Investigation The Effect of oxygen flow rate on the properties of photoconductive TiO_2/Si UV detector

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Abstract:

UV photoconductive detector was fabricated by the deposition of TiO_2 film on silicon by dc magnetron sputtering. Pure oxygen and Argon were used as the reactive and sputtering gases respectively. The gases were mixed prior to the admission in the sputtering chamber [oxygen flow 10, 20, 30, 40 and 50 s.m (stander centimeter cubic per minute) with constant argon flow]. The structure properties of TiO_2 thin films were investigated by means of X-ray diffraction. X-ray diffraction (XRD) patterns showed three phases Rutile, Anatase and Brookite . The ratio between these phases changed and depended on oxygen flow. The deposited TiO_2 film was coated by nanosheet of polyamind polymer to improve the photoresponsivity of the detector and to reduced the response time of the TiO_2 UV detector to about 170 µs. The final device was tested with high speed pulsed nitrogen laser.

The spectral responses of TiO_2/Si junction were studied. The maximum value of responsivity occurred at wavelength equals to 385 nm. The responsivity, quantum efficiency and specific detectivity increased with increasing of the oxygen flow, while the noise equivalent power decreased with increasing the oxygen flow. It has been observed that the best spectral response occurs when the oxygen flow equal to 50 s.m and we can say that this value of oxygen flow is the optimum condition for TiO_2 photoconductive detector preparation.

Keywords: responsivity; quantum efficiency ;specific detectivity; polyamind polymer; noise equivalent power.

استقصاء تاثير معدل تدفق الاوكسجين على خواص كاشف التوصيليه الضوئيه للأشعه فوق البنفسجيه لأوكسيد التيتانيوم/سيليكون

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الخلاصـــه

تم تصتيع كاشف التوصيلية الضوئية بترسيب TiO_2 على ركائز السيليكون بواسطة الترذيذ المغناطيسي المستمر . تم استخدام الأوكسجين النقي والأركون النقي كغاز متفاعل وغاز ترذيذ على التوالي. خلط غاز الأوكسجين بمعايير جريان (10-20-30-40-50)s.m (حجم مكعب لكل دقيقة) والأركون بجريان ثابت مقداره 50 s.m الى قبل دخولهما الى حجرة التفريغ .

وقد تم التحقيق الخصائص التركيبية لأغشية TiO_2 الرقيقة عن طريق حيود الأشعة السينية.أظهرت نتائج حيود الأشعة السينية (XRD) ثلاث أطوار وهي Rutile وAnatase وBrookite، تتغير نسب هذه الأطوار بالاعتماد على تغير تدفق الأوكسجين. تم تحسين الاستجابة الضوئية لأغشيـــه ثنائي أوكسيد التيتانيوم (2.24 A/W) بطلائها بطبقه نانويه من بوليمير نوع (بولي أمايند). أظهرت هذه الكواشف سرعه أستجابه عاليه لأشعه فوق البنفسجيه بزمن نهوض قدره 170 مايكروثانيه عند تعرضها الى ليزر نايتروجين نبضي عالي السرعه.

درست الخصائص الطيفية للمفرق TiO_2/Si ووجدنا أن أعظم قيمة للاستجابة الطيفية حدثت عند طول موجي يساوي385nm.أن الاستجابة والكشفية النوعية والكفاءة الكمية تزداد بزيادة تدفق الأوكسجين، في حين أن القدرة المكافئة للضوضاء تتناقص مع زيادة تدفق الأوكسجين. وقد لوحظ أن أفضل استجابة طيفية تحدث عندما يكون تدفق الأوكسجين مساوي ل 50 sccm وان هذه القيمة هي المثلى لتحضير غشاء ال TiO_2 ليعمل كنبيطة ضوئية.

الكلمات المفتاحية: الاستجابية ، الكفائة الكمية،الكشفية النوعية ، بوليمير بولي أمايند ، القدرة المكافئة للضوضاء .

1-Introduction

Titanium dioxide (titania, TiO_2) is one of the most widely used materials in thin films because it has numerous applications, such as solar cells, photocatalysts, gas sensors, optical coatings, ect[1-4].

