MOS-like structure with Silicon Rich Oxide and its Possible Applications to Silicon Photoconversion.

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1. Abstract

Silicon Rich Oxide is a silicon compatible material formed with SiO_2, SiO_x and elemental silicon. The optical properties of this material have been deeply studied because, between other reasons, they emit under different excitation condition in the visible to the near infrared range. Especially it was found that under UV illumination high photoluminescence is obtained. This particularity has been used to make silicon sensor that extend the silicon capabilities up to the UV. However, it was found and improvement of the silicon response not only in the UV region but in the visible one also. So, new studies have shown that light has an effect on the SRO conductivity, that is, the current in the SRO increases under illumination from UV to visible range. In this paper, recent results on the photoresponse of SRO are presented and discussed. A possible application of the photo-effect can be to increase the response of silicon solar cells. In the discussion of the results a short mention of the drawbacks that will have to be solve before this material can be used to the energy conversion.

2. Introduction

Silicon Rich Oxide (SRO) has been subject of an intense study due to their excellent optoelectronic properties, where the absorption - emission mechanism represents one of the most interesting problems in modern solid state physics. Another important problem has been the compatibility of these materials with the silicon technology in order to integrate optoelectronic functions in a silicon chip. Silicon rich oxide is a material with silicon excess formed by multiple phases (SiO_2, SiO_x and crystalline or amorphous Si-nps). 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 [1, 2, 3]. In particular for LPCVD, silicon excess can be controlled with the flow ratio ($Ro = [N_2O] / [SiH_4]$) between N_2O and SiH_4 as the reactant gasses. This material has been studied due to its interesting structural, electrical and optical properties [4, 5], which have given place to different kind of applications, such as waveguides, non-volatile memory and light detection devices [3-6].
SRO was found that under UV illumination high photoluminescence is obtained. This particularity has been used to make a silicon sensor that extends the silicon capabilities up to the UV. However, it was found an improvement of the silicon response not only in the UV

region but in the visible one also. Due to its responsivity in the whole range from 200 to 1100 nm, the SRO on silicon is visualized as a system to improve the efficiency of silicon solar cells [7].

Also, new studies have shown that light changes augmented the SRO conductivity, that is, the current in the SRO increases under illumination.

In this paper, recent results on the photoresponse of SRO are presented and discussed. In the discussion of the results a short mention of the drawbacks that will have to be solve before this material can be used to the energy conversion.

3. Experiments condition

MOS like structure as that shown in figure 1 were fabricated with single and double layer. Details of the fabrication are somewhere else [8]. SRO was used as dielectric in the MOS like structures. Dark and illuminated I-V measurements were done. In order to study the effect of light on the SRO the measurements were done horizontally. The devices were measured twice. Arbitrarily, one of the contacts was defined as the reference and measurements were done positive and negative with respect to this reference (forward and reverse respectively).

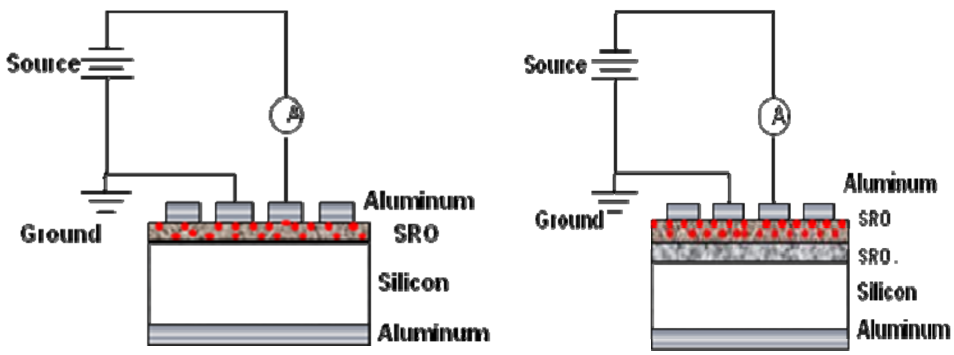

Figure 1. Schematic diagram of the devices and the circuit used to measure the current-voltage characteristics. One of the Al contact is ground as a reference for the bias direction.

4. Results and discussion.

Figures 2a) and 2b) show the dark and illuminated current density of the Al/SRO/Si structures with Ro = 10, and 20 under forward and reverse bias. Figures 3a) and 3b) show the current density versus voltage for the structures with double SRO layer (Al/SRO_{10}/SRO_{30}/Si and Al/SRO_{10}/SRO_{50}/Si). As can be seen, the response to UV and white light is significant for all devices. In the case of the Al/SRO_{10}/SRO_{30}/Si structure, the dark current is approximately 0.1 mA/cm^2. In the case of the Al/SRO_{10}/SRO_{50}/Si structure, the dark forward current is only 1.6 nA/cm^2 at 1 V. Above of 10 V, the current jumps to 0.1 μA/cm^2, and it shows other jumps. In reverse dark current, the current behaves similar to that in forward bias, but with a maximum current of about 0.14 μA/cm^2. When white light is applied the current reaches up to the 0.7 mA/cm^2. Note that for forward bias and white light the current has an erratic behavior jumping up and down up to 17 V.

