IRAQI JOURNAL OF APPLIED PHYSICS
المجلة العراقية للفيزياء التطبيقية

Iraqi J. of Appl. Phys., Vol.1, No.1, 2005, 11-14

Optical Response Characterization of In_2O_3/c-Si Prepared by Spray Pyrolysis

Raid A. Ismail [(1)]
Omar A. A. Sultan [(2)]

(1) School of Applied Sciences, University of Technology, Baghdad, IRAQ
raidismail@yahoo.com

(2) NASSR State Company, Ministry of Industry and Minerals, Baghdad, IRAQ
omarsatar2003@yahoo.com

In_2O_3 thin films have been deposited on silicon substrate by chemical spray pyrolysis. These films show high transparency in the visible and near-IR regions. Photoresponse of In_2O_3/c-Si isotype heterojunction detector without post-deposition heat treatment has been investigated in the visible and near infrared regions. Peak response situated at 600nm was observed. External quantum efficiency was 32% at peak response. C-V measurement revealed that the junction was abrupt type and built-in potential around 1 V has been obtained.

Keywords: *Thin Film Heterojunction, Chemical Spray Pyrolysis, Indium Oxide, Silicon-Base Devices*

Received: 30 July 2004, Revised: 24 October 2004, Accepted: 1 November 2004

1. Introduction

The deposition and processing of wide-band gap transparent conductive oxides (TCO's) heterojunctions have become the topic of many recent investigations for next generation of very large area solar cells [1-5]. One of the most important materials of TCO's is indium oxide (In_2O_3). In_2O_3 is a wide-band gap (3.6eV) semiconductor with n-type conductivity. It has a higher value of mobility for free carriers and thus shows better results than those obtained with some other TCO's[6]. Several deposition techniques have been employed for the growth of polycrystalline In_2O_3 films [7]. One of the promising techniques is the chemical spray pyrolysis (CSP) [8]. This technique is low-cost, simple, and reliable. In this technique, high efficient solar cells have been made [9-12]. Recheva *et al.* [13] showed that In_2O_3:(Sn,Te)/n-Si heterojunction position sensitive photodetector (PSP) has good linearity characteristics. In this paper, we report our experimental results on optoelectronics properties of In_2O_3/n-Si heterojunction made by CSP technique. These results are compared with the conventional p-n junction silicon photodiode.

2. Experiment

The starting material used in the present investigation is single crystalline n-type silicon wafers with orientation of (111) and resistivity of 1-3 Ω.cm. They were preliminary cleaned by boiling alcohol and then dried and then etched with dilute HF acid to remove native oxide. The heterojunctions were prepared by spraying 0.4M of an aqueous solution of $InCl_3$ onto mirror-like silicon and glass substrates heated and maintained at 400°C. In_2O_3 thin film formation can be explained by the following chemical reaction:

$$2InCl_3 + 3H_2O \rightarrow In_2O_3 + 6HCl \quad (1)$$

The experimental set-up of CSP system is presented in Figure (1). The thickness of polycrystalline In_2O_3 film measured by gravimetric method (weighing the substrate before and after film deposition) was about 200nm.

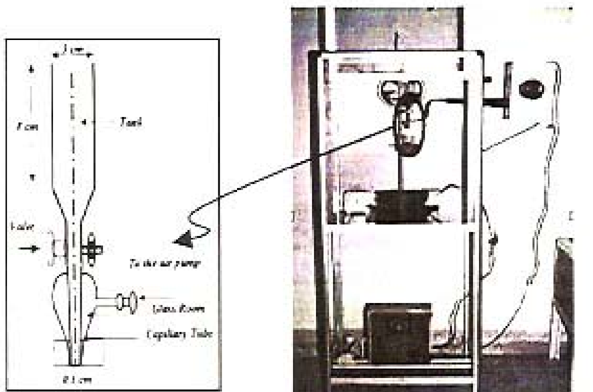

Fig. (1): Experimental Set-up of Spraying Apparatus (Right), and Layout of Enlarged Spraying Glass Nozzle (Left)

The transmittance of the film that deposited on glass substrate was estimated by using spectrophotometer (λ-9) in the range 400-1300nm. Seebeck measurements have been used to investigate the electrical conductivity type of In_2O_3 films. Ag electrode was deposited on