Titanium dioxide (TiO_2) has many excellent physical properties such as a high dielectric constant, a strong mechanical and chemical stability, as well as good insulating properties. Due to its high refractive index and optical transmittance in the visible range, TiO_2 is especially suitable as material for optical coatings and protective layers for very large-scale integrated circuits [5-8].

TiO_2 belongs to the family of transition metal oxides. There are three commonly known polymorphs of TiO_2 found in nature: rutile (tetragonal), anatase (tetragonal) and brookite (orthorhombic) [9].

TiO_2 is an effective ultraviolet (UV) radiation absorber, due to its ability to absorb ultraviolet (UV) radiation with energies equal to or greater than its band gap energy [10].

The UV detector based on polycrystalline TiO_2 thin film shows low responsivity and long response time which is of the order of few minutes. Since the one – dimension TiO_2 nanostructures are characterized by presence of deep level surface trap states, the TiO_2 detector exhibits long lifetime of the photo carriers [11]. Despite a great deal of research on TiO_2 UV detector, most of the research concentrated on the improvements of the micro mask electrodes, in order to enhance the performance of the TiO_2 photoconductive detectors [12-14].

The improvement of the photoresposivity of the TiO_2 UV detectors was carried out by the surface treatment of the TiO_2 thin film. The covering of the TiO_2 film surface with nanosheet of different types of polymers has highly improved the detector performance [15,16]. In this work, a simple and highly reliable technique is used to fabricate photoconductive TiO_2 UV detector.

2-Experimental Work

2-1 Preparation of TiO_2 Thin Film

In d.c magnetron sputtering a circular magnetron with 10 cm diameter and 400 gausses was used.
The discharge characteristics have been controlled using variable d.c supply (5kVand 500 mA). Pure Ti (99.99%) with a diameter of 10 cm and 0.4 cm thickness has been used as a sputtering target; the flow meters were used to control the gases in vacuum chamber. The best distance between target and substrate was 4.2 cm, and the substrate was set above the target. Glass plates and wafer silicon were used as substrate.

Before deposition, The growth chamber was evacuated to a base pressure of 6×10^{-4} pa for 30 min, then Ar (99.99%) and O_2 (99.99%) gases were introduced into the chamber as working gas. The chamber total pressure was fixed at 0.2 Pa during the whole deposition, and pre-sputtering process employed for 10 minutes to clean the target surface. A direct voltage (1000 V the d.c power was maintained at 100W) is applied between the cathode and anode. Sputtering is a removal of surface atoms due to particle bombardment which is caused by atomic collisions at the surface of a target.

The crystalline structure of 200 nm thickness TiO_2 film deposited on

glass substrate was studied by X-ray diffraction using XRD-6000-Schemadzu system ,λ=1.54nm. Photodetector Characteristics (responsivity, quantum efficiency, and signal to noise ratio, noise equivalent power and detectivity) of TiO_2 /Si detector was measured using the system which is consisted of monochrometer in the range (200-900) nm, electrometer and power meter for measuring the radiation power for each wavelength and d.c power supply to supply bias voltage on each side of the detector.

3- Result and Discussion:

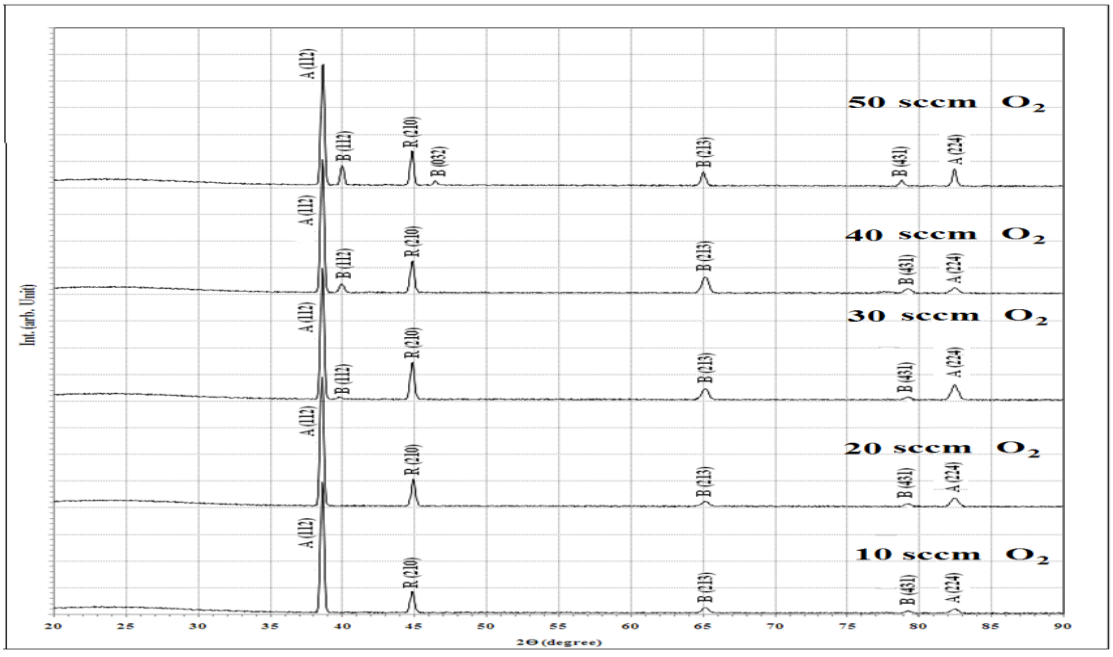
3-1 Structure Characteristic

The XRD pattern of a TiO_2 film is illustrated in Fig. (1). It shows that all films of TiO_2 have multiphase Brookite (B), Anatase (A) and Rutile (R). When the oxygen flow (10 and 20 s.m) there are five peaks A (112), R(210), B(213), B(431) and A(224) at angles (2θ=38.5°), (2θ=46.8°), (2θ=64.9°), (2θ=79.3°)and (2 θ=82.2°) respectively. While when the oxygen flows (30 and 40 s.m), the peak B (112) grown at angle (2θ=39.5°) and another peak B (032) grown in angle (2θ=46.1°) at the oxygen flow became 50s.m.

The grain size (estimated by Scherrer formula:[17]

$$D = \frac{0.9\lambda}{\beta \cos\theta} \quad \text{.....(1)}$$

From the data obtained, we can see decrease in grain size as oxygen flow increased. When the oxygen flow increased from 10 s.m to 50 s.m the grain size was reduced from (32.7 nm to 20.5 nm), (22.6 nm to 21nm) and (27.3 nm to 25nm) for Brookite, Anatase and Rutile respectively. [18]



Fig(1) XRD of TiO_2 thin films on glass substrate for different Oxygen flow rate.

3-2 Spectral Measurements

3-2-1 Spectral Responsivity

The spectral responsivity of an optical detector is a measure of its response to radiation at a specified Wavelength. The responsivity for monochromatic light of wavelength incident normally is given by [19].

$$R_\lambda = \frac{I_{ph}}{P_{in}} \quad \text{or} \quad R_\lambda = \frac{V}{P_{in}} \qquad \ldots\ldots\ldots\ldots(2)$$

Fig.(2) Shows the wavelength dependent of spectral responsivity (R_λ) for TiO_2 thin films at room temperature under different oxygen flow rate 10, 30 and 50 s.m . It is clear that a maximum responsivity appears at the ultraviolet region and its peak is at about 385 nm. When the oxygen flow rate increase from 10 to 50 s.m the responsivity increasing from 0.03 to 0.07 A/W (at 385nm). This is attributed to the increasing roughness with increasing of oxygen flow rate which results to increase absorption coefficient (decrease Transmission) and then more power of the incident radiation is absorption in thin film which are generate electron-hole pairs[20].