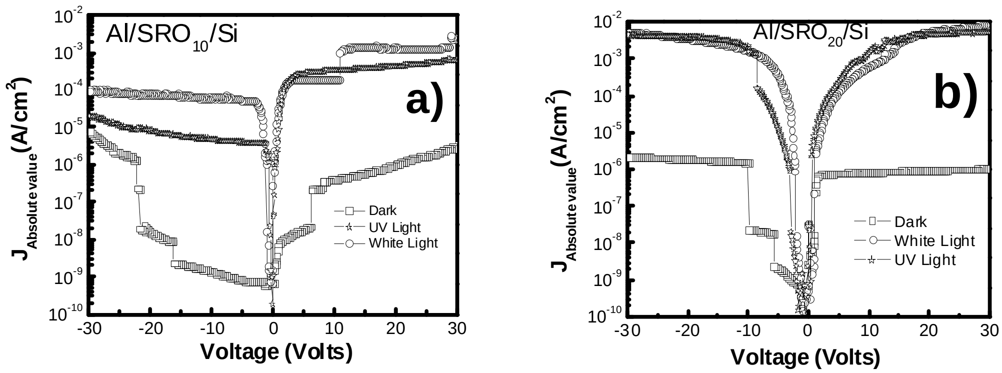

Figure 2. Dark and illuminated I-V characteristics of the Al/SRO/Si MOS like structures.

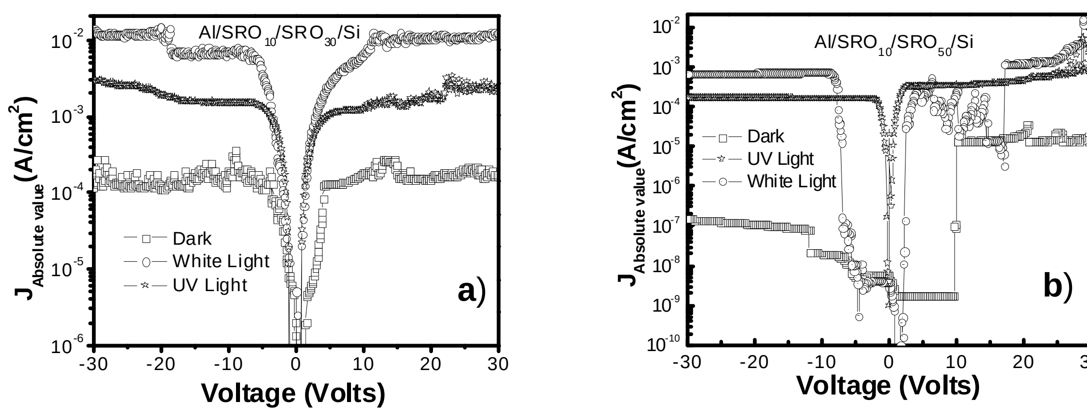

Figure3. Dark and illuminated I-V characteristics of the Al/SRO_{10}/SRO_{30}/Si and Al/SRO_{10}/SRO_{50}/Si MOS like structures.

In Figure 2 the typical I-V curves of single layer structures measured horizontally in dark and under illumination are shown. As can be seen, current jumps are observed in the dark current especially for SRO_{10} and some for SRO_{20}. Similar jumps have been observed in Al/SRO/Si structures measuring the current from the Al gate to the silicon substrate. The jumps are produced by the formation of conductive paths [9]. Therefore, the horizontal current measured in this experiment can be ascribed to conduction in the SRO bulk.

However, the highest dark current observed is for the SRO_{30} contrary to the expected. The SRO_{30} should have the smaller conductivity because of the low silicon excess. Also, I-V characteristics of the structure with SRO_{30} do not show current jumps, so superficial current dominates. Then, we can think that the total current in the horizontal structures is a combination of bulk current and superficial current. When the SRO is conductive enough as in the case of the Ro = 10 the current is meanly across the bulk, but if the SRO film is not conductive, as Ro = 30, the electrons find easier to move on the surface.

When the samples are illuminated the current increases significantly. As shown in figure 2, in all the illuminated samples, including SRO_{30}, the current has jumps. Then, 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 of the SRO films. The conductive paths reduce their resistance, making the bulk current more likely than the surface current.

In the next experiment a barrier was put between the silicon substrate and the highly conductive SRO_{10} as shown in Figure 1(b). Two barriers were used SRO_{30} and SRO_{50} which have silicon excess of about 5 and 1%, respectively [10, 11]. As can be seen in Figure 3 the dark current for these devices have many jumps, implying the currents is in the bulk SRO. So, again we can say that the current is not due to the silicon substrate.

Under illumination again the photocurrent is much higher than in dark for both structures. Particularly, the Ro_{10}/Ro_{50} structure where the current should be mainly through the SRO_{10} the augment in photocurrent is 4 orders of magnitude. We have to point out that the SRO is sensible to wavelength from UV to visible.

