مجلة كلية التربية الاساسية
كلية التربية الاساسية – الجامعة المستنصرية
Journal of the College of Basic Education Vol.30 (NO. 126) 2024, pp. 104-115

High Sensitivity Of Nanocrystalline SnO_2-Y_2O_3 Thin Films Based UV-Detector Prepared Using Chemical Bath Deposition

Imad H. Kadhim *(1)
Ministry of Education,
Baghdad, Iraq
imad.usm.iq@gmail.com

Nabil. M. Abd-Alghafour (2)
Iraqi Ministry of Education, Al-Anbar, Biophysics Department,
College of Applied Science,
University Of Anbar
nabeel.ma@uoanbar.edu.iq

Abstract:
Nanocrystalline Tin dioxide - Yttrium oxide (NC SnO_2-Y_2O_3) thin film was effectively created by employing the chemical bath deposition approach on SiO_2/Si substrates. X-ray diffraction, field emission scanning electron microscopy [FESEM], and energy-dispersive X-ray spectroscopy were used to analyze the structural and the surface morphology of the annealed sample at 500°C for two hours in air. When annealed at 500°C, the SnO_2-Y_2O_3 film crystallized was accomplished with a tetragonal rutile structure. The nanocrystalline SnO_2 thin film was effectively employed as a UV photodetector device (UV PDs). A UV photo detector based on nanocrystalline SnO_2-Y_2O_3 film showed 2988% sensitivity when exposed to a 360 nm wavelength (6 mW/cm^2) at an applied voltage of 3 V. In contrast, the responsivity value was 3.247 A/W. The rise and full times were determined by calculating to be 0.663 s and 0.436 s, respectively. The excellent performance of the device could be correlated with high surface-to-volume proportions including its elevated crystal performance. Given its outstanding stability and reliability, the nanocrystalline SnO_2-Y_2O_3 thin film sensor is the optimum option for commercially photo-electronic applications.
Keywords: SnO_2-Y_2O_3; Tetragonal rutile structure; (UV PDs); Sensitivity.

Introduction:

Tin dioxide (SnO_2) material is a notable and significant n-type semiconductor for use in gas sensors [1, 2], in addition UV photodetectors (UV PDs) applications [3]. SnO_2, a metal oxide, has garnered energy gap of 3.6 eV and wave length exceeding 0.4 µm [4, 5]. Because of these unique properties it has been used in photodetectors applications.

Yttrium oxide (Y_2O_3), possessing a cubic symmetry, is a crucial oxide utilized in infrared ceramic applications. Polycrystalline Y_2O_3 could show superplastic behavior above 1300 C under tensile stresses. So, Y_2O_3 ceramics could appear superplastic ability during both processing and high optical transparency when exposed to anneal [23, 24].

SnO_2 thin films can be produced utilizing different processes likes Chemical Bath Deposition (CBD) [6], sol-gel [7], thermal evaporation [8], slovothermal [9], spray pyrolysis [10], as well as chemical vapor deposition [11]. The CBD approach is based on the slow and controlled precipitation of the desired chemical onto the substrate surface to its source ions within the solution of the reaction bath [12]. Glycerin is addition to prevent cracking [2, 13].

In the present study, nanocrystalline (NC) SnO_2-Y_2O_3 thin film was produced with high porosity of the film surface through adding glycerin with a high surface area-to-volume ratio [14, 15]. As a result, the fabricated device is the most promising for UV photodetector implementations.

Experimental details

A diamond cutter was used to cut p-type Si (100) wafers into 10 mm by 10 mm dimensions. To clean these substrates, Radio Corporation of America (RCA) methodology was applied. Using wet air flow, a tube furnace was utilized to heat the substrates to 900 ^oC for seven hours, resulting in a layer of SiO_2 that was around 1 µm thick. Employing a chemical bath method, the samples were produced, which included 100 mL beakers, 0.75 mL of 0.1 M Yttrium acetate (III) hydrate $Y(NO_3)_3.6H_2O$ and 10 mL of 0.2M Tin Chloride Dihydrate $SnCl_2.2H_2O$, 1 mL of 1M of sodium hydroxide (NaOH), glycerine ($C_3H_8O_3$), and prepared polyvinyl alcohol (PVA) [2,13]. The samples were positioned perpendicularly within a mug filled with a solution combination. After that, the beaker was heated to 95 °C for five hours. The manufactured samples were washed with DI water. Ultimately, the salt was removed from the surface using heated acetone.