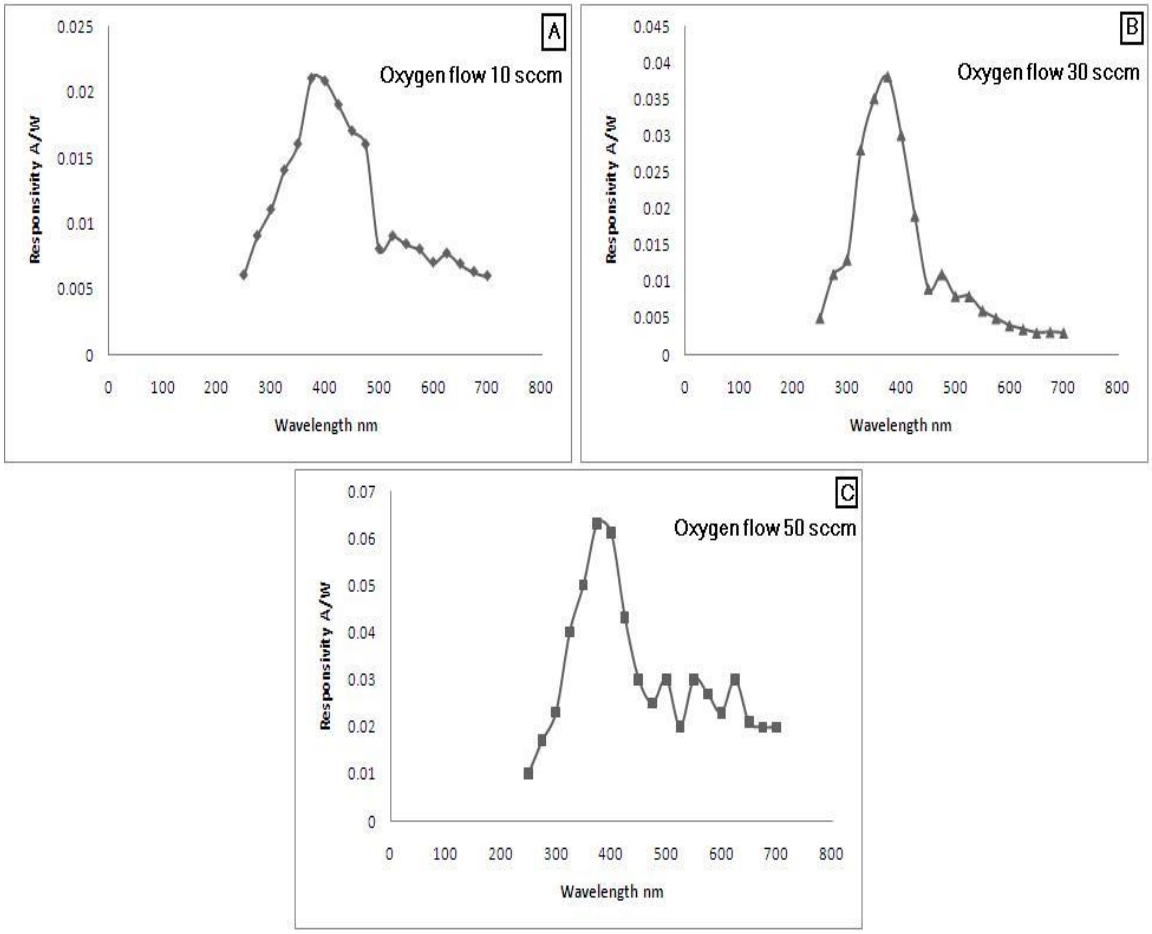


Fig.(2)The variation of spectral responsivity as a function of wavelength for Oxygen flow rate.

3-2-2 Quantum Efficiency

The quantum efficiency was determined as a function of wavelength for TiO_2/Si junction; it can be expressed [19].

$$\eta = (I_{ph}/e).(h\upsilon/p_{in}) \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$\eta = R_\lambda . (h\upsilon/e) \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Fig.(3) Shows the wavelength dependent of quantum efficiency for TiO_2 thin films at room temperature under different oxygen flow rate 10, 30 and 50 s.m. The maximum quantum

efficiency was achieved at 385 nm with a value of 7.4% for TiO_2/Si at Oxygen flow equal 10 s.m and increased to 25% at Oxygen flow equal 50 s.m. The reasons are mentioned earlier in the discussion of the spectral responsivity.

