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3 dimensional polymorphous silicon based metal-insulator-semiconductor position sensitive detectors

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Abstract

In this work we investigate the properties of a polymorphous silicon (pm-Si:H) metal-insulator-semiconductor (MIS) structure used in 3D position sensitive detectors (PSD). For the first time a 3D sensor made-up by pm-Si:H/SiO_2/Au layers is presented. MIS structures present several advantages over p-i-n structures, such as easier fabrication, fast response time and higher resolution. The 1D MIS PSD that constitute the array were extensively studied aiming its application in 3D pattern recognition. The results obtained show that MIS PSD can achieve non-linearities below 2% and sensitivities of 3.2 μA/cm over 6 mm length sensors. The miniaturization of the sensors length to arrays of 6 and 16 mm, respectively showed average non-linearities of about 1.9% for the 16 mm sensor which proved to be the best solution for this MIS structure.

Keywords: Polymorphous silicon; Sensors; Position sensitive detectors; MIS

1. Introduction

Three dimensional (3D) position sensitive detectors (PSD) have been studied as a valuable cost effective alternative to CCD devices, for applications needing unmanned automated systems for image processing in real time [1]. The 3D sensors are the most promising ones for such operations since they have no discrete elements in one direction and so can provide continuous position data information by making use of the surface resistance of a photodiode, either p-i-n, Schottky or metal-insulator-semiconductor (MIS), based on amorphous silicon technology.

The 3D PSD structure consists of an array of one dimension 1D PSD working independently and simultaneously, so that the profile of a laser line is detected. Using a triangulation method the shape and form of an object can be three dimensionally reconstructed by projection on the sensor of a laser line reflected by the object [2].

The Schottky and MIS structures present several advantages over the common p-i-n ones, such as easier fabrication, fast response time and higher resolution. One of the best metals that can be used to form a Schottky contact with Si is Au. This is due to its high work function (≈5.2 eV), which facilitates the formation of rectifying contacts [3] and also (for photon detection) because of its high transparency in the visible region of the spectrum [4] when very thin (<20 nm) films are used, compared to other metals. In spite of these advantages, Au contacts to Si present some problems: Au is a fast diffuser into the silicon at temperatures as low as room temperature [5], which means that the contact will degrade in time. The diffusion occurs by a kick-out mechanism [6], which is followed by the oxidation of the silicon [7] when the sample is exposed to oxygen from the atmosphere, which leads to the destruction of the devices made with these contacts. To avoid this problem we used MIS structures to fabricate the sensors. The diffusion process is avoided when the silicon surface is passivated with a thin oxide layer of at least 0.5 nm, prior to the deposition of the Au contact [8].

This work presents for the first time results in 3D PSD fabricated with a MIS structure based in Au/polymorphous silicon (pm-Si:H) [9] rectifying contact. pm-Si:H is a material similar to amorphous silicon (a-Si:H) but with improved transport properties [10]. It is deposited by plasma enhanced chemical vapour deposition (PECVD) but in a regime close to

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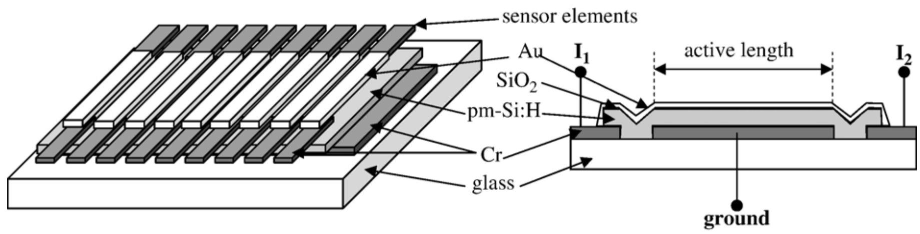

Fig. 1. Schematic of the design of the 3D sensor, consisting of an array of 1D MIS sensor elements and the schematic of the cross-section of a 1D element. A thin (2 nm) oxide layer exist between the pm-Si:H and Au layers.

powder formation, which enables the incorporation of crystalline nanoparticles (2 to 5 nm) during the film growth.

2. Experimental

The 3D sensor consists of an array of 32 1D sensor elements. The scheme of the sensor structure is depicted in Fig. 1, while Fig. 2 shows a picture of the sensor. Each element consists of a MIS sensor made with: Cr (250 nm)/a-Si:H [n+ doped] (40 nm)/pm-Si:H[intrinsic] (500 nm)/SiO_2 (2 nm)/Au (15 nm). The metals were deposited by evaporation in an Electron Gun system. For the semiconductor intrinsic layer we used pm-Si:H [11] deposited by PECVD using a mixture of 10 sccm of SiH_4 and 100 sccm of H_2, at 187 Pa, with 30 mW/cm^2 of power applied by a 27.12 MHz rf generator.