The present investigation utilized XRD Panalytical X' pert Pro MRD with a Cu Kα radiation of (λ = 0.154060 nm) to describe the crystal structure of the manufacturing samples. A FESEM was used to characterize the morphologies and perform EDX spectroscopy.

Device fabrication

The platinum (pd) grid utilized for the front connection on top of the SnO_2 film was deposited in a thickness of 120 nm using a metal mask in the presence of connections at 650°C. In the contact metal construction, there were two conductive contacts (electrodes) with five fingers each. Figure 1 displays the composition and measurements of the shadow mask.

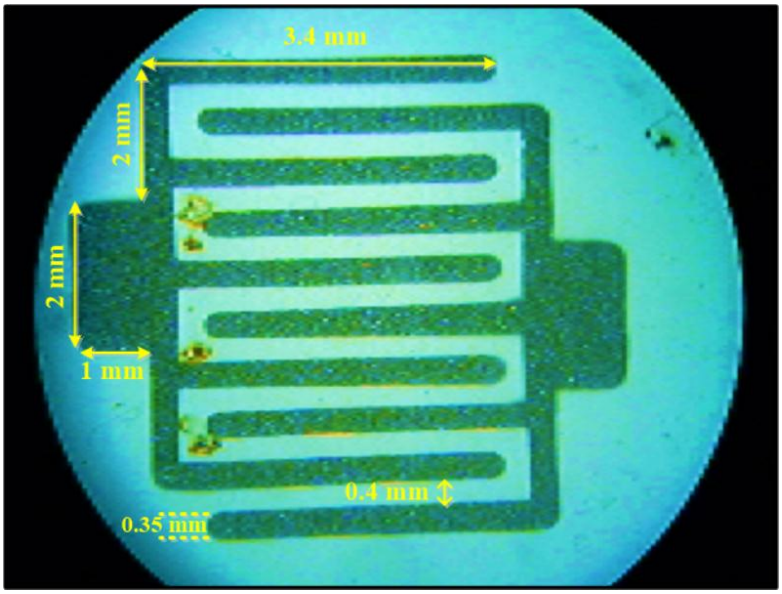

Figure 1: Schematic diagram of Pd grid contact deposited on the NC SnO_2 thin film.

Results and discussion

Typical HR-XRD patterns of fabricated sample generated using the CBD approaches are displayed in Figure 2. The tested sample was annealed at 500 ^oC, as shown in Figure 2, exhibits reflection peaks which are shown in excellent agreement with the conventional tetragonal rutile structure in bulk SnO_2 (JCPDS card No. 041-1455). Diffraction peaks in this Figure's correspond to the (110), (101), (200), (211), (220), and (002) planes. Furthermore, bulk Y_2O_3 is matched with the diffraction peak that emerges at

θ = 29.48° and corresponds to (111). This result is explained by the idea that annealing heat enhances crystallinity [16, 17].

Both high and low magnification Figure 3 shows a FESEM image showing progression of the tested sample. Using the CBD approach, the sample was effectively produced. When the sample was annealed at 500 °C, small nanoparticles were seen, and Figure 2 illustrates the polycrystalline thin film with uniform structures. This happened as a result of improved crystallinity and decreased film imperfections brought about by annealing heat [13, 16].

