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On the fabrication and characterization of amorphous silicon ultra-violet sensor array

D. Caputo [a,*], G. de Cesare [a], A. Nascetti [b], M. Tucci [c]

[a] *Dept. of Electronic Engineering, via Eudossiana 18 00184 Rome, Italy*
[b] *Dept. of Aerospace and Astronautics Engineering University "La Sapienza", via Eudossiana 18 00184 Rome, Italy*
[c] *ENEA, Res. Center Casaccia, via Anguillarese 301, S. Maria di Galeria 00123 Rome, Italy*

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ABSTRACT

In this work we present the design and fabrication of a 16 × 16 ultraviolet sensor array, deposited by Plasma Enhanced Chemical Vapor Deposition on glass substrate, suitable for label-free DNA parallel analysis. Each pixel is constituted by two back-to-back series connected coplanar amorphous silicon/amorphous silicon carbide n–i–p diodes. One junction acts as photosensor (with 1.4 × 1.8 mm^2 area) and the other as switching diode (with 200 × 200 μm^2 area).

The array performances have been optimized as a trade-off between the competitive requirements of the photosensor and of the switching element that have the same n–i–p stacked layers, since they have been deposited during the same deposition run. A responsivity around 60 mA/W in the ultraviolet range and an ON/OFF dark current ratio of six orders of magnitude have been achieved for the photodiode and the switching element, respectively.

1. Introduction

Techniques for the molecular recognition are particularly attracting for the academic and the industrial world and a big effort is nowadays devoted to improve detection performances in terms of analysis time, sensitivity and system cost. The evolution of the microelectronics, micro-electro-mechanical structures (MEMS) and lab-on-chip (LOC) technologies has a fundamental role in the fabrication of innovative and reliable devices. Thanks to these technologies it is now possible to fabricate small-scale devices (micro-arrays) [1], for the analysis of the interaction between biomolecules, and in particular, for the DNA recognition.

The majority of available systems relies on the detection of the fluorescence of biomolecules labeled with high-efficiency fluorophores [2]. This technique shows some important limits, due to the presence of the markers that complicate the sample preparation, and sometimes can alter the bio-molecular interaction.

Several innovative marker free techniques have been proposed in the past years. Some techniques measure the changes of the mass of the material, when the hybridization of the DNA occurs, with a micro-mechanical [3], piezoelectric or surface plasmon resonance based [4] transducers. Other approaches indirectly detect a change in electrical charge, associated with the biomolecular binding, by means of capacitance [5] or field-effect measurements [6].

Recently our group proposed a label-free detection system based on the measurement of the DNA absorbance in the ultraviolet (UV) range using a thin-film amorphous silicon (a-Si:H)/amorphous silicon carbide (a-SiC:H) sensor [7]. This spectrophotometric technique allows the precise quantification of the biomolecules as well as the identification of the DNA melting and hybridization [8]. From an application point of view the previous work, which dealt with single sensors, can be considered a proof of concept: a DNA analysis or recognition system requires a multitude of sensing sites to perform parallel analysis of several DNA fragments and comparison among different targets. Sensors arrays based on a-Si:H devices for detection of visible light have been already studied and developed by different research groups [9–11]. In this work, we developed an innovative 256 UV sensor array suited for label-free DNA parallel analysis. Since this application does not require high readout rate, a diode-addressed array has peen preferred in order to simplify the processing and increase the overall yield.

2. Design and fabrication of the array

In Fig. 1a the schematic of the diode-addressed array is depicted. Each pixel includes an UV photosensor series connected, in back-to-back configuration, with a switching diode. The matrix read-out is performed row by row, applying a negative voltage to the selected row and a positive voltage to the other rows. In this way, the input current (I_{IN}) of each column transimpedance amplifier is given by the current of the UV photosensor I_{PH} (sum of the photocurrent and of the reverse dark current) of the selected row minus the sum of the reverse saturation current of the switching diodes (I_{SW}) of the all other rows. Therefore in a matrix with n rows, it results:

$$I_{IN} = I_{PH} - (n-1)I_{SW} \quad (1)$$

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[*] Corresponding author. Department of Electronic Engineering via Eudossiana 18, 00184 Rome, Italy. Tel.: +39 06 44585832; fax: +39 06 4742647.
E-mail address: caputo@die.uniroma1.it (D. Caputo).

