Off Stoichiometric Silicon Oxide Applied to Enhance the Silicon Responsivity up to UV Region

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Abstract

Silicon Rich Oxide (SRO) is a material compatible with silicon integrated technology, besides it has photoluminescent properties. When SRO is illuminated with UV radiation emission in the range of 600 to 800 nm take place. This radiation has been applied to a silicon PN junction in order to expand the capabilities of silicon improving its detection properties. In this work a more precise characterization of a sensor made of silicon and SRO is done. The response of this sensor goes from 200 nm to standard Si detection range, and in the range of 200 to 400 nm it increases with the wavelength.

1. Introduction

As deposited off stoichiometric silicon oxide, or silicon rich oxide (SRO), is a many phases material, and after annealing a phase separation occurs. Depending on the silicon excess the phases separate in SiO_2, Si and silicon compounds or defects [1]. This phase separation produces different electrical and optical properties. For example, for silicon excess higher that 8 atomic % silicon nanocrystals are formed and high electrical conductivity is observed, however, poor photoemission is obtained. On the other hand, for silicon excess lower than 8 % high electric field is required to obtain electrical current, but high photoluminescence is obtained [2]. Also, implantation of Si atoms into SRO contributes to the photoemission. The silicon excess is normally controlled by the ratio, Ro, of gases used to obtain SRO by Low Pressure Chemical Vapor Deposition (LPCVD). Ro_3 ($Ro = 3$) has a silicon excess of around 17 % and $Ro > 100$ is stoichiometric. As observed a high emission between 600 and 900 nm is obtained when it is excited with UV radiation in the range of 200 to 350 nm. Another advantage of SRO is its compatibility with silicon IC integrated circuit processing, allowing an easy integration of SRO and Si devices and circuits.

On the other hand, silicon technology is nowadays the most used and economical way to produce electronic circuits and great efforts are done to extend its capabilities to invade application normally banned to it. Silicon PN junction are without any doubt the cheaper way to sense light. However, it is well known that silicon has a high responsivity in the range of 600 to 1000 nm, but it is very poor or negligible in the range of 200 to 400 nm.

UV emission is currently detected using high band gap semiconductors such as Gallium nitride [3]. However, in order to improve the silicon responsivity in the high energy region of the electromagnetic spectrum, the manufactures use special production techniques as for example to reduce the doping density in the surface so that the recombination velocity is reduced. However, a real improvement is not achieved. More complicated techniques, including the use of SiC and Si avalanche photodiodes and thinned CCDs coated with phosphor get moderately good results. The technological and economical price paid for the improvement is high, though [4, 5]. The use of Si nanocrystals is other form of extend the responsivity of silicon in the UV range of 200 to 300 nm [6]. However, UV silicon detector have disadvantages such as, not real improvement in the 200 to 400 nm range, high cost, high leakage current, lost of responsivity in the visible to infrared range, etc.

In a precedent paper, a UV Si sensor (UVSiS) that extends the detection of silicon up to 200 nm was presented [7] (patent pending). Then, to extend the silicon range of sensing, the red emission of SRO when excited with UV was used. In this way, silicon can extend its responsivity to detect also in the range from 200 to 400 nm.

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In the paper presented here new and more precise characterization of the sensor is shown. Furthermore, with the knowledge obtained, device optimization is proposed. Also, SRO photoluminescent characteristics are reviewed in order to understand the sensing properties of the device.

2. Experimental procedure

In order to study the photoluminescence of SRO implanted with Si, 550 nm of SRO was deposited on Si substrates, N type and 3 – 5 ohm cm resistivity. SRO with Ro = 10, 20 and 30 were deposited by LPCVD. SiH_4 and N_2O were used as the reactive gases. Then, all samples were Si implanted with a 2 x 10^{16} cm^{-2} doses, and energy of 150 KeV. After implantation the samples were annealed in N_2 at 1100 °C during different times from 0 to 360 minutes.

In order to obtain a Si sensor with extended range from 200 to 1000 nm a PN junction were computer simulated and then fabricated with an SRO layer on the top. The junction depth was four microns. The basic structure is shown in figure 1. No special care was taken to optimize the photoresponse in any range.