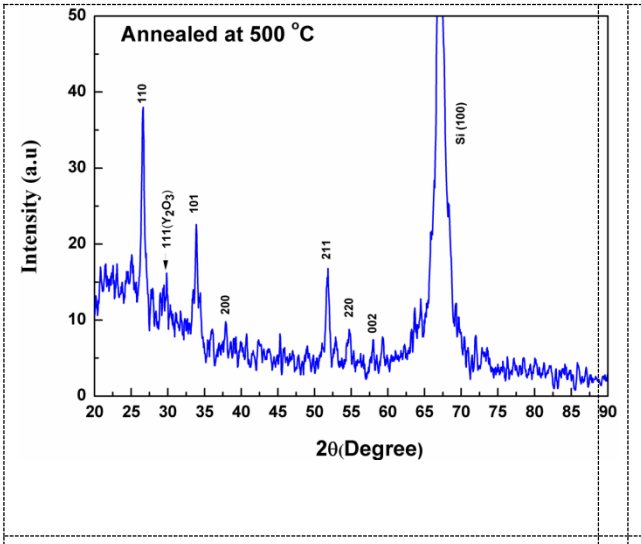

Figure 2. XRD patterns of NC SnO_2-Y_2O_3 thin film annealed at 500 °C for 2 hours in air.

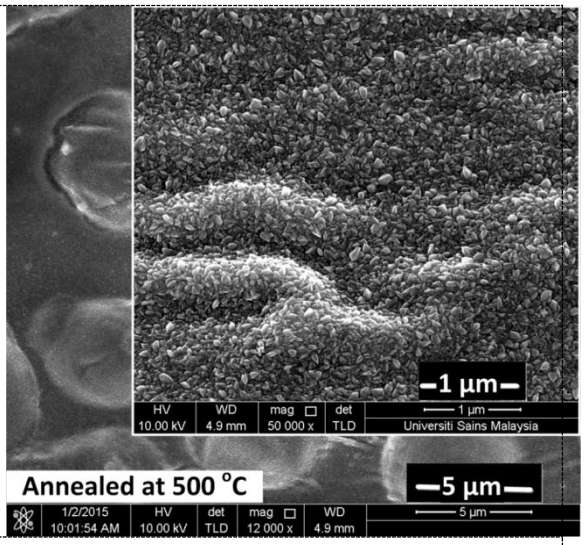

Figure 3. FESEM images of NC SnO_2-Y_2O_3 thin film annealed at 500 °C for 2 hours in air.

The cross-section image of the fabricated sample is shown in Figure 4, and its average thickness was found to be around 330 nm. On top of the silicon substrate, a layer of SiO_2 that is about 880 nm thick also appears.

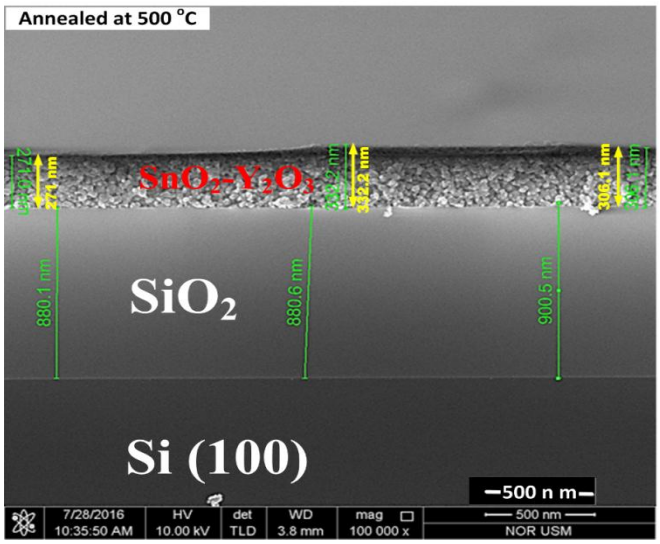

Figure. 4 Cross-section FESEM image for NC SnO_2-Y_2O_3 thin film annealed at 500 °C for 2 hours in air.

UV photodetector application

The current-voltage curves of the UV photodetector, which are based on the SnO_2 thin film, are provided in Figure 5 for both dark and light at a wavelength of 360 nm and incidence energy of 6 mW/cm^2. It is discovered that the light and dark currents are 48.18 µA and 1.56 µA, respectively. The Schottky contacts graphs are demonstrated in both directions. The improvement of the light-sensitive features can be attributed to the Schottky interaction of the UV photodetector [18].