ISSN 1813-2065 Printed in IRAQ

In_2O_3 film and Al electrode was deposited onto the back surface of Si substrate through suitable mask with 450nm thick, using thermal resistive technique. The structure of heterojunction photodetector is shown in Figure (2). The sensitive area of the detector was around $25mm^2$. The spectral responsivity at zero bias was measured using monochromator in the range 450-1100nm. The electrical characteristics of the heterojunctions were examined using C-V measurements at frequency of 0.5MHz. Diode laser with wavelength of 904nm and pulse duration of 100ns (FWHM) was used to measure the rise time of photodetector. Storage CRO (100MHz band width) was used to estimate rise time of photodetector.

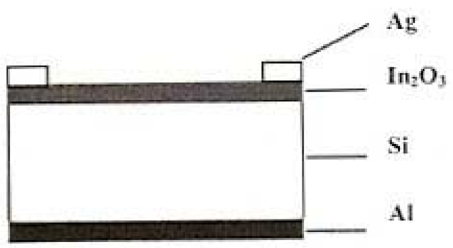

Fig. (2): Cross-sectional view of heterojunction

3. Results And Discussion

Figure (3) presents the transmittance of In_2O_3 films (200nm thick) in the spectral range 450-1000nm. It is obvious that the film exhibits average transparency around 80%, this property acts as window effect for visible and near-IR regions. This property is suitable for silicon photodetector fabrication.

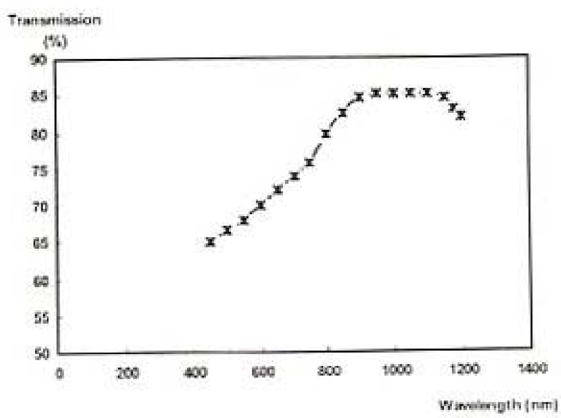

Fig. (3): Transmittance against wavelength curve

The film thickness selected here to exhibits high figure of merit (high T/R) where R is electrical sheet resistance.

Seebeck results showed that conductivity type of In_2O_3 layer was n-type, therefore, isotype heterojunction was formed.

Current-voltage curve (shown in Figure (4)) demonstrates good rectifying behavior, e.g. (rectification factor is about 1250 at 1Volt bias voltage). No soft breakdown is observed in this junction. The I-V under illumination with white light ($150mW/cm^2$) shows good response and no saturation has been observed.

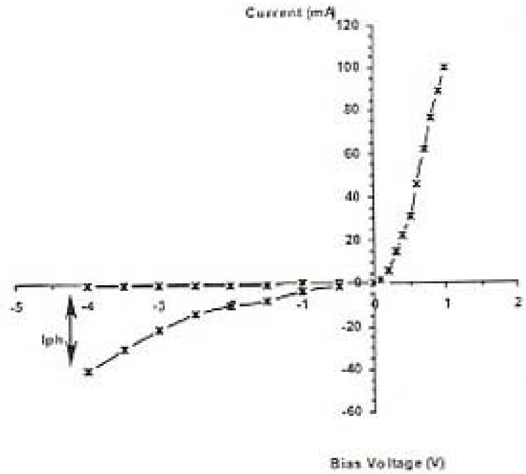

Fig. (4): I-V characteristics in forward and reverse bias under dark and illumination conditions

C-V curve of the isotype heterojunction was shown in Figure (5). This plot confirms that the junction was abrupt type and in good agreement with the standard theory of emission model developed by Anderson [14]. Since the band bending is primarily on the Si side, the C^{-2}-V intercept (not shown here after taking into account the surface capacitance C_o) of 1V on x-axis is essentially equal to the diffusion potential within the Si.