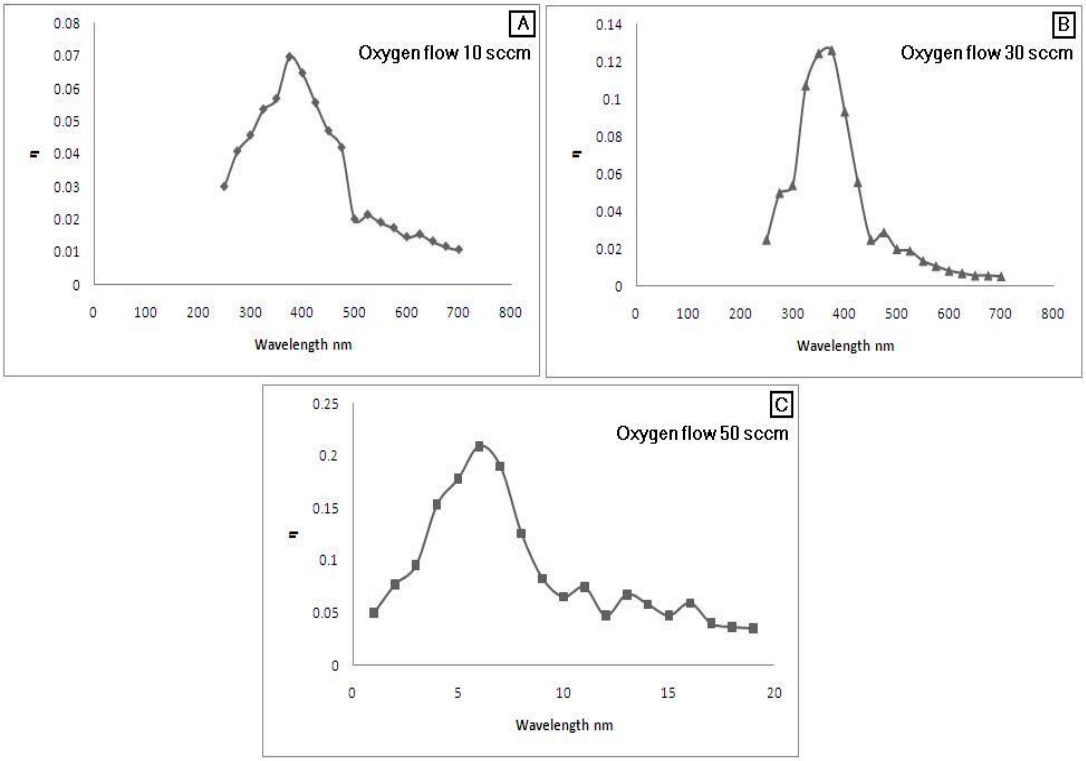


Fig.(3)The variation of quantum efficiency as a function of wavelength for TiO_2 thin films prepared at different Oxygen flow rate.

3-2-3 Noise Equivalent Power

The Noise Equivalent Power (NEP) is a concept often used to quantify the sensitivity of a detector or the power generated by a source of noise on a detector NEP defined as [19]:

$NEP=I_n/ R_\lambda$ Watt **…..……** (5)

The variation of NEP as a function of wavelength under Oxygen flow rates 10, 30 and 50 s.m is shown in Fig. (4).

In general, the minimum NEP occurs when R_λ has the maximum value. From these figures, we can notice that NEP decreases with increasing of Oxygen flow. It decreases from 2.4 $x10^{-8}$(Watt) to $0.35x10^{-8}$(Watt) when Oxygen flow rate varies from 10 s.m to 50 s.m, and we relate this to the defects (voids) which decrease with increaseng Oxygen flow rate, and thus decrease noise current.

3-2-4 Specific Detectivity

The specific detectivity (D*) of the TiO_2 thin films were measured at room temperature as a function of incident light wavelength, it is defined as [19]:

$D^*=D\ (A\ \Delta F)^{1/2}$ cm. $Hz^{1/2}$/Watt… (6)

or

$D^*=R_\lambda(A\ \Delta F)^{1/2}\ /I_n$ ……..…(7)

Results of D* under at different Oxygen flow 10, 30 and 50 s.m are illustrated in Fig.(5). When the Oxygen flow increasing from 10 s.m to 50 s.m the D* increase from 0.16 $\times10^8$ cm.$Hz^{1/2}$.W^{-1} to 3.2 $\times10^8$ cm.$Hz^{1/2}$.W^{-1}. The increase of D* due to the decrease of NEP.

