Laser wavelength and energy effect on optical and structure properties for nano titanium oxide prepared by pulsed laser deposition

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Abstract

Nano TiO_2 thin films on glass substrates were prepared at a constant temperature of (373 K) and base vacuum (10^{-3} mbar), by pulsed laser deposition (PLD) using Nd:YAG laser at 1064 nm wavelength. The effects of different laser energies between (700-1000)mJ on the properties of TiO_2 films was investigated. TiO_2 thin films were characterized by X-ray diffraction (XRD) measurements have shown that the polycrystalline TiO_2 prepared at laser energy 1000 mJ. Preparation also includes optical transmittance and absorption measurements as well as measuring the uniformity of the surface of these films. Optimum parameters have been identified for the growth of high-quality TiO_2 films.

Key words

Thin films, Pulsed laser deposition, Titanium oxide.

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تاثير الطول الموجي و الطاقة على الخصائص البصرية و التركيبية لاوكسيد التيتانيوم النانوي المحضر باستخدام طريقة الترسيب بالليزر النبضي

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الخلاصة

تم تحضير اغشية اوكسيد التيتانيوم النانوية الرقيقة على قواعد زجاجية عند درجة حرارة ثابتة تساوي 373 كلفن و تحت الفراغ بمقدار يصل الى 10^{-3} ملي بار, باستخدام تقنية الترسيب بالليزر النبضي حيث تم استخدام ليزر النديميوم- ياك عند الطول الموجي 1064 نانومتر. و تمت دراسة تاثير اختلاف طاقة الليزر ما بين 700-1000 ملي جول على خصائص اغشية اوكسيد التيتانيوم. اظهرت فحص حيود الاشعة السينية ان غشاء اوكسيد التيتانيوم المحضر عند طاقة ليزر تساوي 1000 ملي جول كان متعدد البلورات. و ايضا التحضير كان يشمل قياسات النفاذية البصرية و الامتصاص وكذلك قياس انتظامية السطح لهذه الاغشية . و قد تم التعرف على افضل المعلمات لنمو احسن غشاء لاوكسيد التيتانيوم.

Introduction

Pulsed laser deposition (PLD) technique used for thin film preparation has become one of the focal areas due to its simplicity, versatility and capability in the synthesis of high quality films at relatively low growth temperatures. PLD has been extensively employed for the preparation of stoichiometric films of oxides. It is almost the only method that can transfer complex monolayer structures from ceramic targets onto substrates [1-4]. Currently, many oxide thin film materials, like titanium dioxide (TiO_2) has been investigated extensively due to their photocatalysts [5], self-cleaning, and antifogging properties [6], in application indoor and outdoor environments [7].

Titanium dioxide films have attracted much attention in different application fields such as optical coatings and optoelectronic devices [8, 9], electrodes for solar energy conversion [10], and water and air purifications [11] due to its superior physical, chemical properties, and high stability. In the present work we demonstrate that there is possibility of using TiO_2 at wavelength 1064 nm in manufacturing optoelectronic device such as (solar cells, gas sensors and detectors).

Experimental work

TiO_2 thin films were deposited by using the pulsed laser deposition technique. The chamber was evacuated to a base pressure of (10^{-3} mbar) by using a substrate temperature of 373 K. Q-switched Nd: YAG laser with a wavelength of 1064 nm with different laser energies (700-1000)mJ was used; the focal length of the lens was about 12 cm with a repetition rate of 1 Hz. The distance between the target and the substrate was kept at 2.5cm. Fig. (1(a,b)) shows the setup of PLD. After deposition, the crystallographic structure of the films was investigated by X-ray (XRD) system Shimatzu (6000) using CuKa radiation. The optical transmittance of TiO_2 thin films on glass substrate prepared by PLD were measured by UV-VIS (SP8001) Shimatzu double beam spectrophotometer. The surface morphologies of the thin films were investigated by using an atomic force microscope (Shimatzu AA3000 Scanning Probe Microscope).

Results and discussion

The optical transmittances of TiO_2 thin films on glass substrate prepared by PLD were measured by UV-Vis spectrophotometer. For film preparation the influence of laser energy on the optical transmission spectra of TiO_2 with constant number of pulses is shown in Fig. (2(a)), it was found that the transmission was decreased with the increase in the laser power density due to increase the deposition ablation efficiency and then the concentration of TiO_2, these values of transmission are about (20-60) % with laser energies between (1000-700) mJ at wavelength 1064 nm also we found that these values of transmission at wavelength 1064 nm are very closed to the values of transmission at wavelength 532 nm see Fig.(2(b)). The deposited films in vacuum were dark in color and show low transmittance; it was found also that there is no change in the transmission in the laser energy of 700mJ and 800mJ.

