainly near the i-n interface. In dark no-carrier generation occurs inside the base, and the electrical field at the emitter and collector junctions stays in thermodynamic equilibrium. Driven by the applied voltage, the transistor either operates in the active normal or in the reverse mode.

Under negative bias and red illumination, the TCO/p emitter junction is forward biased and the i/n collector reversed. The opposite occurs under positive bias. In both modes, the transconductance, and so the collected photocurrent from the green scanner, is controlled by optical bias intensity.

5. Conclusions

A non-optimized optically-addressed image sensor deposited on plastic was presented and compared with the same sensor deposited on glass. A trade-off between the readout parameters (light pattern and scanner wavelengths and applied voltages) was established in order to improve the resolution and the contrast of the image**.**

Preliminary results show that an optimization of the front contact is needed to improve the light to dark sensitivity, mainly when plastic substrates are used.

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1. H. Gleskova and S. Wagner, *IEEE Electron Device Lett.* **20** (1999) 473.
2. S. Wagner, S.J. Fonash, T.N. Jackson, and J.C. Sturm, *SPIE Symp. Proc.* **19** (2001) 4362.
3. P.I. Hsu *et al.*, *Applied Physics Lett.* **81** (2002) 1723.
4. M. Vieira *et al.*, *IEEE Sensors Journal,* **1** (2001) 158.
5. M. Vieira, M. Fernandes, P. Louro, R. Schwarz, and M. Schubert, *J. Non-Cryst. Solids* **299-302** (2002) 1245.
6. M. Vieira, A. Fantoni, M. Fernandes, P. Louro, and I. Rodrigues, *Mat. Res. Soc. Symp. Proc.* (2003) A.18.13.
7. J.W. Horton, R.V. Mazza, and H. Dym, *Proc. IEEE* **52** (1964) 1513.
8. G.S. Hobson, *Proc. IEEE* **124** (1977) 925.
9. G.F. Amelio, *Scientifc American* **230** (1974) 22.