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Research Article

Study of optical sensors of the form Al/a-SiC:H/c-Si(n) with high sensitivity.

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Abstract

In the present work optical sensors of the form Al/a-SiC:H/c-Si(n), for different thickness of a-SiC:H thin films are studied. More specifically, a-SiC:H thin films were deposited by rf sputtering technique on c-Si(n) substrates for different thickness of the amorphous semiconductor and, subsequently, the samples were annealed in the temperature range from 300°C up to 675 °C. Experimental measurements of the optical response of these sensors showed that for thicknesses of a-SiC:H greater than a critical value, which depends on annealing temperature, a mechanism of losses is appeared in the region of wavelengths from 525nm up to 625nm. This behaviour is attributed to the recombination of photo-generated electrons-hole pairs in the neutral region of a-SiC:H, when this exceeds the diffusion length of minority carries, L_p. Also, the value of the reverse bias voltage appears to influence considerably the optical response of these sensors when $d > L_p$ in the case where the a-SiC: H thin films were annealed at 600°C.

Keywords: Thermal annealing, Optical Sensors, Heterojunctions

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1. Introduction

During the last thirty years a-SiC:H thin films present increasing interest in many applications of microelectronic elements, such as LED [1], thyristor [2], sensor of gases [3], photovoltaic elements [4,5] and photosensors [6-8]. The main reason of this interest is due to the fact that a-SiC:H presents very attractive properties (thermal and chemical stability, high resistance in radiations, high values of hardness and considerable absorption in the blue region of the visible spectrum). Depending on the preparation technique or on deposition conditions the properties of a-SiC:H can be modified so that a suitable combination that requires each application can be achieved. The high absorption in the blue region of the visible spectrum is very attractive for manufacturing optical sensors using a-SiC:H.
Even though the optimization of such optical sensors has been mainly focused on the improvement of optoelectronic properties of a-SiC:H thin films by using different preparation technique or by changing deposition conditions [8-12], very few works studied further quality improvement of a-SiC:H by thermal annealing [13,14]. On the other hand, although a-SiC:H is an interesting material for photosensing applications in the low wavelength and UV range of the spectrum, very few works have been published on the optoelectronic properties of Metal/a-SiC:H Schottky diodes [8,15]. Consequently, it is important to study the effect of the annealing process of a-SiC:H thin films on the optoelectronic properties of Al/a-SiC:H/c-Si(n) Schottky diodes.

The aim of the present work is to study optical sensors of the form Al/a-SiC:H/c-Si(n) with different thickness of the amorphous material, d, by means of thermal annealing of the a-SiC:H thin films. The experimental results of optical response of these structures have shown high and constant values of quantum efficiency over the wave length from 500nm up to 850 nm, for the case that the a-SiC:H has been annealed at 600°C and its thickness is less than the diffusion length of minority carriers in a-SiC:H, L_p. On the contrary, in the case that $d > L_p$ a loss mechanism in the region from 525nm up to 625 nm is presented.

2. Fabrication of Al/A-SiC:H/c-Si(n) structures.

A-SiC:H thin films were deposited by r.f. sputtering on n-type c-Si (ρ=5-10Ωcm) substrates. The target used was poly-SiC of constant composition (C 66 wt% and Si 34 wt%) and of 99.8% purity. The r.f. power was 250W and the target to substrate distance was 5.5 cm. The substrate temperature (T_s) was 120°C and the sputtering chamber was evacuated to a pressure lower than $5x10^{-7}$ Torr, before the introduction of argon. During the deposition, the flow rate of argon and hydrogen was 20 sccm, and the pressure in the sputtering chamber was $5x10^{-3}$ Torr. The film thickness was varied from 2.500 Å up to 10.000 Å. From a previous work it has been found that under these deposition conditions an optimum of electrical and optical properties of a-SiC:H is achieved [7].

