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A simple Al/SRO/Si Structure with Silicon Nanoparticles as a UV and Vis Photodetector

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Abstract

A photodetector that shows high photocurrent in the ultraviolet and visible wavelengths has been fabricated. The device consists of a metal-oxide-semiconductor (MOS)-like grid structure where the dielectric layer is a silicon-rich oxide (SRO) film. Its fabrication is completely compatible with silicon technology. SRO thin films with 1 to 12% silicon excess were deposited on silicon wafers by low pressure chemical vapour deposition technique. After thermal annealing, silicon nanoagglomerates were created. Current-voltage measurements in dark and under illumination conditions were done to test the devices.

Keywords: Photodetector, Silicon rich oxide, Photocurrent, Silicon nanoparticles, Electrical properties.

1. Introduction

In the past various photodetector structures have been developed from pn junction, pin junction, bipolar transistor, avalanche photodiodes (APD), and metal-semiconductor-metal, MSM, structures [1-7]. In these structures different semiconductor such as Si, III-V and II-VI compounds have been used, depending on the wavelength range to be detected. Nowadays, photodetectors are important components for the optoelectronic integration. The silicon is an important semiconductor in the integrated circuit technology, but silicon has an indirect bandgap inhibiting optical functions. Silicon sensors are used in the visible-to near infrared (VIS-NIR) range. However some commercial Si sensors have been enhanced to detect in the ultraviolet (UV) range, but they have one or more of the following weaknesses: very expensive, reduced responsivity in the VIS-NIR range, lack of compatibility with IC processes, complex technology, see for example [2]. So, most of the available materials for UV detection are not silicon but compound semiconductors [3]. Then, many works have been done to study Si-based optoelectronics materials to overcome the drawback of silicon. Silicon rich oxide (SRO) is one of such materials that have been studied due to its interesting optical and electrical characteristics. The SRO characteristics vary with the silicon excess in the films

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[4-5], and leads towards a variety of applications such as waveguide, non volatile memories, voltage peaks suppressers, detectors and emitting light devices [1-8].

In this work, a photodetector made of a simple Al/SRO/Si MOS-like grid structure is reported. The photodetection range goes from UV to VIS-NIR radiation, with high responsivity in whole range. This structure requires few fabrication process steps and is compatible with CMOS technology.

2. Experiment

SRO films were deposited on N type Silicon (100) substrates with resistivity of 2000-5000 Ω-cm and with a N+ implanted region in the back side. SRO layers were obtained in a horizontal LPCVD hot wall reactor using SiH_4 (silane) and N_2O (nitrous oxide) as reactive gases at 700 ºC. The gas flow ratio, Ro = $[N_2O]/[SiH_4]$, was used to control the amount of silicon excess in the SRO films. Ro = 10, 20, and 30, corresponding to a silicon excess of 12 to 5 %, were used for this experiment. After deposition, the samples were thermally annealed at 1000° C in N_2 atmosphere for 30 minutes. Aluminum grids were patterned on the SRO surface by evaporation and standard photo-lithography. Fig. 1 shows an image of the fabricated structure. The area of the Al grids electrode s was A = 0.033 cm^2. Ellipsometric measurements were made with a Gaertner L117 ellipsometer to obtain the thickness and refractive index of the SRO films before annealing, whose values are shown in Table I. Current versus voltage (I-V) measurements were performed at room temperature, illuminated with UV or white light and under dark conditions, using a computer controlled Keithley 6517A Electrometer. The voltage sweep was done at a rate of 0.1 V s^{-1}. Illumination was performed with an UV lamp (UVG-54, 5 to 6 eV approximated range) and a white light lamp (1.7 to 4 eV approximated range) with output power of 6.12 mW/cm^2 and 2.19 $\mu W/cm^2$, respectively. The power of lamps was measured using a radiometer (International Light, USA. IL1 400A).

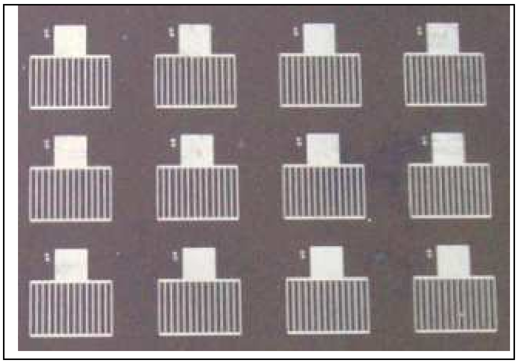

Fig. 1. Micro-photographic view of the devices used.

Table I. Refractive index and thickness of SRO films.

Ro	Refractive index	Thickness (Å)
10	1.775 ± 0.005	720 ± 28
20	1.55 ± 0.03	755 ± 25
30	1.46 ± 0.01	591 ± 3

3. Results

Fig. 2a) and 2b) show, respectively, the typical I-V characteristics of devices with Ro = 10 and 30 at the surface inversion condition, in dark and under UV and white light illumination. The dark current is in the order of 10^{-10} A indicating a low leakage in these structures. However, a large photocurrent was obtained when the structures were illuminated, indicative of high optical sensitivity in this simple structure. Similar photo-response was obtained with structures made of Ro = 20.