It is well known that SRO is a mix of Si-(Si_xO_{x-4}) with x varying from 0 to 4, [12]. It has been proposed for various authors that in SRO are traps that can accept or donate one electron [13, 14]. 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 the “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 [15]. With these ideas on mind, the band model shown in Figure 4 is proposed for the Al/SRO_{10}/SRO_{50}/Si structure measured horizontally. In this diagram, under an electric field electrons will move in the conduction band of the nanocrystals. Electron also will move between nanocrystals using the density of traps in the SiO_x, forming conduction paths [16]. When the electric field is applied in dark, electrons will move through the paths, but some electrons will be trapped and then blocking some conductive paths. As voltage increases, some electron trapped will be released and new path will add increasing the current, i.e. a jump will be register in the I-V curve.

When the device is biased and is under illumination, more e-h pairs will be created in the nanocrystals, but also the trapped electrons will be released due to photons energy. As a result more conductive paths and carriers will contribute to the photocurrent.

The band diagram shown in Figure 4 can be extended to lower silicon excess films. As the silicon excess reduces, the Si-ncs bands widths reduces and that encircled in the Figure increases. At the end the band diagram of a dielectric with a traps distribution is reached, as proposed in [13].

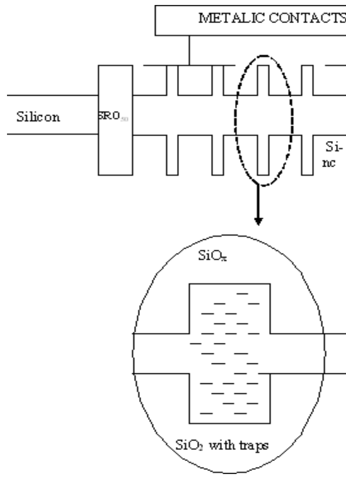

Figure 4. Band Diagram for the structure Al/SRO_{10}/SRO_{50}/Si measure horizontally.

Figure 5 reproduce with more detail the curves shown in Figure 2 when the voltages cross trough cero. As can be seen the photocurrent looks like increasing when voltage is cero. 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 could be due to the SRO film, as reported in [17], or could be due an effect of the silicon. In our case, however, the PV effect was neither observed in the double layer structures, nor in the SRO_{20}. So, no evidence is observed that PV effect is produced in the SRO bulk. Rather, it could be due to an induced PN junction in the silicon surface that already has been used as a photodetector [18]. The induced PN junction can be provoked by trapped charge in the SRO films.

As presented and discussed here the SRO by self respond to light increasing its conductivity. This fact has been also evidenced in different experimental results as mentioned in the introduction. In addition, it is well known that SRO has traps that can trap electrons. In [19] the densities of electronic states (traps) are calculated supposing that photoluminescence is due to the decay of electrons between donors and acceptors (DAD). Then, there is enough evidence to accept that light impinging on the traps release electros, and then the SRO could be used to build photovoltaic devices.

The main problem is how to separate the electric carriers to provide a photocurrent in the absence of an external electric field. Researcher have been try to solve this problem using thin film pn junctions, and built an internal electric field, [20]. However, it has not been achieved until now.

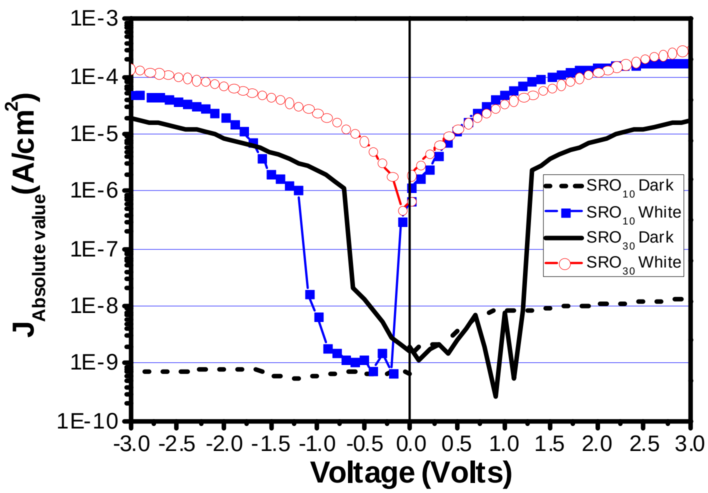

Figure 5. Detail of current density against voltage for Al/SRO/Si with Ro = 10 and 30, in dark and illuminated with white light.

5. Conclusión

We demonstrated that the photoconduction is possible in SRO thin films. High photoconduction between two horizontal contacts in Al/SRO/Al estructures was obtained under bias when UV and white light was used as an excitation source. Using an electronic barrier, the silicon substrate contribution to the current was eliminated, in this way the effect of photons is associated to the SRO. A model that explains the increase of photoconductivity was presented. A photovoltaic effect was also observed. However, the PV effect could be attributed to an induced PN junction.

Acknowledgments

This work has been partially supported by CONACyT. The authors thank Pablo Alarcón, Mauro Landa, Ignacio Juárez and Netzhualcoyotl Carlos for helping in the preparation of the samples.

6. References

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