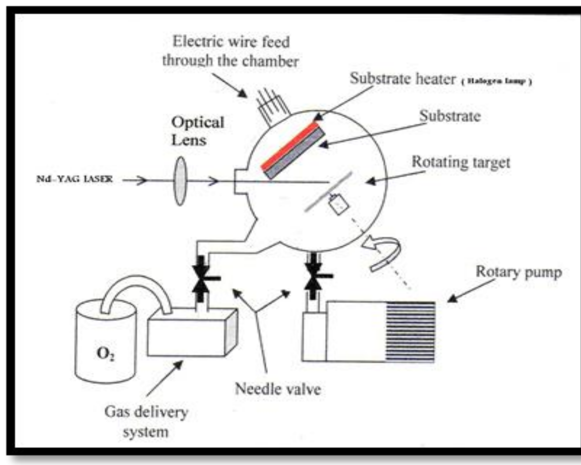

Fig. (1(a)): A-Schematic diagram of the PLD system used.

Fig. (1(b)): Experiment setup used.

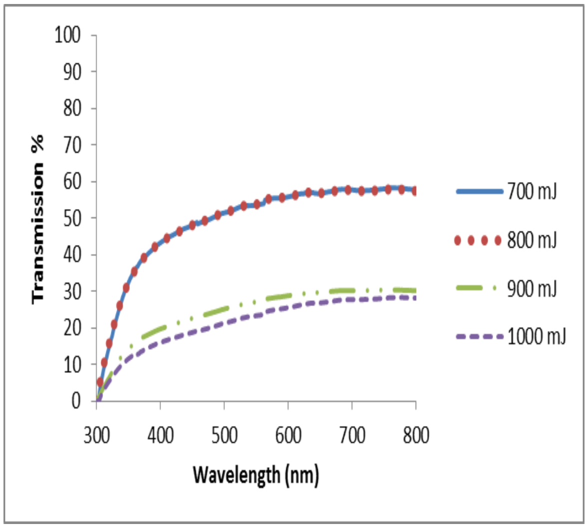

Fig.(2(a)): The optical transmission of TiO_2 thin films on glass substrate prepared by PLD at wavelength 1064 nm for different laser energies.

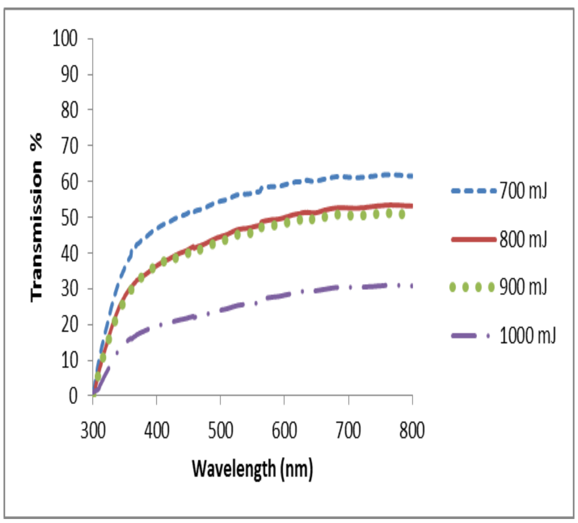

Fig. (2(b)): The optical transmission of TiO_2 thin films on glass substrate prepared by PLD at wavelength 532 nm for different laser energies.

In Fig.(3(a)) shows the optical absorption edges, these edges have as lightly blue shift with the increase of laser power due to increase in particle size. In fact, increasing the fluency means delivering more energy that implies ablating larger amount of material, because of the plasma plume becomes more intense and the TiO_2 particles cloud becomes bushy. Most likely, this means that big particles will be present due to longer growth time and to the high probability of deposit particles muster. In other words, atoms and nano scale particles deposited under laser radiation tend to muster during and after the laser pulse. This reality leads to generate of larger particles that becomes more distinguished when the density of the TiO_2 particles increases further with increasing the fluency, also in Fig. (3(b)) show the optical absorption edges are very closed to the edges in Fig. (3(a)).

