Duality MOS–PN Junction in the Al/Silicon Rich Oxide/Si Structure as a Radiation Sensor

M. Aceves,* J. Carrillo, J. Carranza, W. Calleja, P. Rosales.
INAOE, Apdo. 51 Puebla, Puebla México 72000.

C. Falcony
CINVESTAV, Phys. D. Apdo 14-740 México D.F., México 07000.

In this work an experimental investigation on the possibilities of using the induced PN junction as a photon detector in the Al/SRO/Si devices is done. The devices were fabricated on high resistivity silicon substrates, the silicon rich oxide Ro used was 20. The experimental results show that this device is sensitive to visible light, and that is possible in a controlled and simple manner to use the PN induced junction as a detector.

PACS : 72.20.-i, 73.40.Qv, 85.60.Dw.

Keywords : Silicon Rich Oxide, Photodetectors, Induced Junction

1. Introduction

The off-stoichiometry silicon oxide, or silicon rich oxide (SRO) also known as semi-insulating polysilicon (SIPOS), is a two-phase material formed by silicon dioxide with excess silicon [1]. The excess silicon can be as high as 17% for SRO, and around 90% for SIPOS [2]. This material is normally obtained by Chemical Vapor Deposition (CVD) from silane and nitrous oxide as the reactive gases. In this method, the gas flow ratio Ro= $[N_2O]/[SiH_4]$ is used as a parameter that determines the silicon excess. Lately [3], SRO obtained by silicon implantation into silicon oxide has also been reported.

It has been already proposed that compared to a regular MOS structure [4 – 6], the devices obtained by deposition of SRO on silicon, and with a top electrode, show different properties depending on the characteristics of both materials. That is, the Al/SRO/Si device depends on the SRO silicon excess, Ro, and the type and impurity concentration of the silicon substrate. One of these behaviors is twofold, i.e., it has a dual comportment: as a capacitor and as a reverse biased PN junction.

In this paper, it is shown for the first time that the induced PN junction in the Al/SRO/Si can be used to detect visible light, and that the induced PN junction behaves similar to an implanted junction. Preliminary experimental results will be shown.

2. Experimental procedure

Sample preparation

SRO films with Ro = 20 were deposited on (100) N type Si-wafers with impurity concentration 10^{12} cm^{-3}. A hot wall Low Pressure Chemical Vapor Deposition system was used, and the reactive gases used were nitrous oxide and silane. The deposition temperature was 700 °C, and the pressure was 1.2 Torr. In order to have back contacts an N^+ implantation was performed. Al gate electrodes with area of $1.49x10^{-2}$ cm^2 were patterned on the SRO layer. Al was also evaporated for back contact. Finally the samples were sintered at 450 °C in forming gas. The SRO thickness was measured just after deposition using an ellipsometer Gaertner L117 with a 632.8 nm He–Ne laser. The average thickness was 95 nm.

Measurements

The samples were measured under two wavelengths 633 and 543 nm, the power was 12.2 and 0.8 mW respectively. The samples were edge illuminated because of the aluminum, and biased from 0 to –100 volts. The electrical current was measured as a function of the applied voltage, first in dark and then a laser beam was used to illuminate the sample. The sample was hand tilted to obtain the higher current at each wavelength. The I-V was measured using an electrometer Keithley 617 and a power supply Keithley 230. The I-V measurement systems were computer controlled. A two second step ramp voltage was applied for all I-V curves. The samples were first I-V tested in a wafer tester to check for low dark current. Then they were cut and mounted on a TO type package.

3. Results

Figure 1 shows that Al/SRO/Si device is light sensitive. In this figure the devices were on the silicon wafer. Note that the dark current is around 10^{-10} A (~ 3.3 x 10^{-8} A/cm^2). The data were taken when the ramp voltage 0 to –100 V was running. As can be seen in the figure the tester light was turned on shining the whole wafer, and then the 679 nm wavelength, 0.5 mW, laser pointer was shined on the sample.

The figure 2 shows device I–V characteristics in dark and under 633 and 543 nm radiation. As can be seen the current increases when the sample is illuminated. Note that the dark current degrades after the packaging process to ~10^{-6} A. The photocurrent under 633 nm light increases as a function of voltage to –100V, but when the device is illuminated by light of 543 nm wavelength the current remains constant after ~ -15 volts.