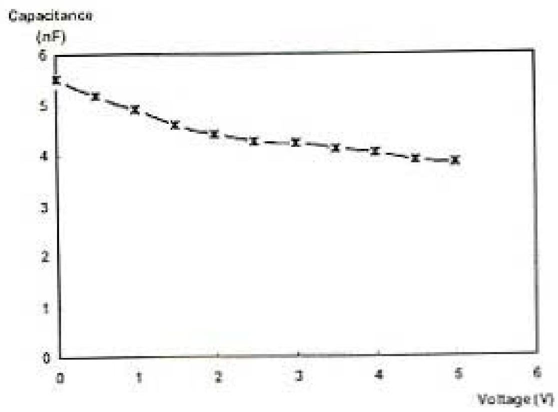

Fig. (5): Capacitance vs. reverse voltage curve

Figure (6) reveals the spectral responsivity plot of hetero-photodiode. It is obvious that the peak response was at 600nm, this is because the band gap of In_2O_3 layer. In contrary to the conventional Si p-n junction photodiode that has peak response at 900±50nm. The shape of responsivity at the low wavelength region depends on the surface condition. Photons of these wavelengths are absorbed at the vicinity of the surface, where they generate charge carrier pairs, which may recombine, before they reach the junction. The recombination reduces carrier availability and consequently the responsivity [15]. On the other hand, it is evident from Figure (5) the responsivity curve has fall-off steeper for short wavelengths than long wavelengths region. For short wavelengths, this effect can be attributed to the parasitic light absorption in the In_2O_3 (via band-to-band transition) [16].

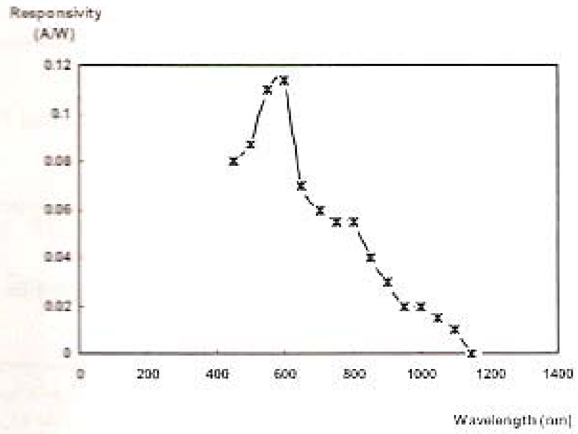

Fig. (6): Spectral responsivity for In_2O_3/c-Si diode

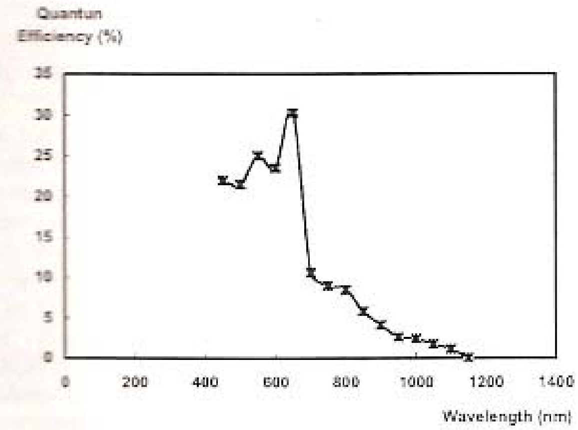

Fig. (7): EQE against wavelength

The external quantum efficiency (EQE) curve is presented in Figure (7). Its maximum value is small in comparison with silicon homojunction and other types of heterojunctions; this is probably due to the interfacial states arises from the defects accompanied the high lattice mismatch between In_2O_3 and Si (about 60%, arising from cubic structure of In_2O_3). The performance of photodiode under specific operating conditions is defined in terms of certain figures of merit. The most important figure of merit is specific spectral detectivity (D). The expression for D of a heterojunction photodiode is given by:

$$D = \frac{\eta\lambda}{2hc}\left(\frac{qA}{I_S}\right)^{1/2} \qquad (2)$$

where I_S is saturation current (600nA), A is sensitive area of photodiode, q is electron charge, h is Plank's constant, and c is speed of light.

Figure (8) shows the dependence of D (calculated from equation 1) on the wavelength at 300K. Maximum value of D is comparable to that for diffused silicon.

Time analysis result shows that the rise time of this photodetector is around 50ns and the fall time is longer than 50ns. No significant change in the photodetector main parameters was observed when operating temperature was raised to 60°C, indicating good thermal stability characteristics.