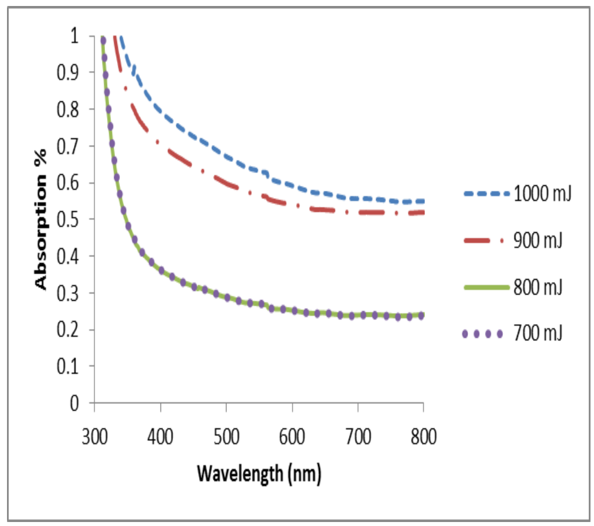

Fig. (3(a)): The optical absorption of TiO_2 thin films on glass substrate prepared by PLD at wavelength 1064 nm for different laser energies.

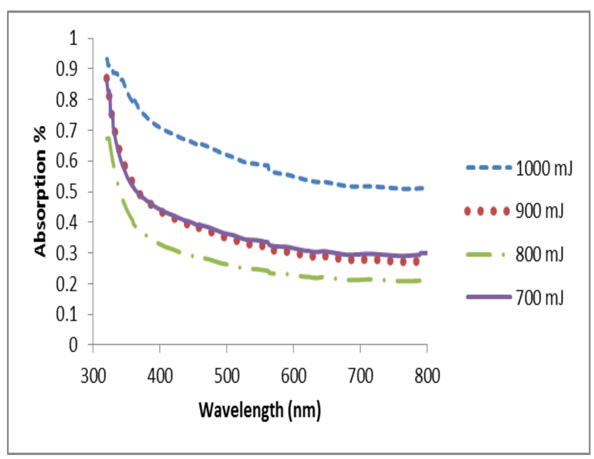

Fig. (3(b)): The optical absorption of TiO_2 thin films on glass substrate prepared by PLD at wavelength 532 nm for different laser energies.

The optical band gap energy E_g is found by plot $(\alpha h\nu)^2$ vs. hν as shown in figure (4(a)). The calculated band gap energy is about (3.9eV) corresponding to the (1000 mJ) laser energy and at wavelength 1064 nm this value is higher than the bulk TiO_2 [12], because of reduction in particle sizes reason due to the quantum confinement effect and increase of surface/volume ratio. TiO_2 has been grown on a glass substrate at substrate temperature 373 K and under vacuum. These values of E_g are very closed to the values are obtained when we used the laser energy (1000 mJ) at wavelength 532 nm in figure (4(b)).

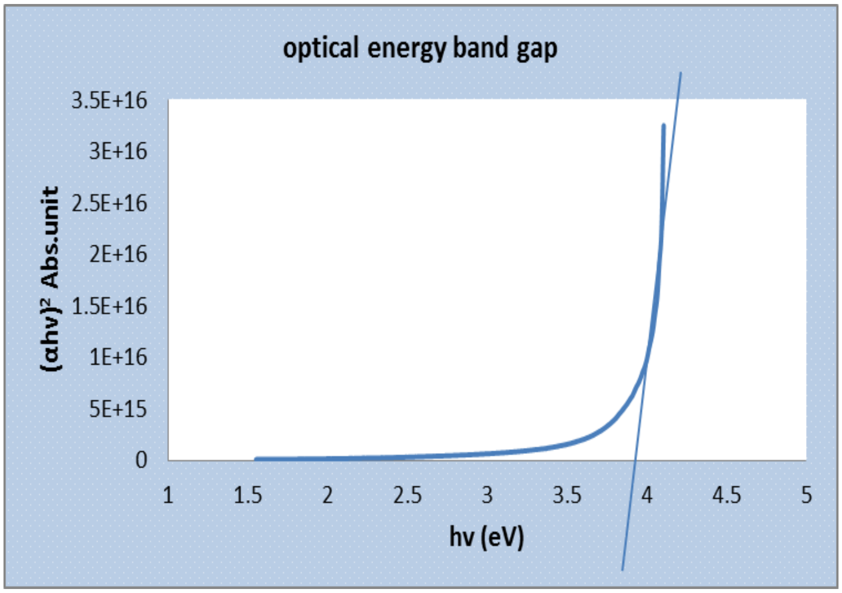

Fig. (4(a)): The optical energy band gap of TiO_2 thin film at wavelength 1064 nm and laser energy 1000 mJ.