*: e-mail: maceves@inaoep.mx

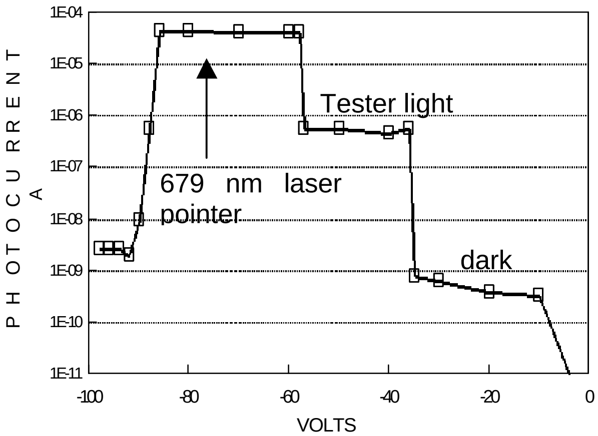

Figure 1. On wafer device photocurrent; in dark, illuminated by light from the tester lamp, and from a laser pointer.

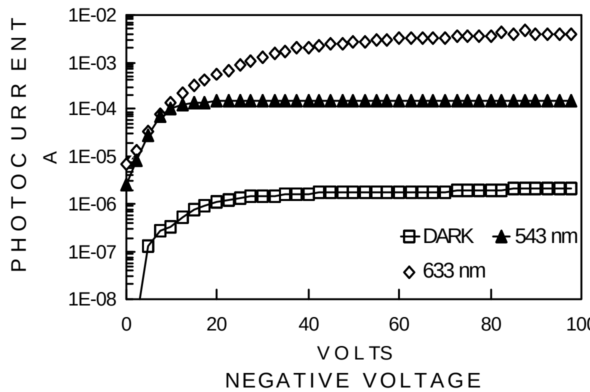

Figure 2. Packaged device Photocurrent versus Voltage in dark, and illuminated by 633 and 543 nm wavelength light.

4. Discussion

In [7] it was shown that leaky dielectrics in MIS capacitor produce non-equilibrium capacitor, and since then it was shown that they were sensitive to visible light. However, after that, many efforts have been made to use the induced PN junction in MIS structures in controlled manner. Among the need of more complicated structures, noisy corona discharge, and water electrodes, the MIS devices use very thin tunneling oxides that degrade or limit the current flow [8].

As it was already stated, using the adequate Ro in the SRO layer of the Al/SRO/Si device, it is possible to produce an induced PN junction and at the same time to have enough conductivity to allow the photocurrent to flow. In this way a “connection” is done to the induced PN junction. On our previous experience a layer of SRO Ro = 20 would have enough resistivity to allow the formation of an inversion layer, but would have enough conductivity to let the photocurrent to flow.

As in a silicon PIN photodiode, photons with shortest wavelength should be absorbed nearer to the surface than photons with longer wavelength [9]. As can be seen in Figure 2 in the Al/SRO/Si induced junction, the photocurrent for 543 nm remains constant after certain voltage, meaning that photons are absorbed near to the surface and then no voltage dependence is observed. That is not the case for 633 nm, neither is for the dark current.

In [10] it is proposed that in PIN photodiodes the current can be expressed as a function of the applied voltage when the generation current dominates. So, the linear relationship

$$J^2 = \frac{1.8*10^{-23}}{\tau^2}(\varphi_j + V_a) \quad (1)$$

is obtained, where J is the current density in A/cm^2, τ is the generation lifetime, φ_j is the built in voltage, and V_a is the applied voltage. Figures 3 and 4 are graphs of J^2 vs. V from our results. There is a tendency to a straight line following equation (1). This means, the photocurrent depends on the depletion layer width for both dark and 633 nm radiation, and the current is mainly generated in the depletion region. So the current is a generation current. Similar to our results with PIN diodes [10].

From the Figure 3, it is possible to estimate the τ and φ_j when no light is shining on the samples as 23 μs and 5.3 V, respectively. Note that φ_j has a higher value than a one side abrupt or linear PN junction. So, it is important to realize that in this device the φ_j does not have the same meaning that it has in a PN junction. In this case the MOS behavior and the SRO conductive characteristics have to be taken in consideration.