The response time of the fabricated TiO_2 UV detector was tested with nitrogen laser of 0.3 ns pulse duration and 50μj energy.

It can be noticed from the traced pulse shape that the rise time was of the order of 170μs and the fall time was about 750μs.

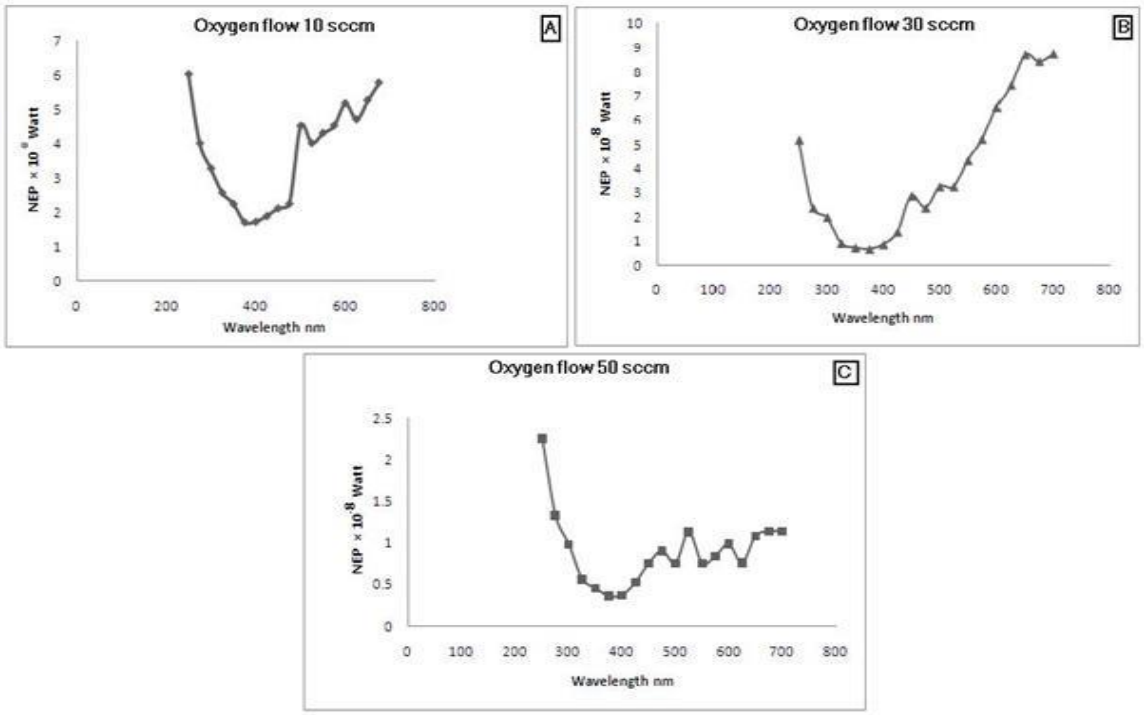


Fig.(4)The variation of NEP as a function of wavelength for TiO_2 thin films prepared at different Oxygen flows.