The as deposited a-SiC:H films were annealed in the temperature range from 300°C to 675°C for 1 hour. At each temperature the samples were encapsulated in quartz tubes, which were evacuated down to a pressure 10^{-5} Torr. The

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annealing process was terminated at 675°C because for higher T_a complete degradation of the properties of the Al/a-SiC:H Schottky diodes is observed, as it has been reported in a previous work [8]. Afterwards the annealing process, ohmic contacts were formed by evaporating Al on the back side of c-Si(n), and the samples were carefully cleaned [7]. Sequentially, the above samples were placed in a high vacuum evaporator (pressure lower than $2x10^{-6}$ Torr), where aluminum dots (1mm in diameter) are deposited on the amorphous thin films forming the Al/a-SiC:H Schottky diodes. Figure 1(a) shows the typical structure of the Al/a-SiC:H/c-Si(n) structure used in the present work. It is important to note that the a-SC:H/c-Si(n) junction is isotype with lower potential barrier in comparison with that of A/a-SiC:H Schottky junction, so that the electrical behavior of the whole structure Al/a-SiC:H/c-Si(n) is determined by the Schottky one. However, the optical study of these structures showed the existence of both junctions, since both of them affect their optical response. In order to study the spectral response of the Al/a-SiC:H Schottky diode, the Al electrode on the amorphous thin film had the shape shown in Figure 1(b). The Al electrode on the amorphous thin film had the shape shown in Fig. 1(b). The metal film in the center of the circular disc was very thin (≤20 Å), in order to be transparent to the incident light, whereas at its circumference it was much thicker (about 4,000 Å) to allow for the connection of electrodes. The process used in order to be achieved this form of Figure 1(b) is described in a previous work [8]. Finally, the optical response measurements of the Al/a-SiC:H/c-Si(n) structures were carried out in the range from 350nm up to 1000nm, using chopped light with a frequency of 100Hz and under conditions of reverse bias voltage.

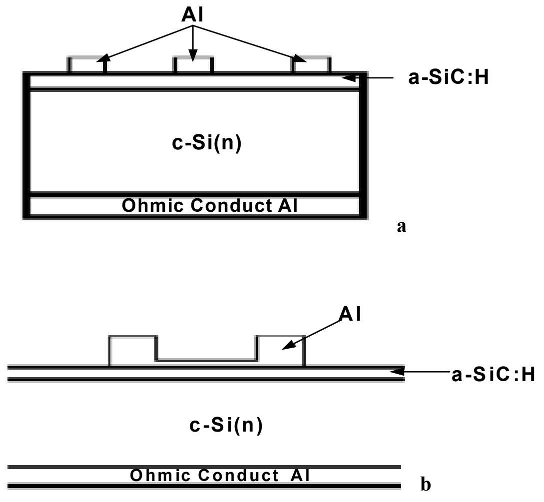

Fig.1 (a) Typical form of the Al/a-SiC:H/c-Si(n) structures.**(b)** Typical form used for the measurement of the spectral response of the Al/a-SiC:H/c-Si(n) structures.

3. Experimental Results and Discussion.

From previous reseach works it has been concluded that the thermal annealing process of a-SiC:H thin films causes a gradual improvement of their properties as T_a increases from 400°C up to 600°C, with the optimum result to be achieved at 600°C. For further increase of T_a it has been observed rapid degradation of their properties, due to hydrogen evolution from the amorphous network [15].

In figures 2 (a) and 2 (b) the optical response of the Al/a-SiC:H/c-Si(n) structures for different thicknesses of the amorphous semiconductor and for two different annealing temperatures 400°C and 600°C, respectively, is presented. As it is shown in these figures, when d is relatively small, which depends on T_a, the quantum efficiency of these structures presents two maximum values one in the range of wavelengths from 525nm up to 600nm and the other at λ=850nm. These maxima are attributed to the Al/a-SiC:H and a-SiC:H/c-Si(n) junctions, respectively, and their position is determined by the optical energy gap of the a-SiC: H and c-Si, in which becomes the absorption, according to the relation [8]:

$$\lambda = \left(\frac{1.24}{\mathbf{E_g}} \right) \ \mu\mathbf{m} \qquad (1)$$

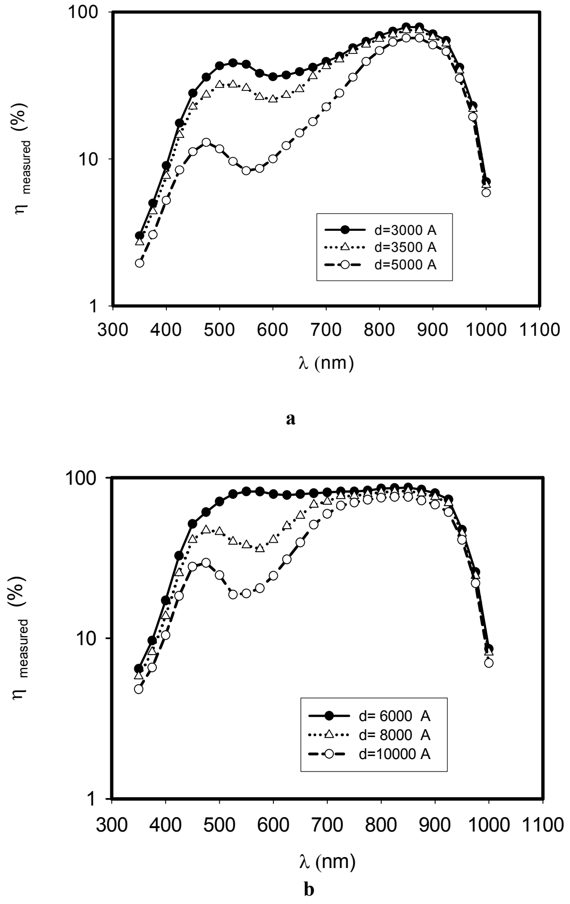

Fig. 2 Measured quantum efficiency, ηmeasured, of the Al/a-SiC:H/c-Si(n) structures as a function of the wavelength, λ, for different thickness of a-SiC:H, d, and for annealing temperature, Ta, **(a)** 400°C και **(b)** 600°C.

Taking into account previous works [7,8], after illuminating the structure Al/a-SiC:H/c-Si(n)/Al from the side of the Al/a-SiC:H junction, the high energy photons are absorbed near the surface of the a-SiC:H, resulting in the generation of electron-hole pairs which cross the depletion region (electron and holes moving in opposite directions) of the Schottky junction and are collected. As the wavelength increases, the a-SiC:H gradually becomes more and more transparent and the main region where absorption of photons takes place, is shifted towards to the a-SiC:H/c-Si(n) junction, where the photogenerated carriers are collected. Consequently, the measured quantum efficiency, $\boldsymbol{\eta}_{\text{measured}}$, is the total result of the spectral response of both junctions, Al/a-SiC:H **,** $\boldsymbol{\eta}_1$, and a-SiC:H/c-S(n), $\boldsymbol{\eta}_2$:

$$\eta_{\text{measured}} = \eta_1 + \eta_2 \qquad (2)$$

Taking into account the spectra of optical absorption of semiconductors and the fact that the a-SiC:H/c-S(n) junction is one sided [7], it is concluded that the measured quantum efficiency, η_{measured} , in the range of wavelength from 350nm up to 600nm is mainly due to the Al/a-SiC:H junction ($\eta_{\text{measured}} = \eta_1$), whereas in the range from 700nm up to 1000nm is mainly due to the a-SiC:H/c-Si(n) isotype heterojunction.

Also, as it is shown in figure 2 (b), when d is greater than >8000 Å a loss mechanism is presented in the region of wavelengths from 525nm up to 625nm, and becomes more intense with further increase of d. This behavior of quantum efficiency is attributed to the fact that as d increases and exceeds the diffusion length of minority carriers (holes), the photogenerated ones disappeared by recombination, before they reach the depletion region of either of the above two junctions. According to this analysis it is observed that the loss mechanism will be presented when:

$$d \geq L_p + w_s + w_h \qquad (3)$$

where w_s , w_h are the widths of depletion region of Al/a-SiC:H Schottky junction and of a-SiC:H/c-Si(n) isotype heterojunction in a-SiC:H, respectively. Taking into consideration that the a-SiC:H/c-Si(n) heterojunction is one sided, since the active density of localized gap states in a-SiC:H for T_a=600°C is two orders of magnitude greater than c-Si(n) substrate [13], it can be concluded that $w_h \to 0$. Also, the magnitude of w_s can be estimated from the relation:

$$w_s = \left(\frac{2\varepsilon\varepsilon_o}{qN_d}(V_{bi} - V)\right)^{1/2} \qquad (4)$$

where ε is the dielectric constant of a-SiC:H (a reasonable value is 10 [16]), ε_o is the free space permittivity, N_d , is the active density of localized gap states in a-SiC:H in a-SiC:H, V_{bi} is the diffusion potential of the junction ($\cong$ 0.7V) and the V is the bias voltage. According to these it has been calculated that w_s= 200 Å. From the experimental results it has been found that the critical thickness, in which the loss mechanism is presented, is d=7500 Å, and using the relation (3) it has been observed the value of L_p=7300 Å. This value is very close to 7450 Å, that has been determined in a previous work [8], using different methodology.

From Figure 2(a) it is clear that the critical value where the loss mechanism takes place is about 3500Å, suggesting also lower value for L_p for this case in comparison for the one of T_a=600°C. This result would be expected, since the optoelectronic properties of a-SiC:H for T_a=600°C are superior than that of T_a=400°C [13]. Using the above methodology, it has been observed that L_p=3340 Å, a value that appears to be very close to that found in a previous work (3350 Å) [8].

Figure 3 shows the optical response of Al/a-SiC:H/c-Si(n) structures for T_a=600°C, d>7500 Å and for two different values of reverse bias voltage (V=-2V and V=-0,2V). As it is obvious from this figure, the optical response shows qualitatively the same dependence on the wavelength presenting two maxima, one at 500nm and the other at 850 nm. However, the loss mechanism declines as the reverse bias voltage increases. Also, it is observed elevation of the first maximum with the increase of the reverse bias voltage. This behavior can be attributed to the increase of the width of depletion region of the Schottky junction, leading to the decrease of the neutral region in the a-SiC:H.

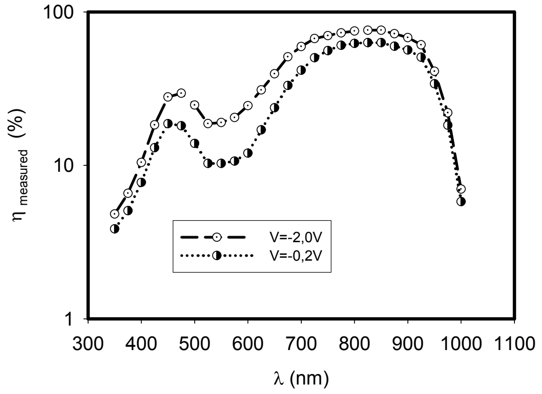

Fig. 3 The measured quantum efficiency of the Al/a-SiC:H/c-Si(n) structures as a function of wavelength, λ, for two different reverse bias voltage, (d=10.000Å , Ta= 600°C).

4. Conclusions

In the present work the effect of thickness of amorphous semiconductor on the sensitivity of optical sensors of form Al/a-SiC:H/c-Si (n), for different annealing temperatures has been studied. The experimental results showed that:

a) The dependence of quantum efficiency of the Al/a-SiC:H/c-Si(n) structures on wavelength shows two maximum values, one at 525nm and the other 850nm up to a critical value of d (d≤ L_p). For higher values of d, a mechanism of losses is presented in the region of wavelengths from 525nm up to 625nm, which is attributed to the loss of photogenerated carriers by recombination, before they reach the depletion region of either of the above two junctions. For further increases of d, the loss mechanism becomes more intense.

b) Taking into account the critical value of d, where the loss mechanism takes place, the diffusion length of minority carriers has been calculated for the case of T_a =400°C and 600°C. The calculated values are very close to that have been found in previous work using different methodology.

c) For the case of T_a=600°C, as the reverse bias voltage of the Al/a-SiC:H/c-Si(n) structures for T_a =600°C increases, the loss mechanism in the range of wavelengths from 525nm up to 625nm declines, which can be attributed to the decrease of the neutral region in the a-SiC:H.