The photoluminescence measurements were done using a spectrofluorometer LS-50B with a Xenon lamp. The Lamp and the monochromator of the spectrofluorometer were used to illuminate the Si sensor in order to obtain the photoresponse. Current versus wavelength at constant reverse voltage were done under illumination and in dark. The current was measured with a voltage source/electrometer Keithly 517. Average optical power was measured using a radiometer IL1400. A commercial Si photodiode UV enhanced was used to compare our results.

3. Results

Figure 2 shows the typical emission of SRO implanted with silicon for two Ro’s. A 600 to 850 nm range emission is recurrently obtained for all samples after annealing. Figure 3 shows the emission peak as a function of the excitation wavelength. As can be observed the excitation energy varies from 200 to 400 nm, and then the silicon responsivity could be extended up to these wavelengths.

Figure 4 shows the current density of two of the sensor developed (UVSiS) and that of the commercial Si photodiode as a function of the wavelength. As seen a notable response is obtained in the UV region and in the visible region the response is similar to that of a silicon sensor.

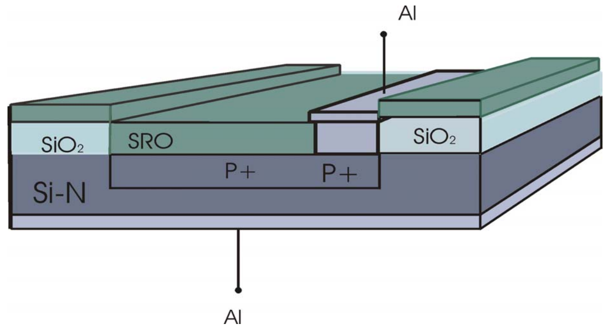

Figure 1. Basic sensor structure.

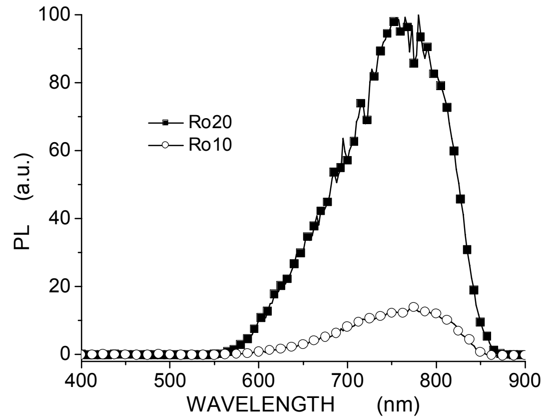

Figure 2. Photoluminescence of SRO implanted with $2x10^{16}$ cm^{-2} of silicon atoms and annealed at 1100 °C during 360 minutes.

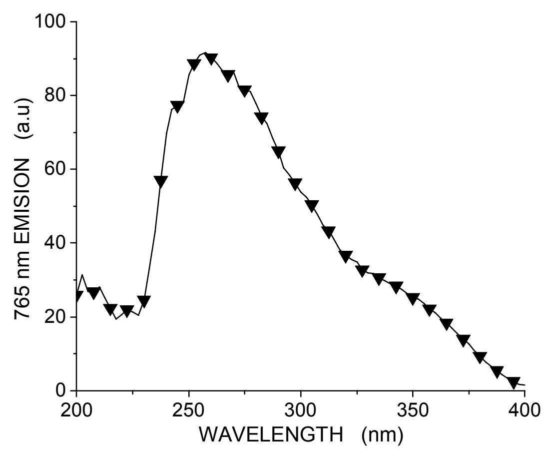

Figure 3. Emission peak intensity as a function of the excitation energy for SRO_{20} and $2x10^{16}$ cm^{-2} implantation doses, and annealed at 1100 °C during 360 minutes.

