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# Colour filtering in a-SiC:H based p-i-n-p-i-n cells: A trade-off between bias polarity and absorption regions

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**Abstract**

A large area colour imager optically addressed is presented. The colour imager consists of a thin wide band gap p-i-n a-SiC:H filtering element deposited on the top of a thick large area a-SiC:H(-p)/a-Si:H(-i)/a-SiC:H(-n) image sensor, which reveals itself an intrinsic colour filter.

In order to tune the external applied voltage for full colour discrimination the photocurrent generated by a modulated red light is measured under different optical and electrical bias. Results reveal that the integrated device behaves itself as an imager and a filter giving information not only on the position where the optical image is absorbed but also on it wavelength and intensity.

The amplitude and sign of the image signals are electrically tuneable. In a wide range of incident fluxes and under reverse bias, the red and blue image signals are opposite in sign and the green signal is suppressed allowing blue and red colour recognition. The green information is obtained under forward bias, where the blue signal goes down to zero and the red and green remain constant. Combining the information obtained at this two applied voltages a RGB colour image picture can be acquired without the need of the usual colour filters or pixel architecture. A numerical simulation supports the colour filter analysis.

*Keywords:* Colour and image sensitive detectors; Spectral sensitivity; Light filtering; Self-biasing effect; Multi-layer devices

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## 1. Introduction

Red, green and blue (RGB) are the additive fundamental perceptual components of the visible spectrum and can be easily separated by using appropriate detectors and/or bandpass filters [1,2]. Light filtering, employing distinct wavelength optimized structures, in an array, is rather complex and is an expensive solution. Optical filters may be eliminated by using a-SiC:H multi-layer stacked devices, in which the detector structure, itself, behaves as a filter. In the stacked structure, information about the spectrum corresponds to information about where the radiation is absorbed. By sampling the absorption region with different bias voltages, and extracting separately the integrated information about the radiation absorbed in each region is possible to identify the RGB components of the visible spectrum [3–6]. In those devices, blue light is usually detected in the front of the structure, green light at the centre and red light at the bottom.

Large area single and stacked p-i-n image sensors based on amorphous hydrogenated silicon alloys were proposed as optically addressed laser scanned photodiode (LSP) [7,8]. The LSP sensor is different from the electrically scanned image systems since it is based on one single sensing element, and uses a modulated low-power beam of laser light to scan the active area directly. Advantages to this approach are large area imaging, high resolution and uniformity of measurement along the sensor. The complexity of the interconnection is reduced, while the colour information is extracted by applying a sequence of test voltages.

In this paper, we propose to optimize the sensor design in order to apply the optical addressed Laser Scanned Photodiode technique to full colour discrimination. The effect of the applied voltage on the colour selectivity and image intensity is discussed and supported by a self-biasing model.

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## 2. Sensor design, characterization and operation

The sensing element consists of two stacked amorphous cells [p(SiC:H)/i(SiC:H)/n(SiC:H)/p(SiC:H)/i(Si:H)/n(Si:H)] and two conductive contacts. As transparent conductors are required, for both front and back illuminated surfaces, indium tin oxide, produced by thermal evaporation, was used. The intrinsic and doped layers were fabricated by plasma enhanced chemical vapour deposition at 13.56 MHz radio frequency.

The design attempts to optimize the most important performance attributes of the colour imager which are the spatial resolution, the colour sensitivity and the dynamic range. In this configuration, full colour detection is attempted based on spatially separated absorption of different wavelengths. The blue sensitivity and the red transmittance were optimized, respectively, through a thin a-SiC:H absorber (200 nm) with an optical gap of 2.1 eV and thick a-SiH back absorbers (NC #4/500 nm; NC #5/1000 nm) having optical gap around 1.8 eV. Their thicknesses are a trade-off between the full absorption of the blue light into the front diode and green across both. To decrease the lateral currents that could lead to image smearing and to enhance the blue sensitivity, the doped layers (20 nm thick) are based on a-SiC:H [9]. The doped layers provide rectifying contacts but do not contribute to the light sensitivity because doping causes a high density of charge dangling bond defects in a-SiC:H. Doping level in the internal recombination junction is about half the doping level of the external p and n-layers. The internal lightly doped layers are ionized and cause a reduction of the field at the contacts increasing the breakdown field.