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References

1. S.B. Patil, A.A. Kumbhar, S. Saraswat, R.O. Dusane, (2003) “Preliminary results on a-SiC:H based thin film light emitting diode by hot wire CVD”, Thin Solid Films 430, p.257.
2. E. Dimitriades, N. Georgoulas, and A. Thanailakis, (1992) “New a-SiC Optically Controlled Thyristor like Switch” Electronics Lett.28, p.1622.
3. A. Baranzahi, A. L. Spetz, P. Tobias, I. Lundstroem, P. Martensson, M. Glavmo, A. Goeras, J. Nytomt, P. Salomonsson, H. Larsson, (1997) Fast responding air/fuel sensor for individual cylinder combustion monitoring, SAE Technical Paper Series 972940, Combustion and Emission Formation in SI Engines (SP-1300), p. 231–240 .
4. A. Catalano, J. Newton, and A. Rothwarf, (1990), “a-SiC:H Alloy for Multifunction Solar Cells”, IEEE Transactions on Electron Devices, 37 (2), p.391.
5. P. Louro, M. Fernandes, A. Fantoni, G. Lavareda, C. Nunes de Carvalho, R.S. Schwazz, M. Vieira, (2006) “An amorphous SiC/Si image photodedector with voltage – selectable spectral response”, Thin Solid Films 511-512, p.167.
6. M. Vieira , M. Fernandes, P. Louro, A. Fantoni, G. Lavareda, C. Nunes de Carvalho, Y.Vygranenko, (2005), “A two terminal optical signal and processing p-i-n/p-i-n image and colour sensor”, Sensor and Actuators A, 123-124, p.331.
7. L. Magafas (2003), “Optical Response Study of the Al/a-SiC:H Schottky Diode for Different Substrate Temperatures of the RF Sputtered a-SiC:H Thin Films.” Active and Passive Electronic Components 26(2), p.63.
8. L. Magafas, J. Kalomiros (2007), “Optimization of Al/a-SiC:H optical sensor device by means of thermal annealing”, Microelectronics Journal, 38, p.1196.
9. L. Magafas, N. Georgoulas, D. Girginoudi and A. Thanailakis, 1991, "The Dependence of Electrical and Optical Properties of RF Sputtered Amorphous Silicon-Carbon Thin Films on Substrate Temperature and Hydrogen Flow Rate", Physica Status Solidi (a), 126, p.143 .
10. L. Wang, J. Xu, T. Ma, W. Li, X. Huang and K. Cher, (1999) “The influence of the growth conditions on the structural and optical properties of hydrogenated amorphous silicon carbide thin films” Journal of Alloys and Compounds, 1-2 , p.273.
11. L. Battezati, F. Demichelis, C.F. Pirri, A. Tagliaferro and E. Tresso. (1991), Investigation on Structural Changes in Amorphous Tetrahedral Alloy by means of Differential Scanning Calorimetry”, J.Non-Crystalline Solids. 137&138, p.87.
12. J. Bullot and H.P. Schmidt (1987), ″Physics of Amorphous Silicon-Carbon Alloys″, Phys. Stat. Sol.(b) 143 p345.
13. L. Magafas, D. Bandekas, A.K. Boglou and A.N. Anagnostopoloulos (2007), “Optimization Electrical Properties of Annealed a-SiC:H Thin Films”, Journal of Non Crystalline Solids, 353, p.1065.
14. L. Magafas, K. Mertzanidis, D. Bandekas, N. Athanasiades (2007), “Thermal annealing effects on the optical and electrical properties of a-SiC:H thin films sputtered at different hydrogen flow rates”, Journal of Optoelectronics and Advanced Materials, 9, p.2030.
15. L. Magafas, J. Kalomiros, D. Bandekas and G. Tsirigotis (2006), “Optimization of the electrical Properties of Al/a-SiC:H Schottky diodes by means of thermal annealing of a-SiC:H thin films” Microelectronics Journal 37, 1352.
16. D. Brassard and M.A. El Khakani (2003), “Dielectric Properties of Amorphous Hydrogenated Silicon Carbide Thin Films grown by Plasma-enhanched Chemical Vapor Deposition”. Journal, of Applied Physics 93 (7), p.4066.