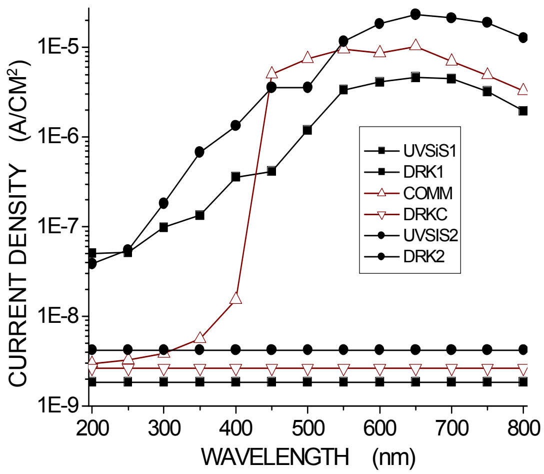

Figure 4. Current density as a function of the wavelength for UVSiS and commercial Si photodiode.

4. Discussion

Figure 5 shows the responsivity of UVSiS and that of the commercial photodiode. As expected, because of the current results, the UVSiS response is at least two orders of magnitude higher than that of the commercial photodiode in whole UV range, and comparable in the visible range. The response of the UVSiS was fitted by a linear relation, and it grows up in the whole UV range. This behavior is not expected because the emission has a maximum when excited at 250 nm. Then, it was expected that the responsivity to act similar to figure 3, and more investigation has to be done to understand this results.

Figure 6 shows the SRO emission spectrum and the typical photoresponse of Si. The emission take place from 600 to 800 nm and average responsivity in this range is taken as 0.5. On the other hand, from figure 5, an average responsivity of the UVSiS is $8x10^{-3}$, between 250 and 400 nm. Then, the ratio between average responsivities allows us estimate the conversion of UV energy into visible light as 1.6 %. It has to be clarified that the total conversion percent is bigger than that estimated. The conversion ratio only take into account the light that arrives to the surface of the silicon, but evidently much of the emitted light should be lost. Then there is a great opportunity of increase furthermore the UVSiS responsivity by designing structures that reduce the emitted light loses.

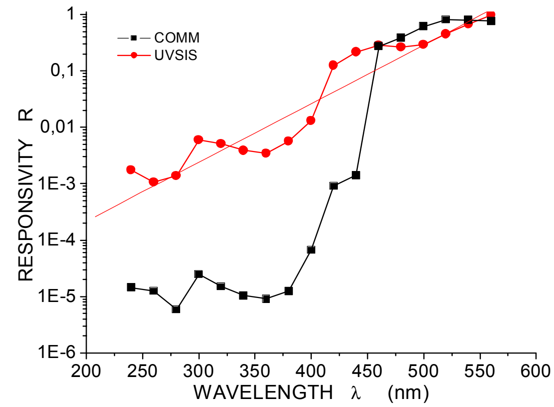

Figure 5. UVSiS and commercial photodiode response to the wavelength. UVSiS responsivity was fitted with $\lg R = 0.01\lambda - 5.74$.

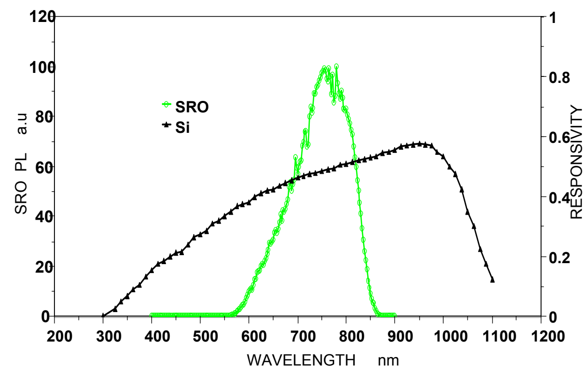

Figure 6. Typical Si responsivity compared with the SRO emission in function of the wavelength.

5. Conclusions

A review of the emission characteristics of SRO was made. This emission corresponds to the higher photosensitivity of silicon PN diodes. A Si structure made of Si and SRO that extend the range of Si detection was built and characterized. The responsivity of this sensor, UVSiS, was presented and show that it increases the UV response in the range from 200 to 400 nm compared with that of a commercial silicon photodetector. An interesting observed fact was that the responsivity increases as the wavelength increases in the range of 200 to 400 nm, then more work has to be done in order to understand this behavior. With the results obtained, the percent of UV light converted to visible light was estimated.

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