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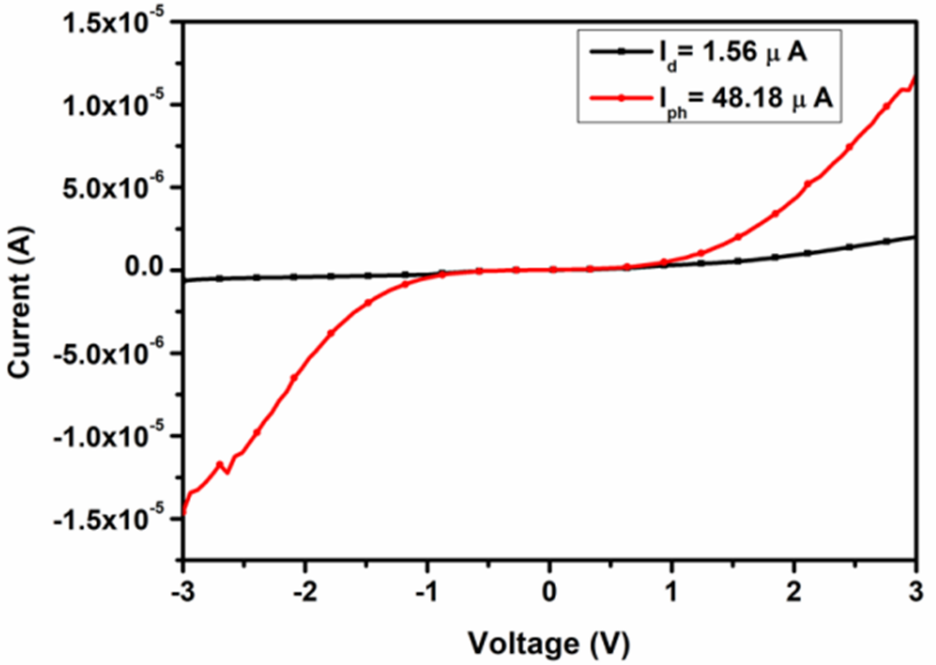

Figure. 5 Current-voltage characteristics of the (SnO_2/Si) UV photodetector under dark and UV illumination

The UV photodetector's photo-responsivity based on SnO_2 thin film is shown in Figure 6. The photocurrent increased to a wavelength of 360 nm before sharply decreasing to 380 nm. The response's greatest value is measured between 360 and 365 nm, with a break-off wavelength of 380 nm. Under light of 360 nm, the UV photodetector's optimal response value is 3.23 A/W. This increased responsiveness can be explained by the SnO_2/Si generating an effective photodetector and the SnO_2 thin film offering high density with larger and rougher surface areas [19]. The light-current (I_{ph}) created per light power (P_{in}) on the detector's activity area can be used to determine the response value (R), and it can be computed as follows [20]:

$$R = \frac{I_{ph}(A)}{P_{in}(W)} = \frac{I_{ph}(A)}{E(W/cm^2)A(cm^2)} \quad (1)$$

where E, the UV light's irradiance, is equivalent to 6 mW/cm^2. An active area of 0.25 cm^2 is denoted by A.

