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Synthesis ZnO/ZnTe/Si thin films by pulsed laser deposition for photodetector applications

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ABSTRACT

Zinc telluride (ZnTe)/zinc oxide (ZnO) nanoheterostructure ZnTe and ZnO nanofilms were grown via pulse laser deposition technique for photodetector applications. The films were deposited on n-type silicon and fluorine-doped tin oxide (FTO) glass substrate at 180 MJ and 700 and 900 pulses). The structural properties were studied using X-ray diffraction patterns, which showed the crystallized hexagonal and cubic structures of the film. The elemental compositions of the thin ZnTe and ZnO films were identified through energy dispersive X-ray analysis. Field-emission scanning electron microscopy examinations revealed that the films displayed a good homogeneity of particles distributed on the surface and that the average particle size increased with the increase in the number of laser pulses. Silver (Ag) electrodes were deposited on the ZnTe/ZnO/Si films, and detector characteristics, including (I-V) those in illuminated and dark conditions, were determined. Photosensitivity studies indicated that the maximum detector responsivity was 31.892 µA/mW at 460 nm. The highest values of specific detectivity and external quantum efficiency were 3.26×10^{17} Jones and 96.075%, respectively. ON/OFF measurement was performed to investigate the response/recovery time and switch behavior of the photodetectors.

INTRODUCTION

Zinc oxide (ZnO) and zinc telluride (ZnTe) films have attracted the attention of many researchers in the field of optoelectronic technology because of their properties that make them suitable for electro-optical devices, including photovoltaic devices, photodetectors, light-emitting diodes, and window layers in heterojunction of solar cells. ZnO films have gained importance for several reasons: they are relatively cheaper compared with other material and grow along the (001) direction at relatively low temperatures. Growing ZnO on substrates, such as glass, quartz, and silicon, at relatively low temperatures is important in solar cells, gas-sensing devices, and photodetectors [1]. In addition, ZnO has a wide and direct energy gap of approximately 3.37 eV [2, 3]. This compound is characterized by high thermal conductivity and electronic mobility [4]

ZnO is one of the important environmentally friendly oxides [5]. Thin films are deposited through several techniques, the most important of which is pulsed laser deposition (PLD) technique, which is considered a good deposition technique because of its various advantages, such as low processing temperatures, easy implementation, and the absence of corrosive gas [6].

Optical detectors, in general, are electronic devices that convert incident light rays into an external electrical signal. Detectors are types (photon detectors, thermal detectors), where thermal detectors depend in their work on absorbing the heat of the incident rays [7], as they cause a change in the temperature of the absorbing layer. The absorption light causes a change in the temperature of the device and thus leads to a change in some properties such as electrical conductivity. The output of the thermal detector is proportional to the amount of energy absorbed per unit time by the detector, given that the absorption efficiency is constant for all wavelengths. As for photonic detectors, the basis of their

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work depends on the flux of incident photons [8]. These photons interact with materials, electrons are emitted from the valence band to the conduction band of the semiconductor, or between the doped levels and one of the energy bands in the non-self-conductor, this type of excitation causes a change in the density of the charge carriers of the semiconductor, and thus a change in electrical conductivity.

Material and Methods

ZnO and ZnTe powders with a purity of 99.99 were used. The powders were pressed to prepare the target, which was disk shaped and had a thickness of 0.5 cm and a diameter of 2 cm. Afterward, ZnO and ZnTe films were grown as layers on a Si (111) (n-type) and FTO glass substrate via the PLD technique, and the substrate was placed parallel to the target to obtain a good homogeneous films. Deposition was carried out inside a vacuum chamber evacuated to a pressure of 5×10^{-4} mbar using a Nd:YAG laser with a wavelength of 1064 nm, frequency of 6 Hz, energy of 180 MJ, and 700 pulses. Photodetectors were manufactured through the deposition of silver metal (Ag) on ZnTe/ZnO/Si using a metal mask containing a set of surface holes via the high-vacuum (10^{-4} mbar) DC sputtering method. Detector measurements, including those of I-V characteristics in the light and dark, spectral response, detectivity, and quantum efficiency, were conducted.

Figure 1. PLD technique

Results and Discussion

Figure (2) shows the X-ray diffraction (XRD) pattern of ZnTe/ZnO films deposited on the FTO glass. The figure shows the appearance of the peaks {(101), (200), (211), (220), (310)}, which belong to the FTO substrate. According to the international standard card (JCPDS No. 014-1445), the peaks {(100), (002), (101), (102), (110), (103), (112)} belong to ZnO, which has a polycrystalline structure of the hexagonal type. This finding is in well agreement with the international standard card (JCPDS No. 36-1451) for ZnO. The other peaks {(111), (220), (440), (331)} belong to ZnTe, with the cubic phase as the dominant phase of growth in the direction of (111). These peaks agree well with the international standard card (JCPDS No. 15-0746) for ZnTe. The high peaks belonging to ZnO and ZnTe indicate the good crystallinity of the prepared films [9].

When the number of laser pulses increased, the number and size of nanostructures on the surface of the prepared films increased because the particles aggregated to produce larger particles [10].