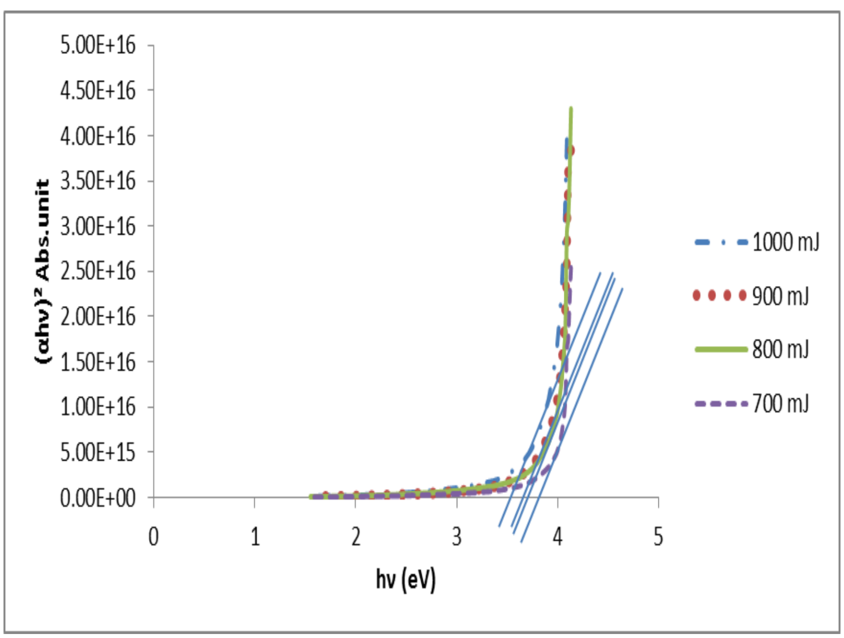

Fig. (4(b)): The optical energy band gap of TiO_2 thin film at wavelength 532 nm and laser energy 1000mJ.

We note that there is a convergence of a very large in the results of the optical properties when using wavelength 1064 and 532 nm with the knowledge that the best results optic wavelength 1064 nm when the laser energy equal to 1000 mJ while the best results for the wavelength 532 nm when the laser energy is equal to 800 mJ.

Figures (5(a,b)) show the AFM surface morphology images for TiO_2 thin films that deposited at constant laser energy 1000 mJ and at different wavelength (1064 and 532) nm. The surface morphology of the TiO_2 thin films as observed from the AFM micrographs proves that the grains are uniformly distributed within the scanning area (2μm x 2μm), with individual columnar grains extending upwards. This surface characteristic is important from the topographic images it can be seen that the films deposited at 1064 nm appears to be more uniform, smooth and homogeneous than the topography of the sample deposited at 532 nm. The result in a Fig. (5 (a)) shows a root mean square (RMS) value (12.1 nm) that revealed low roughness's of about (8.7 nm) which insure homogeneity in size values comparing with Fig. (5(b)) where the RMS was (31.9nm) and the roughness about (24.1) the increase in its value on second case related to the re-distribution of oxide atoms with increasing laser energy.