To create the MIS structure an SiO_2 layer was grown prior to the Au metallization by heating the sample for 5 h at 180 °C in a furnace with O_2 flow. This process forms 2 nm of oxide that was characterized by spectroscopic ellipsometry, which is a highly sensitive technique to the surface properties of silicon due to the lowering of the refractive index at the surface when an oxide is present [12].

Two active lengths of arrays were fabricated: 6 and 16 mm. The width of the sensor lines was 300 μm, which corresponds to the width of the Au layer, and lines are spaced by 500 μm. The Cr and silicon layers were not individualized for each line.

One technological problem arising from the fabrication of this structure is the difficulty for the Au film (with ideally 7 nm thickness) to achieve a full homogeneous and continuous coverage of the silicon step, which is 500 nm thick and, to make a good electric contact to the output Cr pads. Indeed, the Au layer must be very thin to have a high resistance (>500 Ω in the line) and to be transparent [13]. Nevertheless, if the sensor is put directly over the evaporator to process the Au metallization, a non continuous Au film is formed at the edges of the silicon, interrupting the contact to the Cr (see Fig. 1). The solution was to put the sensor at 45° with respect to the evaporator source and rotating it, and to increase the Au thickness to 15 nm. Further research is already undergoing to improve this point.

The sensor's linearity was determined by scanning the sensor with a red (λ=635 nm) laser line (3 cm×0.75 mm) of 1 mW of power, using a proper set-up [14]. The MIS sensors have their maximum spectral response at 540 nm, and so a green laser should ideally be used to measure them. But due to technical problems it was only possible to measure the larger (6 cm) 1D sensors with the green laser. The step for the movement of the laser line was 100 μm. The output signal from each line was determined by measuring the lateral currents (I_1 and I_2) generated by the laser at each terminal by a current to voltage converter, which sends the voltage signals to a PC acquisition board with 64 channels. The position signal is then calculated by making the

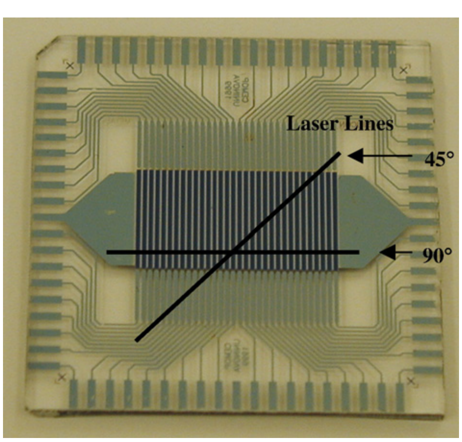

Fig. 2. Picture of the 6 mm length 3D sensor with 32 elements, showing the angle of the laser lines relative to the lines, for the cross talk experiment.

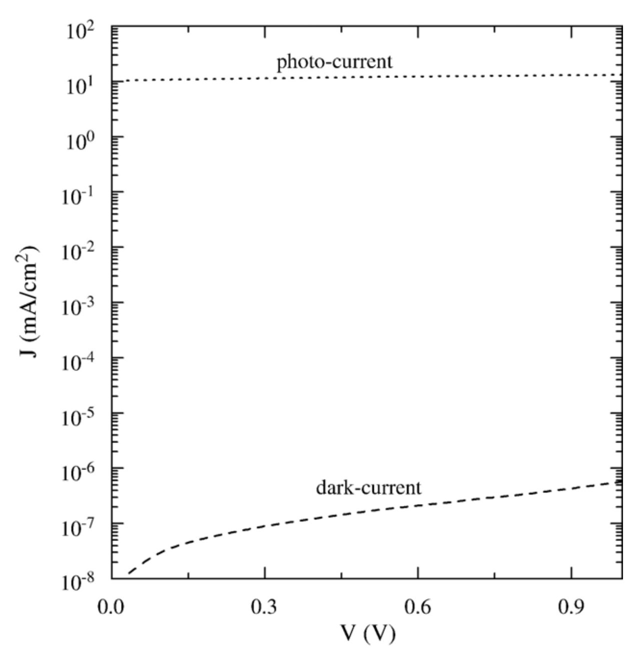

Fig. 3. I-V characteristic of the pm-Si:H/Au MIS structure under reverse polarization, in dark and under AM 1.5 illumination conditions.