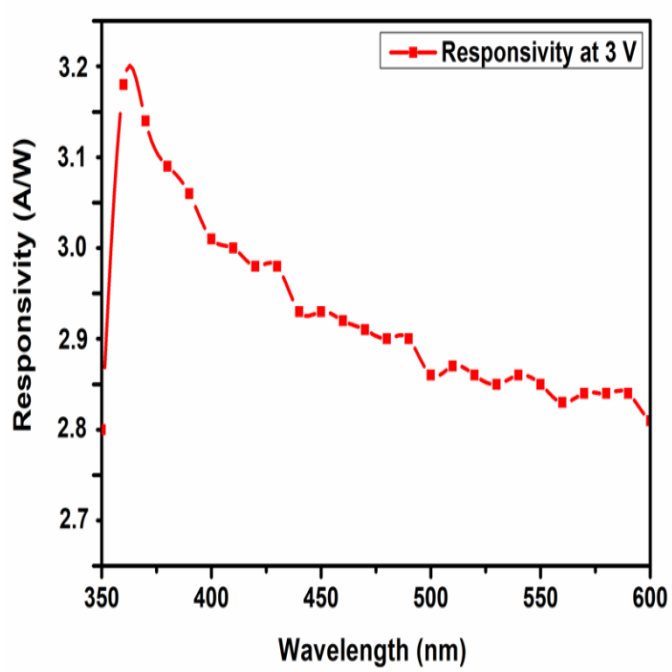

Figure 6. Room temperature responsivity spectra of the SnO_2 thin film UV photodetector

To determine the device's sensitivity (S) to UV light, apply the formula below [21]:

$$S = \frac{I_{ph} - I_d}{I_d} \times 100 \quad (2)$$

Where I_{ph} is the photocurrent and I_d is the dark current. The S value of 2988% was evaluated at a 3 V bias against 360 nm wavelength and 6 mW/cm^2 intensity of UV light. When the grain size is less than the produced depletion layers or the space charge zone's width, the sensitivity significantly increases [22]. The UV photodetector's exchanging behavior is shown in Figure 7 when the UV light source (incidence energy = 6 mW/cm^2) is controlled for 20 seconds at an applied bias voltage of 3 V. The light-current of the SnO_2 UV photodetector increases continuously as the UV lighting is turned on. However, it then sharply decreases to its initial stage, indicating increased product stability and photodetector repeatability. Table 1 provides an overview of the outcomes of the photodetector using ultraviolet light.

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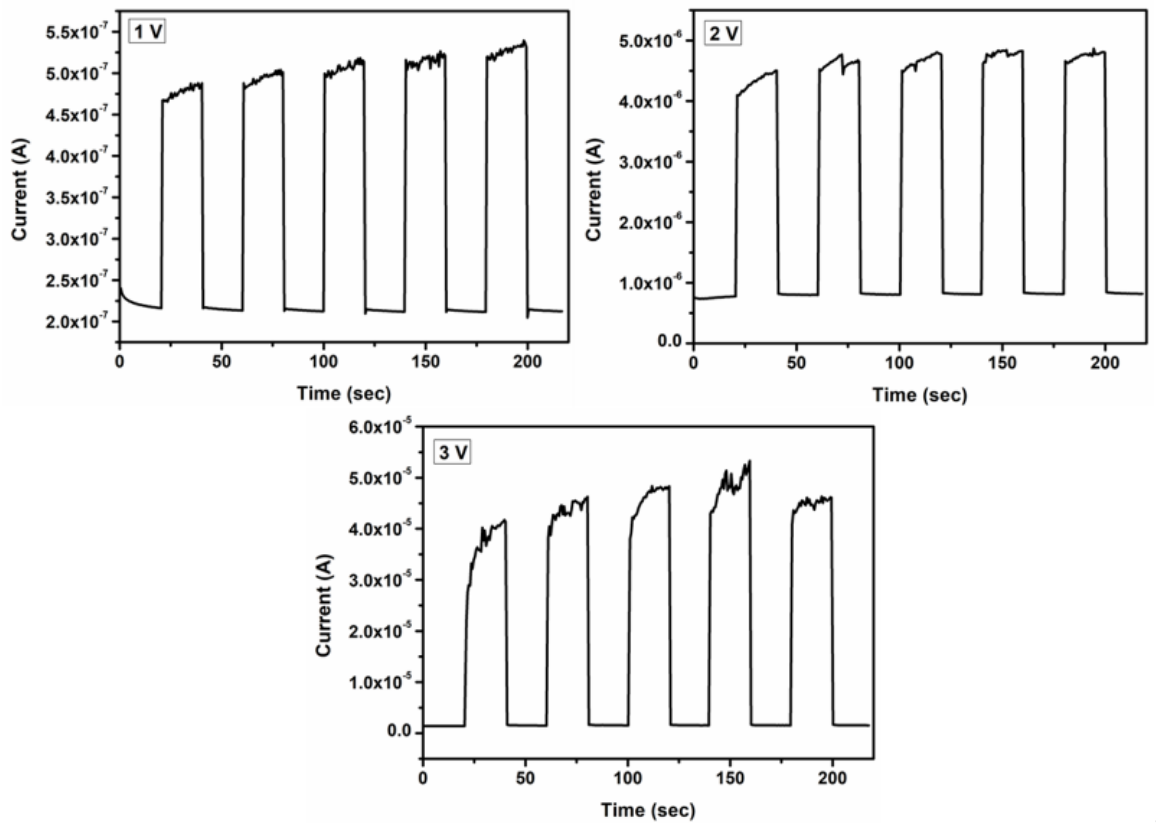