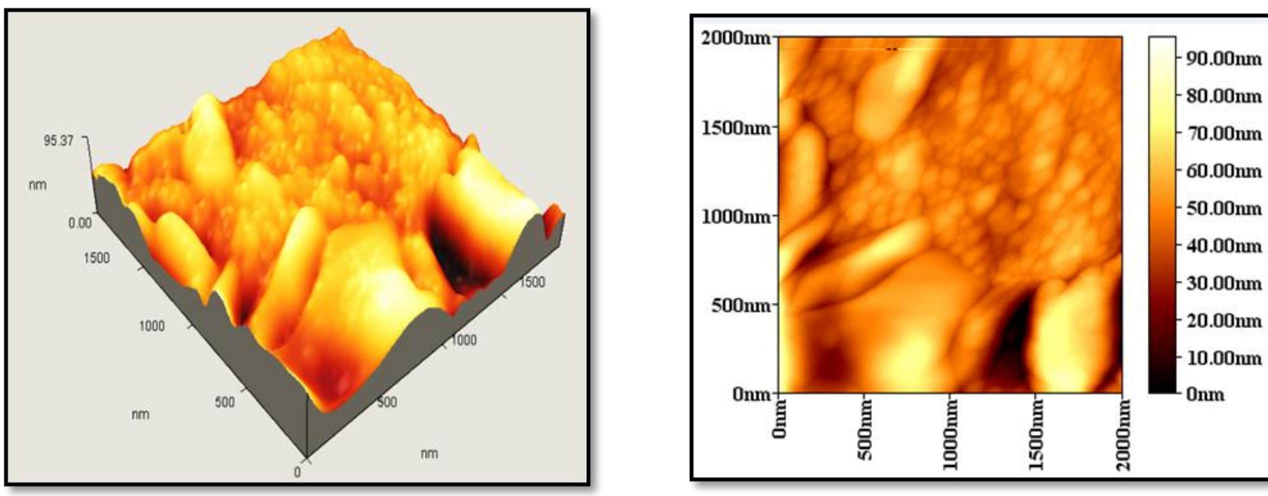

Fig. (5(a)): AFM results at 1064 nm wavelength and 1000 mJ laser energy.

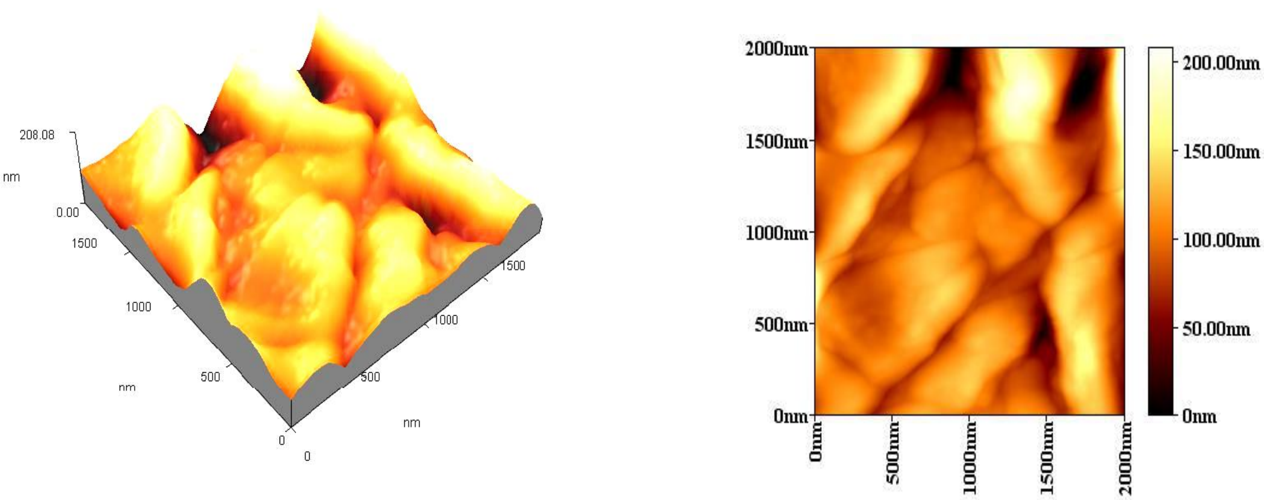

Fig. (5(b)): AFM results at 532 nm wavelength and 1000 mJ laser energy.

In Fig. (6(a)) shows the XRD pattern of TiO_2 thin film deposited at 373 K at 1000 mJ laser pulse energy, the films in the deposited conditions have polycrystalline structure, in the notation of mirror induces, "R" indicates rutile-phase crystal and "A" indicates anatase-type crystal. Note the presence of peaks attributable to the rutile phase (110) at 2Ɵ=27.3° and those attributable to the anatase phase (101) at 2Ɵ=25° these results agree with [13, 14]. It is clearly noticed that at the laser energy (1000 mJ) and wavelength (1064 nm) the film has high intensity in the anatase phase. But in Fig. (6(b)) the film deposited at laser energy 1000 mJ and wavelength (532 nm) this film has high intensity in the rutile phase.