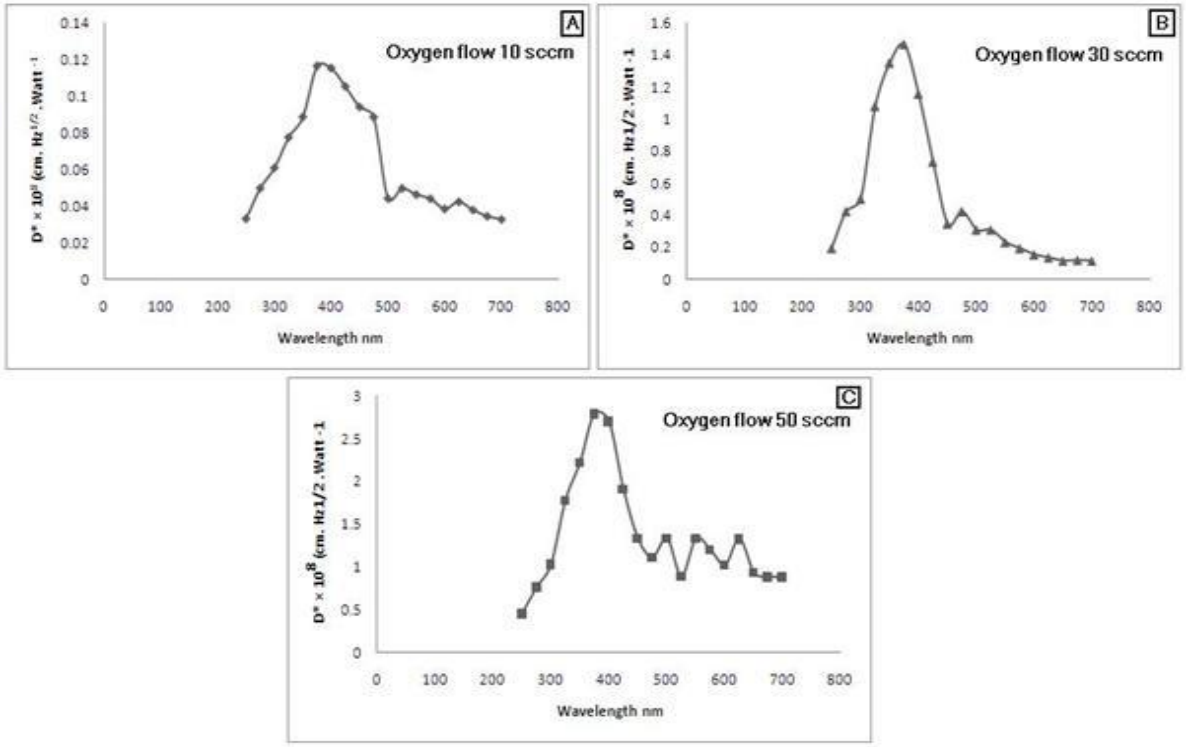


Fig. (5)The variation of Specific Detectivity as a function of wavelength for TiO_2 thin films prepared at different Oxygen flows

The slow decay time is due to slow escape of holes from the tarps. . Hole captured into the hole traps may be emitted back into the valance band according to a time constant depends on energy separation between the corresponding hole traps and the edge of the valance band. The deep traps have slow response and this may explain the slow fall time of the output pulse as shown in Fig .(6). The long tail accompanied with the pulse is due to sample heating by the high repetitions rate N_2 laser illuminate the TiO_2 photoconductive detector [21].

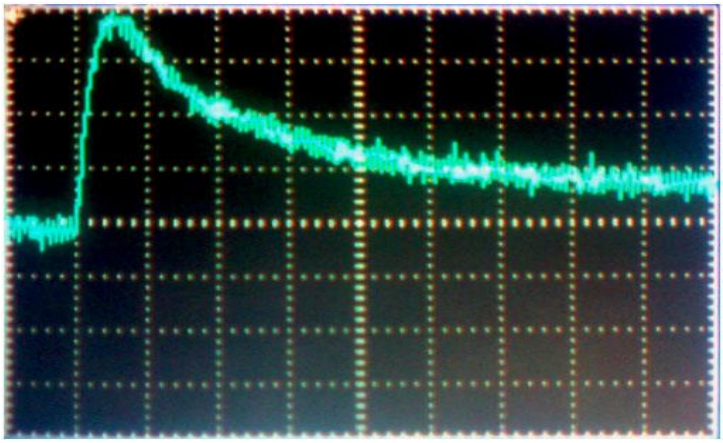


Fig.(6) The photoresponse time of fabricated TiO_2 UV detector to the nitrogen laser. The time base on x-

4- Conclusion:

The conclusions of this work The XRD analysis showed that TiO2 thin mixture (Rutile, Anatase and Brookite). Dependence on oxygen flow rate. Spectral Measurements show that the responsivity, specific detectivity and quantum efficiency increase with increasing of oxygen flow rate, while noise equivalent power decreases with films was polycrystalline in sputtering in oxide mode and have three phases increasing oxygen flow. The functionalization of the TiO_2 film surface by polyamide nylon highly improved the photoresponse time reaches to 170μs which is six orders of magnitudes faster than that of TiO_2 photoconductive detector.

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