The image to acquire is optically mapped onto the front photodiode and a low-power light spot ($\lambda_S = 650$ nm; $\Phi_S = 10\ \mu\text{W cm}^{-2}$) scans the device by the opposite side. The photocurrent generated by the moving spot is recorded as the electronic image signal, and its magnitude depends on the light pattern localization, wavelength and intensity [3]. The line scan speed is close to 1 kHz. No image processing algorithms are used during the image reconstruction process.

The devices were characterized through the analysis of the photocurrent and spectral response (in the range of 400–800 nm) under different RGB optical bias ($\lambda_L = 450$, 550 and 650 nm; $\Phi_L = 200\ \mu\text{W cm}^{-2}$) and in dark, for different applied voltages ($-6\ \text{V} < V < 6\ \text{V}$). In these measurements the device was uniformly illuminated through the a-Si:H back diode with red chopped light ($\lambda_S = 650$ nm, $\Phi_S = 10\ \mu\text{W cm}^{-2}$) and the optical bias was applied through the a-SiC:H front one. The photocurrent under different optical and electric bias conditions was measured using a lock-in amplifier.

## 3. Experimental results

### 3.1. Sensor responsivity and colour rejection

In order to optimize, for each sensor, the applied voltages that lead to colour filtering and to evaluate the responsivity to different light pattern wavelengths, the photocurrent generated by a red pulsed laser (the scanner) was measured under different steady-state illumination conditions and different electrical bias. This image signal (difference between the photocurrent with and without optical bias) is displayed in Fig. 1. Here the photocurrent at 750 nm was assumed as the dark level.

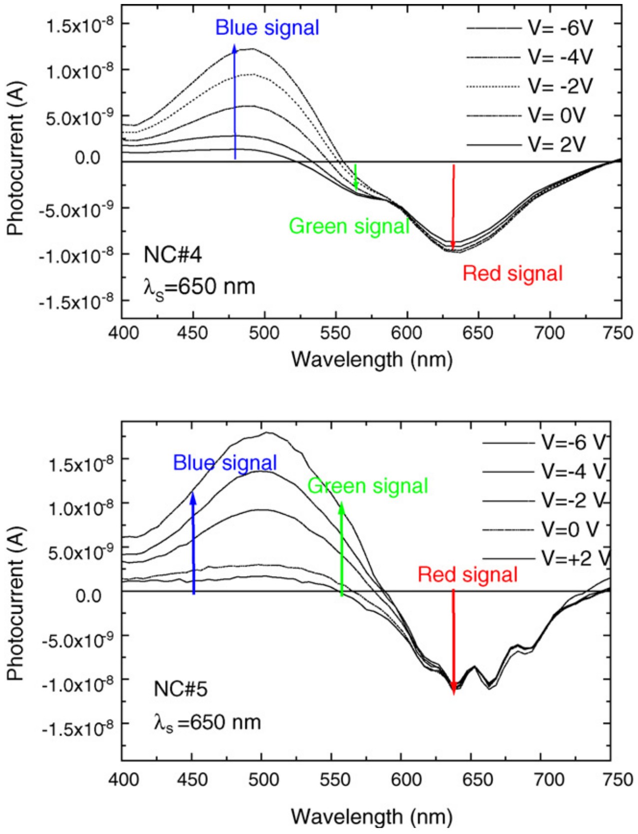

Fig. 1. Image signal as a function of the optical bias and under different applied voltages.

In order to tune correctly, for each sensor, the readout voltage that enables colour rejection (no image signal), the photocurrents generated by the same scanner, as a function of the applied bias and under different steady-state illumination conditions, are displayed in Fig. 2 and compared with their values without optical bias. The arrows (dotted in sensor NC #4 and solid in NC #5) guide the eyes towards the values where colour rejection is achieved (crossover between the photocurrents with and without optical bias).

To be sure that these readout voltages are independent on the image intensity, the photocurrent generated by the scanner was measured under red, green and blue steady-state illumination ($0\ \mu\text{W cm}^{-2} < \Phi_L < 160\ \mu\text{W cm}^{-2}$). In these measurements the element sensor was uniformly illuminated through the front diode with red pulsed light and the optical bias applied through the back one. For sensor NC #5, Fig. 3 shows this dependence.

### 3.2. Image and colour recognition

To show the ability of the sensor as a colour image sensor, the acquired images (difference between the photocurrents with and