Figure 7. Photocurrent response spectra of the SnO_2 thin film photodetector under UV illumination at different bias voltages

Table 1 Summary of results of the SnO_2 thin film UV photodetector

Voltages	Rise time (s)	Full time (s)	Sensitivity%
1 V	0.504	0.449	124
2 V	0.665	0.543	453
3 V	0.663	0.436	2988

Conclusion:

On SiO_2/Si substrates, NC SnO_2-Y_2O_3 was effectively produced via a straightforward, economical CBD process. The tested samples that exposed to anneal 500 ^oC for two hours have a Monocrystalline structurer, according to detailed structural characterization. The XRD and FESEM measurements demonstrated that the sample under examination had achieved high-quality crystallinity. UV photodetector device shown a noteworthy sensing capability, with values for responsivity and sensitivity of 2988% and 3.247 A/W at 3 V applied bias voltages.

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الحساسية العالية للأغشية SnO_2-Y_2O_3 النانوية البلورية للكشف عن الأشعة فوق البنفسجية المحضرة باستخدام ترسيب الحمام الكيميائي الرقيقة من مادة

عماد حسين كاظم[1]
وزارة التربية / مديرية تربية الكرخ الثانية
07737229395

نبيل محمد عبد الغفور[2]
وزارة التربية /مديرية تربية الانبار
جامعة الانبار- كلية العلوم التطبيقية- هيت
07805746644

imad.usm.iq@gmail.com nabeel.ma@uoanbar.edu.iq

مستخلص البحث:
تم تحضير أغشية رقيقة من البلورات النانوية SnO_2-Y_2O_3 وبنقاوة عالية من خلال استخدام طريقة ترسيب الحمام الكيميائي على أرضيات SiO_2/Si. تم استخدام حيود الأشعة السينية، والمجهر الإلكتروني لمسح الانبعاث الميداني، والتحليل الطيفي للأشعة السينية المشتتة من الطاقة لتحليل التركيب الهيكلي والسطحي للعينة الملدنة عند 500 درجة مئوية لمدة ساعتين في الهواء. عند التلدين عند 500 درجة مئوية، تم الحصول على تبلور الفيلم SnO_2-$Y2O_3$ ذات التركيب هيكل روتيل رباعي الزوايا. تم استخدام الغشاء الرقيق SnO_2 النانوي بشكل فعال كجهاز كاشف ضوئي للأشعة فوق البنفسجية. أظهر كاشف الأشعة فوق البنفسجية المعتمد على الغشاء الرقيق النانوي البلوري SnO_2-Y_2O_3 أداءً استشعاريًا كبيرًا، حيث تقترب قيم الحساسية والاستجابة من 2988 % و A / W 3.247 عند (3 V) من الفولتية المطبقة. نظرًا لاستقراره وموثوقيته المتميزتين، يعد مستشعر الأغشية الرقيقة SnO_2-Y_2O_3 البلوري النانوي هو الخيار الأمثل لتطبيقات الصور الإلكترونية التجارية.

الكلمات المفتاحية : SnO_2-Y_2O_3، هيكل الروتيل رباعي الزوايا، كاشف الأشعة فوق البنفسجية، الحساسية.

ملاحظة : هل البحث مستل من رسالة ماجستير او اطروحة دكتوراه ؟ نعم : كلا كلا :