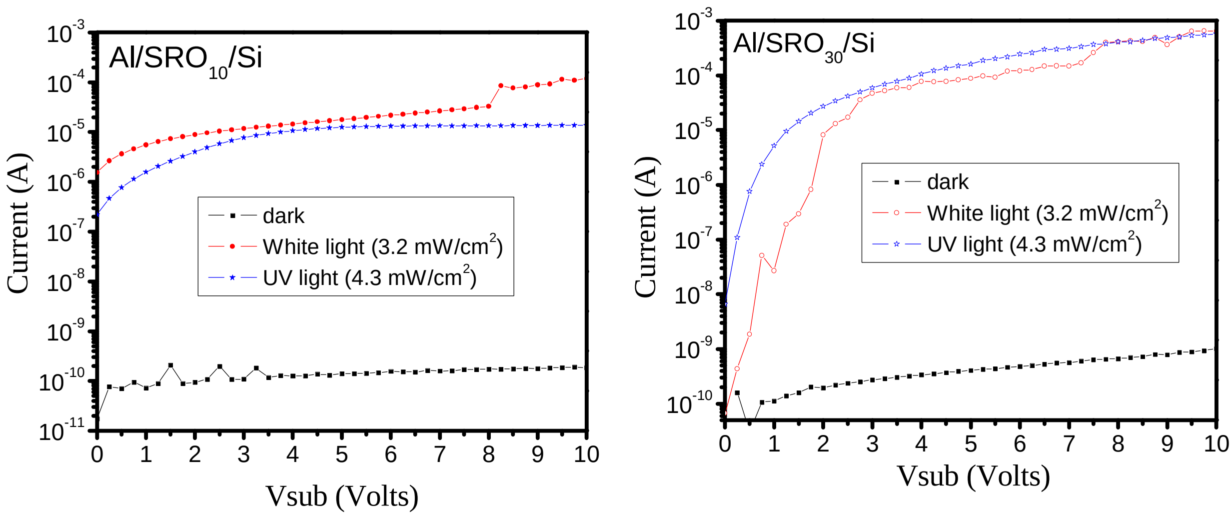

Fig. 2. I-V curves of the Al/SRO/Si MOS-like grid structure for a) SRO_{10} and b) SRO_{30} under dark and illumination conditions.

The current versus wavelength in the VIS-NIR range for SRO_{10} and SRO_{30} films are shows in Fig. 3. In this case, a high response was obtained for both SRO films in the whole range (350-1000 nm).

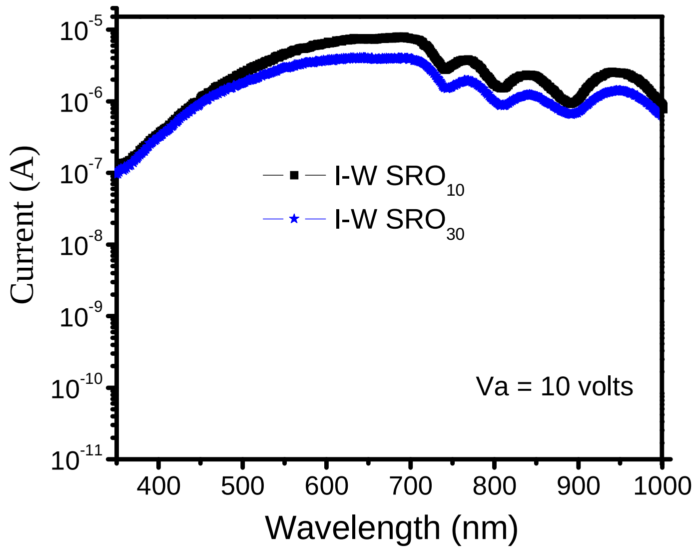

Fig. 3. Current versus Wavelength (I-W) characteristics of the Al/SRO/Si MOS-like grid structure. Voltage applied (Va = 10 V.)

4. Discussion

The results show that Al/SRO/Si grid structures have high photocurrent to different wavelengths. The large photocurrent is due to the photocarriers generation in the SRO films and also in the depletion layer of the Si substrate that forms an induced pn junction [9-10]. The carrier transport in SRO layer is via tunneling [11]. High density of Si-nps and defects in SRO film create conduction paths and then the photogenerated carriers can move through them allowing large photocurrent, as shown in Fig. 2. This simple structure presents high optical sensitivity even for UV light (254 nm) as depicted in Fig. 2. The UV response can be explained because the p inversion layer is a thin inversion layer at the surface of the silicon; this greatly reduces the optical losses in UV range. Also, the fact that the light that shines on the opaque Al can not arrive to the active area, but the light that impinge on the SRO between the grids leads to a component of the photocurrent produced in the SRO itself. In reference [12] is shown that SRO itself has a photoresponse characteristic. The combination of an induced pn junction and the photosensibility of the SRO produce high optical sensitivity for both UV and visible light. The responsivity of the device can be estimated to be ~ 3.2 mA-cm^2/W and 0.046 A-cm^2/W, only for UV and white light, respectively.

5. Conclusion

Al/SRO/Si MOS-like grid structure was fabricated as photodetector. This structure shows very high optical sensitivity for UV-VIS light. The high photocurrent results from the photocarrier generation in the pn induced junction and to the photoresponse of the SRO.

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