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Photoelectric Properties of MOS-like Structures with Twofold SRO Films

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Abstract

The optical properties of silicon rich oxide (SRO) have been deeply studied because, between other reasons, they emit an intense photoluminescence (PL) from visible to the near infrared range when excited with UV light. MOS-like structures with SRO film as the active layer have shown an enhanced conductivity under different illumination conditions. In this paper, MOS-like structures with double SRO layer were fabricated in order to have a barrier to isolate the silicon substrate from the active SRO layer. Results show that all structures have a higher current when light shines on them than that obtained under dark conditions. A possible application of this photo-effect can be used to increase the response of photodetectors and silicon solar cells.

Keywords: SRO; LPCVD; Photocon duction; Photolumiscence; MOS;

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1. Introduction

Silicon rich oxide (SRO) has been studied due to its interesting electrical and optical properties [1, 2], which have given place to different kinds of applications, such as waveguides, non-volatile memories and light detection devices [1-3]. The SRO on silicon is visualized as a system to improve the efficiency of photodetectors, electroluminescent devices and silicon solar cells [1, 3-4]. SRO has excellent optoelectronic properties, where the absorption - emission mechanism represents one of the most interesting problems in modern solid state physics. An important characteristic of the SRO films is their compatibility with the silicon technology in order to integrate optoelectronic functions. SRO is a material with silicon excess formed by multiple phases (SiO2, SiOx and crystalline or amorphous Si-nps) [7-9, 11-12]. SRO films can be obtained by different techniques, such as low pressure chemical vapour deposition (LPCVD), plasma enhanced CVD (PECVD), silicon implantation into thermal silicon dioxide, etc, [5, 6, 7]. In particular, for LPCVD the silicon excess in SRO films is controlled with the flow ratio between the

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reactant gasses used (N_2O and SiH_4) as Ro = [N_2O] / [SiH_4]. Silicon excess of 17 at.% is obtained with Ro = 3, and silicon dioxide is obtained with Ro ≥ 50 [11].

Previous studies have shown that SRO films deposited by LPCVD exhibit an intense photoluminescence (PL) in the red visible region when excited with UV light [7-8, 10-11]. This particularity has been used to make a silicon sensor that extends the silicon capabilities up to the UV [4]. Also, new studies on MOS-like structures using the SRO films as active layer have shown photoconduction properties. That is, under illumination the SRO films produce a photocurrent, and depending of the wavelength the photocurrent is increased.

In this paper, the photoelectric and photoconduction properties of devices with twofold SRO films were studied. Devices with SRO_{10}/SRO_{50}, SRO_{20}/SRO_{50} and SRO_{30}/SRO_{50} (subindex indicates the Ro value) were fabricated. The SRO_{50} layer has the purpose of isolating the silicon bulk effects from the SRO effect. A worthwhile conclusion is the fact that this material has useful properties to be used in energy conversion.

2. Experiment

SRO films were deposited on N type silicon (100) substrates with resistivity of 4000 Ω-cm. The substrates were implanted on the back side (E = 150 keV, dose = $5x10^{15}$ Si-ions/cm^2) to have good contacts. SRO layers were obtained in a horizontal LPCVD hot wall reactor using SiH_4 (silane) and N_2O (nitrous oxide) as reactive gases at 720 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, 30 and 50, corresponding to a silicon excess of 12% to 1%, were used for this experiment [7-12]. Double layers, which consist of SRO_{10}/SRO_{50}, SRO_{20}/SRO_{50} and SRO_{30}/SRO_{50} (the subindex indicates the Ro value) were deposited. The total pressure was varied for each Ro from 1.5 to 2 Torrs. After deposition, the samples were thermally annealed at 1000° C in N_2 atmosphere for 30 minutes. Circular aluminum (Al) contacts with area A= 0.0314 cm^2 separated 0.2 cm were deposited on the SRO surface by evaporation. Ellipsometric measurements were made with a Gaertner L117 ellipsometer to obtain the refractive index and thickness of the SRO films after annealing, whose values are shown in Table I.

Table 1. Refractive index and thickness of single SRO films.

Ro	Refractive index	Thickness (Å)
10	1.78 ± 0.01	640 ± 30
20	1.67 ± 0.03	779 ± 50
30	1.42 ± 0.01	837 ± 60
50	1.46 ± 0.01	1365 ± 90

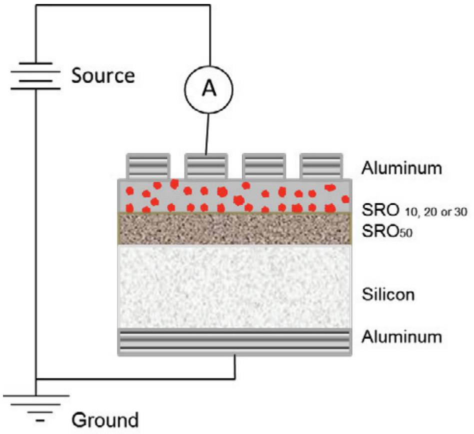

Figure 1. Schematic diagram of the devices and the circuit used to measure the current-voltage characteristics. One of the Al contact is at ground potential as a reference for the bias direction.