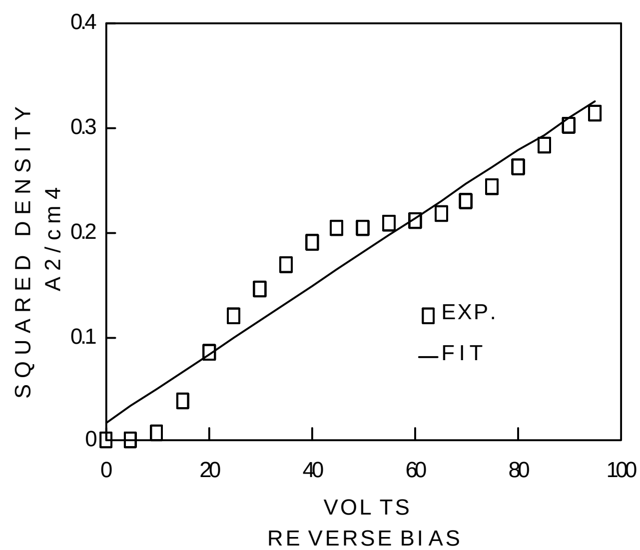

Figure 3. Al/SRO/Si device J^2 vs. V in dark

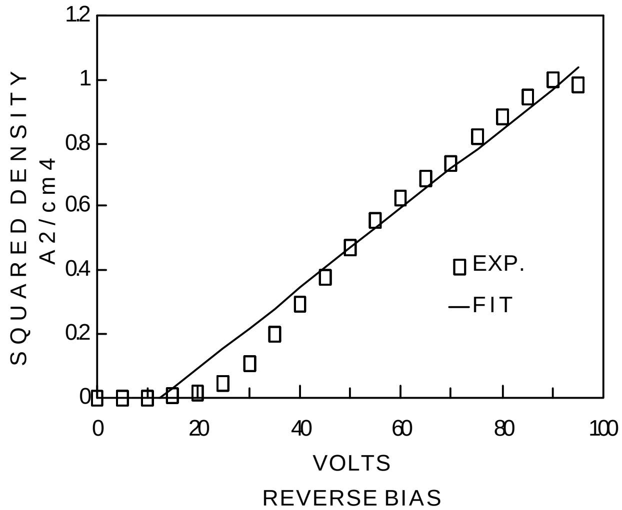

Figure 4. Al/SRO/Si Device J^2 vs. V under 633 nm wavelength light.

5. Conclusions

In this work, it has been shown that the induced PN junction obtained in the Al/SRO/Si when properly biased can be used to detect visible light similar to a PIN diode. It was shown that this junction photocurrent is dominated by generation in the depleted region in our devices. It is shown that using the proper Ro, the photocurrent can be driven through the SRO into the Aluminum electrode.

Acknowledgements.

The authors want to thanks to the technicians of the microelectronics laboratory for their help on the preparation and electrical measurements of the samples. Specially to Pablo Alarcón and Eliezer Jara. This project is supported by CONACyT.

References

[1] D. Dong, E. A. Irene, D. R. Young, J. Electrochem. Soc. **125**, 819 (1978).
[2] M. Hamasaki, T. Adachi, S. Wakayama, M. Kikuchi, J. Appl. Phys. **49**, 3987 (1978).
[3] A. Kalnitsky, A. R. Boothroyd, J. P. Ellul. Solid-State Electronics **33**, 893 (1990).
[4] M. Aceves, C. Falcony, A. Reynoso, W. Calleja, A. Torres. Solid-State Electronics **39**, 637 (1996).
[5] M. Aceves, C. Falcony, J. A. Reynoso, W. Calleja, R. Pérez. Material science in semiconductor processing **2** 173 (1999).
[6] M. Aceves, J. Pedraza, J. Apolinar Reynoso-Hernandez, C. Falcony, and W. Calleja. Microelectronics Journal **30** 855 (1999).
[7] F. H: Hielscher and H. M. Preier. Solid State Electronics **12**, 527 (1969).
[8] Booker R. Geist J. Appl. Optics **23**, 1940 (1984).
[9] See for example, Sheng S. Li “semiconductor physical electronics” pp 358 – 353. Plenum Press (1993).
[10] Pedro Rosales Quintero, “Fabricación de Sensores de Radiación de Alta Energía” Master Thesis, INAOE, Puebla, Pue. Mexico (1999).