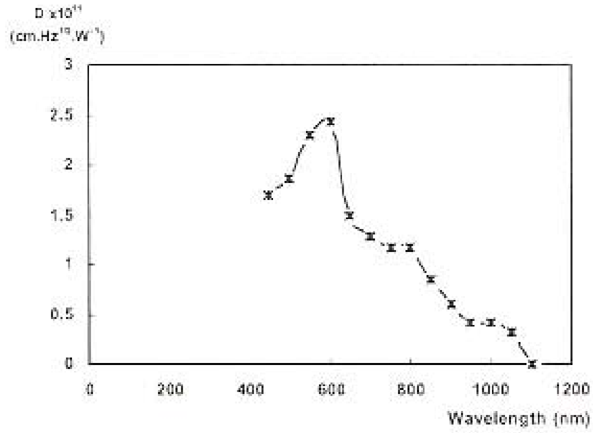

Fig. (8): Specific detectivity as a function of wavelength

4. Conclusions

We have studied elementary characteristics of In_2O_3/Si heterojunction photodiode to provide an economical visible-enhanced photodetector in contrast to silicon homojunction photodiode. The sensitivity to the red line is interpreted to the avoidance of interfacial reactions. These results demonstrate that the In_2O_3/Si heterojunction is a technologically attractive hetero-pairing for the creation of photodiodes applicable in the visible spectral range. Optimization of photodetector performance by controlling the deposition condition of In_2O_3 film is underway.

References

[1] H. Kobayashi et al., *J. Appl. Phys.*, 69, 1736 (1991).
[2] H. Kobayashi et al., *J. Appl. Phys.*, 74, 4756 (1993).
[3] T. Ishida et al., *J. Electrochem. Soc.*, 141, 1357 (1994).
[4] H. Kobayashi etal., *J. Appl. Phys.*, 81, 7630 (1997).
[5] D. Song et al., *17 European PV Conference*. Munich, 2001, p.1.
[6] A. Rasa, P. Agnihotry, B. Gupta, *J. Phys. D: Appl. Phys.*, 10, 1871 (1977).
[7] G. Kiriakidis etal., *Mater. Phys.*, 1, 83 (2000).

[8] S. M. Rozati, M. A. Zanjanch, R. Ghanbarzadeh, World Renewable Energy Congress 7, 29 June-5 July, 2002, Cologne/ Germany.

[9] T. Feng, K. Ghosh, C. Fishman, *Appl. Phys. Lett.*, 35, 266 (1979).

[10] F. Garcra and J. Momuci, *Thin Solid Films*, 97, 47 (1982).

[11] A. Phavdwaj et al., *Solar Cells*, 5, 305 (1982).

[12] R. A. Ismail, A. Alsamar'ai, O. A. Sultan, *J. Eng. Technol.*, 20, 486 (2001).

[13] T. Resheva, V. Vassilev and M. Nanova, *Proc. 12th Conference on Photodetectors*, Bulgaria, 1986, p.275.

[14] R. Anderson, *Solid State Electron.*, 5, 341 (1962).

[15] W. Budde, "**Optical Radiation Measurements**", Academic Press (New York), p.240.

[16] Korzo and Ryabova, *Sov. Phys. Solid States*, 9, 745 (1967).

This article was reviewed at Bulgarian Academy of Science, Bulgaria, University of Hanover, Germany and The University of Technology, Baghdad 35010, Iraq

تحضير ودراسة خصائص المفرق In_2O_3/c-Si المصنع بطريقة الرش الكيميائي الحراري

تم ترسيب غشاء In_2O_3 على قاعدة سليكونية بطريقة الرش الكيميائي الحراري. أظهرت هذه الأغشية نفاذية عالية في المنطقتين المرئية وتحت الحمراء القريبة. جرى دراسة الاستجابية الطيفية للثنائي الضوئي المتجانس In_2O_3/Si في المنطقتين المرئية وتحت الحمراء القريبة وبدون إجراء أي تعاملات حرارية بعد التحضير. لقد لوحظ أن قمة الاستجابة تقع عند الطول الموجي 600nm. لقد بلغت الكفاءة الكمية الخارجية عند قمة الاستجابة 32%. كشفت قياسات سعة-جهد أن المفرق من النوع الحاد وإن جهد البناء الداخلي لهذا المفرق حوالي 1eV.