Current versus voltage (I-V) measurements were performed at room temperature in dark and under illumination using a computer controlled Keithley 2400 electrometer in a screening box. The voltage sweep was done at a rate of 0.1 V/s. Illumination was performed with short (254 nm) and large (365 nm) wavelengths-UV light (UVG-54) and a white light lamp. Dark current and photocurrent were measured between two Al contacts, as shown in Figure 1. The measurements were done at forward (+ respect to ground) and reverse bias (- respect to ground).

3. Results

Figure 2 shows the PL spectra of SRO films after annealing. For Ro = 10 the emission range appears from 600 to 900 nm with the main peak at 814 nm. For Ro = 20 the emission band shows a blue-shift. Meanwhile two PL bands were obtained for Ro = 30, from 400 to 550 nm and from 650 to 870 with lesser intensity. As observed in figure, the PL intensity increases with silicon content in SRO films.

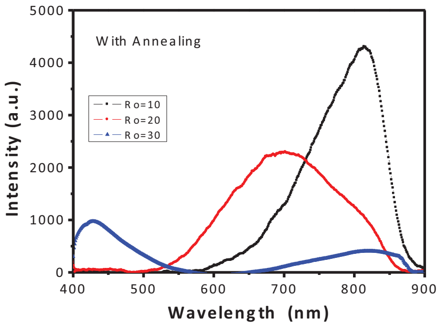

Figure 2. Photoluminescence spectra of SRO films with different Si excess and annealing at 1000° C in N_2 atmosphere for 30 minutes.

Figures 3a), 3b) and 3c) show, respectively, the I-V curves of the Al/SRO_{Ro}/SRO_{50}/Si structures with Ro = 10, 20 and 30 under dark and illumination conditions. As can be seen, the response to UV and white light is significant for all Ro values. Furthermore, the photocurrent is almost symmetric for both forward and reverse bias.

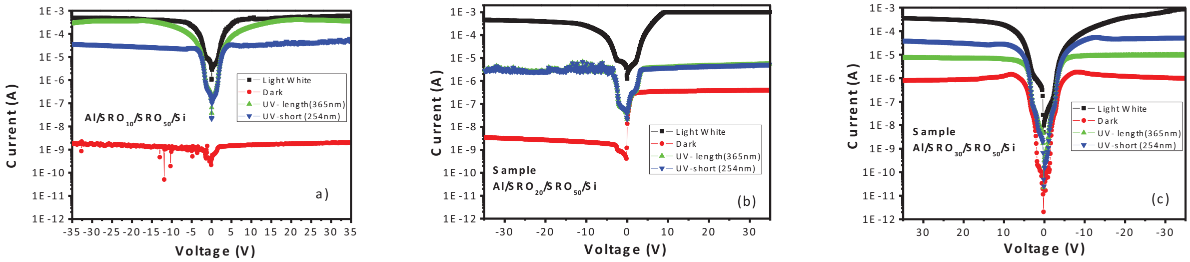

Figure 3. I-V characteristics of the Al/SRO_{Ro}/SRO_{50}/Si MOS like structures Ro = a) 10, b) 20 and c) 30 under dark and light conditions.

When the Al/SRO_{10}/SRO_{50}/Si structure is under forward bias and illuminated with white light, the current increases rapidly to about 5.1 μA at 1 V. When the voltage is 5 V the current increase at about 0.42 mA and to higher voltages the current saturates at 0.5 mA. The current also increases rapidly (under white light excitation) with a similar behavior when the Al/SRO_{10}/SRO_{50}/Si structure is reversely biased. The forward and reverse current ratios with respect to dark current are about 5.5 orders of magnitude. If the structure is illuminated with UV light, the photocurrent is similar to that obtained with white light. However, a decrease of approximately one order of magnitude is observed for short-wavelength UV light. For structures with SRO_{20}/SRO_{50} and SRO_{30}/SRO_{50}, the current behaves similarly to that of SRO_{10}/SRO_{50}, but with some cases with lesser photocurrent. Also, smaller differences in the current values with the different type of illumination are observed.