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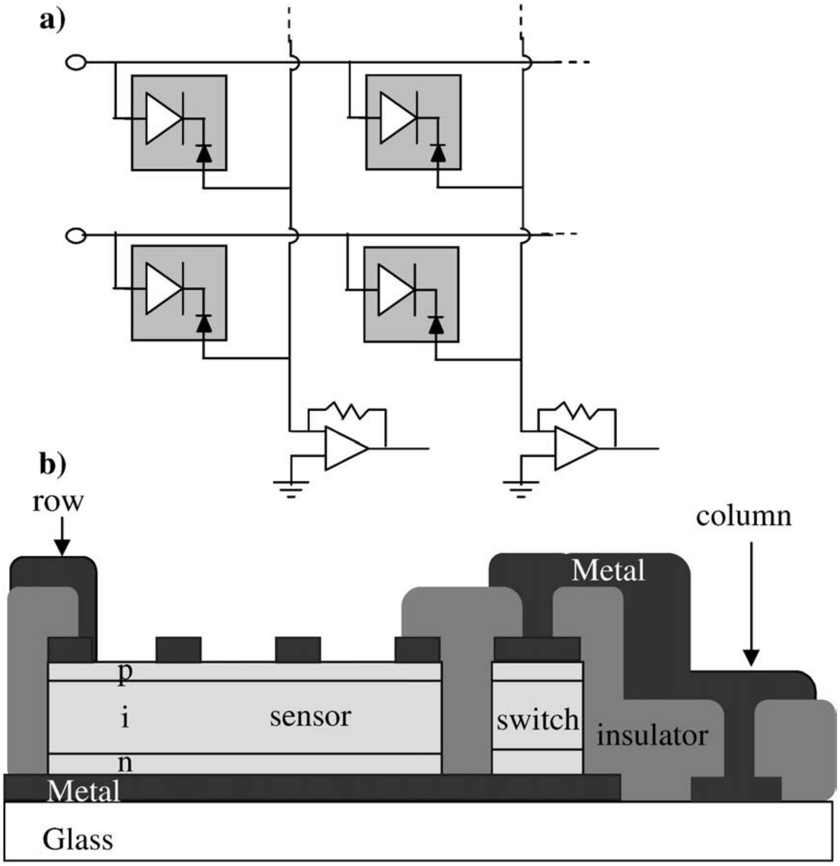

Fig. 1. a) Schematic view of the diode addressed array. The matrix read-out is performed row by row through the column transimpedance amplifier. b) Structure of one pixel of the matrix.

Fig. 1b reports the structure of one pixel of the matrix. The photodiode and the switching diode have the same a-Si:H/a-SiC:H n–i–p stacked layers, since they have been deposited during the same deposition run. The UV radiation impinges on the sensor through a grid metal electrode connected to the row. Thickness and optical properties of the three a-Si:H layers have been optimized as a trade-off between sensitivity and selectivity of the sensor and the off current of the switching. In the UV spectrum, the most of the photo-generation occurs in the p-doped layer [12]. The electrons diffuse toward the p–i interface, where they are swept toward the n-region by the electric field existing in the intrinsic region. To ensure a good collection efficiency even at shorter wavelengths, the thickness of the p-type layer has to be less than the electron diffusion length. On the other hand, to achieve good performance of the switching element a highest built-in potential is needed. We found that a good trade-off between these two competitive requirements is obtained by choosing high energy gap amorphous silicon carbide p-doped film and setting its thickness equal to 5 nm [12].

Thickness of the i-layer has been chosen to achieve a minimum of the inverse saturation current trading off between the thermal generation current, which increases with thickness, and the tunneling current, which instead decreases with thickness. We have found that a value of 150 nm allows to obtain an inverse saturation current around 5×10^{-10} A/cm^2 at reverse bias (<1 V) in dark and room temperature conditions. This thickness enhances the selectivity of the photosensor toward the UV range (below 400 nm) reducing the absorption of the visible light in the intrinsic layer.

The n-layer does not play a crucial role in the structure behavior as long as its thickness is thick enough to substain the built-in junction potential.

We have fabricated a 16 × 16 active matrix, reported in Fig. 2a, on a 5 × 5 cm^2 7059 Corning glass. Three test devices (indicated in the figure) have been included in the fabrication process in order to characterize the single photosensor, the single switching element and the single pixel outside the matrix. All the row and column lines are located on one side of the substrate to allow an easy electrical connection to the read-out circuitry. The array fabrication requires a four mask process through the following technological steps:

1. vacuum evaporation of a three layer metal stack chromium/aluminum/chromium (30/150/30 nm thick) and its patterning for the definition of bottom electrodes and the array columns (mask 1);
2. PECVD deposition of the stacked n–i–p structure of the UV photosensor and the switching diode;
3. vacuum evaporation of a chromium layer (50 nm thick);
4. mesa patterning of the metal and of the amorphous films (mask 2) for the definition of the devices of the matrix;
5. PECVD deposition of 700 nm thick amorphous silicon nitride as insulation layer and opening of the window over the sensor and the diode and of the via holes for the electrical connections to the column (mask 3);
6. vacuum evaporation of a three layer metal stack chromium/aluminum/chromium (30/150/30 nm thick) and its pattering (mask 4) to define the top metal grid directly connected to the row line and the connection of the switching elements to the column lines.

In Fig. 2b a picture of one pixel of the array is reported. The pitch is 2 mm, the sensor area 1.8 × 1.4 mm^2 and the diode area 0.2 × 0.2 mm^2. The fill factor results 63%. The grid electrode has four 50 µm width