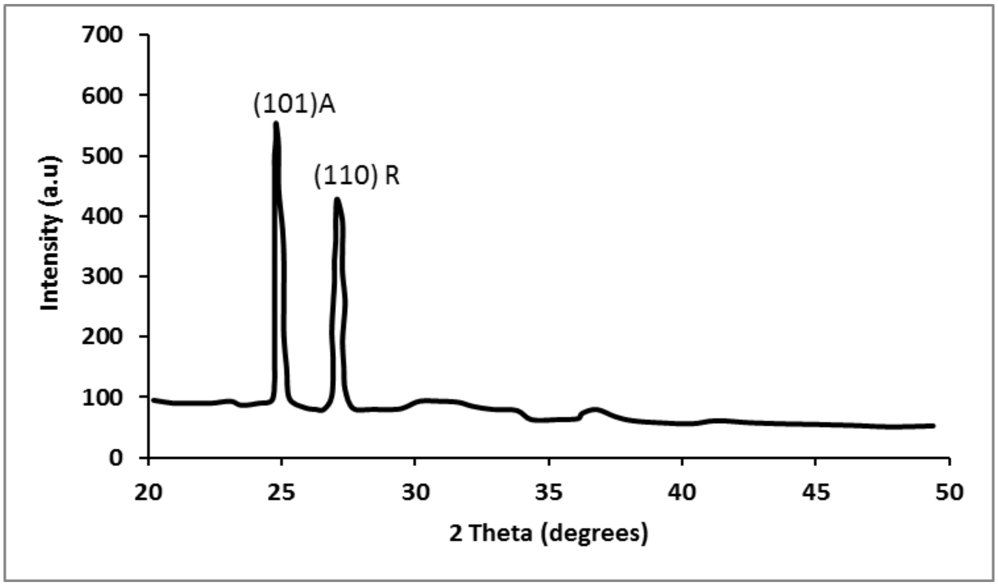

Fig. (6(a)): XRD patterns of TiO_2 at 1064 nm wavelength and 1000 mj laser energy R=rutile and A= anatase.

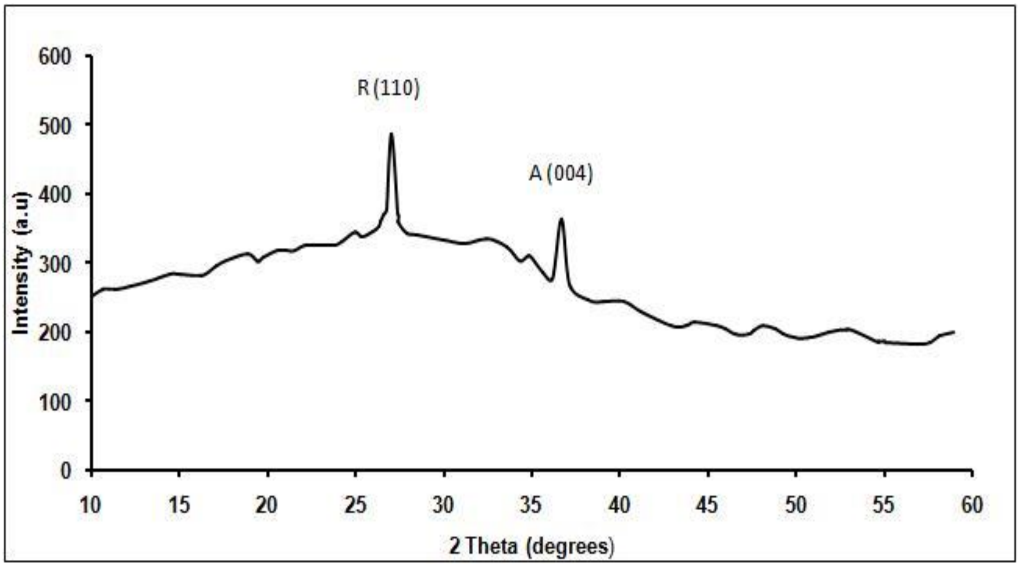

Fig.(6(b)): XRD patterns of TiO_2 at 532 nm wavelength and 1000 mJ laser energy R=rutile and A= anatase.

Conclusions

Nanostructures highly conducting titanium oxide thin films were prepared using pulsed laser deposition technique in this study. It is noticeable in the case of TiO_2 films that substrate heating to 373 K results the intensity of the peaks attributed to anatase TiO_2 phase at 1000 mJ. Results presented above we demonstrate that there are possibility of using wavelength 1064 nm in manufacturing optoelectronic device such as (solar cells, gas sensors and detectors) and we find that there is a limited use of wavelength 532 nm in the deposition applications such as (white pigment and antireflection coating).

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