4. Discussion

In Figure 3 the typical I-V curves of twofold SRO layer structures measured horizontally in dark and under illumination are shown. As can be seen, the dark current, especially for SRO_{10}/SRO_{50} and SRO_{20}/SRO_{50}, is low and symmetric. The presence of Si-nps within the SRO films deposited by LPCVD has been shown [7-8, 11]. Si-nps of 4.1, 2.7 and 1.5 nm were observed in SRO films for Ro = 10, 20 and 30, respectively [7-8, 11]. Moreover, it has been proposed that these Si-nps could be creating conductive paths within the SRO and then affecting its electrical behavior [7-8, 10-11]. Therefore, the horizontal current measured in this experimental configuration can be ascribed to the conduction paths through the SRO bulk.

However, the highest dark current observed for the structure with SRO_{30} is contrary to the expected. The SRO_{30} should have the smaller conductivity because of the low silicon excess. Then, we can think that the total current in the horizontal structures is a combination of bulk and surface currents. When the SRO is conductive enough as in the case of the SRO_{10} the current is meanly across the bulk, but if the SRO film is not conductive, as Ro = 30, the electrons tend to flow more easily on the surface.

When the samples are illuminated, the current increases significantly. As shown in figure 3, in all the illuminated samples, including SRO_{30}, the current shows higher photocurrent values. In this case, the electrons are moving trough conduction trajectories in the SRO. That is, the current is due to the SRO bulk. So, under illumination photo-electrons are generated inside the SRO film. The conductive paths reduce the resistance to electron flow, making the bulk current more likely than the surface current.

In addition, a dielectric barrier (SRO_{50}) was placed between the silicon substrate and the highly conductive $SRO_{10,}$ SRO_{20} or SRO_{30}, as shown in Figure 1. Therefore, the dark current for these devices is in the bulk SRO. So, again we can say that the current is not due to the silicon substrate. Particularly, the Ro_{10}/Ro_{50} structure where the current should be mainly through the SRO_{10}, the increase in photocurrent is 5.5 orders of magnitude. Moreover, we have to point out that the SRO is sensible to light with wavelength from UV to visible.

It is well known that the SRO is a mixing of Si-(Si_xO_{x-4}) compounds with x varying from 0 to 4, [8, 11]. It has been proposed by various authors that traps exist within SRO films that can accept or donate one electron [3, 10-11]. Also, it has been observed experimentally that in SRO_{10} a high electronic conduction is present, but neither high carriers trapping nor high photoemission have been observed. This is due to the existence of "big nanocrystals" that behave as conductive paths. Then e-h pairs generated by light decay but do not emit. In the other case, for SRO_{30} there are not nanocrystals but perhaps Si, or Si-(Si_xO_{x-4}) compounds, agglomerates that allow the trapping of carriers and then emissive decay when illuminated [7-8, 11].

Figure 4 reproduces in more detail the curves shown in Figure 2 a) when they cross the zero voltage value. As can be seen, the photocurrent looks like increasing when voltage is zero. Even this way is not a good one to test a photovoltaic (PV) effect; the structure seems to be photovoltaic. If there is a PV effect it could be due to the SRO film, as reported in [13]. In our case, however, the PV effect was observed in the double layer structures.

As it was presented and discussed here, the SRO by itself responds to light increasing its conductivity. This fact has also been evidenced in different experimental results as mentioned. In addition, it is well known that SRO has electron traps. Then, there is enough evidence to accept that light impinging on the traps release electrons, and then the SRO could be used to build photovoltaic devices.

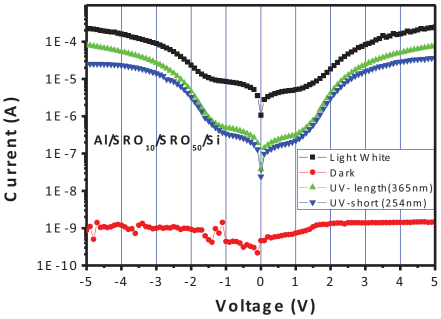

Figure 4. Detail of current against voltage for $Al/SRO_{Ro}/SRO_{50}/Si$ with Ro = 10, in dark and illuminated with UV and white light.

5. Conclusion

We demonstrated that the photoconduction is possible in twofold SRO films using Al/SRO/SRO/Si structures. High photoconduction between two horizontal contacts was obtained under UV and white light and for both forward and reverse bias. Using an electronic barrier (SRO_{50}), the silicon substrate contribution to the current was eliminated. We believe that there are several key factors for the photoresponse in the SRO films such as silicon excess and Si nanoparticles size, which allow the SRO film to act as a photoconductor. However, more research has to be done in order to understand how these variables modify the photocurrent. A photovoltaic (PV) effect was also observed in structures with electronic barrier. This PV effect could be attributed to SRO films.

Acknowledgments

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