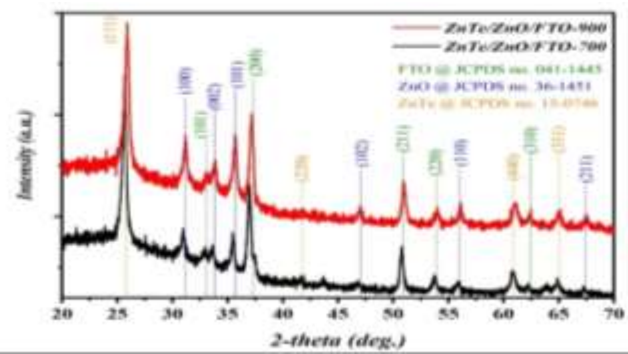

Figure 2. XRD patterns of ZnTe/ZnO/FTO at different laser pulses (700 and 900).

Figure 3 shows the field-emission scanning electron microscopy (FE-SEM) images of ZnO/ZnTe/Si films prepared via the PLD technique. PLD Si-based ZnO films prepared with the ZnTe layer as the buffer layer were characterized by a good crystallization quality, and spherical and condensed particles were observed; the white particles were ZnO particles randomly distributed on the substrate, and this result is agreement with that of another research [11]. A smooth surface morphology was achieved by introducing the ZnO layer into the silicon substrate with ZnTe as a buffer layer. The ZnTe films displayed homogeneous and smooth surfaces and were full of closely packed grains and free of voids and cracks.

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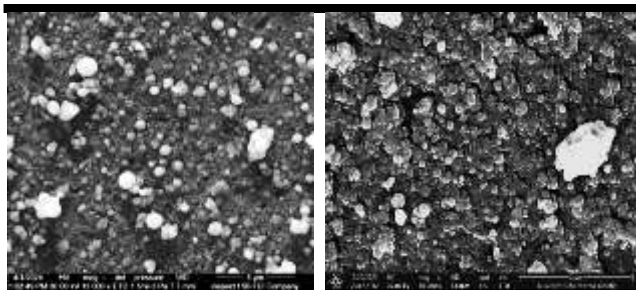

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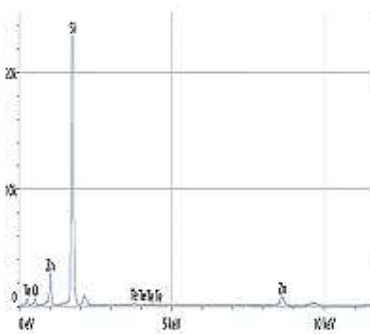
Figure 3 FE-SEM images of ZnO/ZnTe/Si at different laser pulses prepared at (A) 700 and (B) 900 pulses at 180 MJ.

The chemical composition of the ZnO/ZnTe film was confirmed through energy dispersive X-ray spectroscopy (EDX) analysis (Figure 4). Figure 4 shows the presence of peaks belonging to O and Zn, which originated from ZnO and ZnTe nanostructures determined through elementary characterization. Another peak was observed for Te, which came from the ZnTe layer only, and another peak for Si, which originated from the substrate. The prepared films were characterized by their good purity and the absence of other impurities except the basic elements mentioned.



Element	Weight %
O	10.9
Si	73.2
Zn	13.8
Te	2.0

Figure 4 EDX analyses of ZnO/ZnTe/Si thin films at 700 pulses.

4- Characteristics of (ZnO/ZnTe/Si) photodetectors

Figure 5 shows the curve of the I-V characteristics in illuminated and dark conditions and in forward and reverse biases for the ZnO/ZnTe/Si detector manufactured at different numbers of laser pulses and light intensities (6, 14, and 26 MW/cm), where the curve (I-V) showed a direct relationship between the current and applied optical power. A distinct increase in the current was obtained when the applied optical power was increased at the forward and reverse bias voltages. In addition, the forward illumination/dark current showed an increased behavior with the increased applied bias voltage; the increased reverse photocurrent as a function of bias voltage was attributed to the possible surface leakage [12].

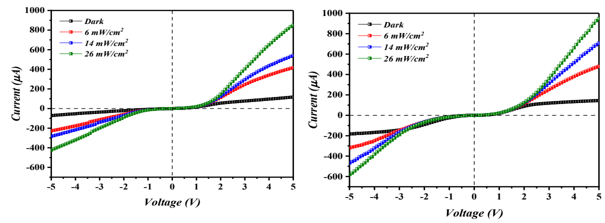


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Figure 5 I-V characteristics of the ZnO/ZnTe/Si photodetector prepared at different laser pulses and a laser energy of 180 MJ. (A) 700 and (B) 900 pulses.

Figure 6 shows the current–time curves for the manufactured ZnO/ZnTe/Si photodetector. ON/OFF measurements were performed to verify the response/recovery times and switching behavior of the manufactured photodetectors at various laser pulses. These measurements were carried out over 20 s and at a light intensity of 26 MW/cm2 for different states (ON/OFF). The resulting current grew rapidly to specific values with the increase in laser pulses. The photoresponse behavior depended on the number of laser pulses used. The detector manufactured at 900 pulses showed a better optical response. The response and recovery times of the detector were measured and reached 0.52 and 0.32 s, respectively. This behavior indicates the rapid injection of electrons and their relatively slow (e-h) recombination [13].

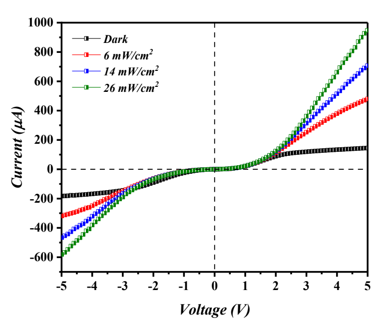
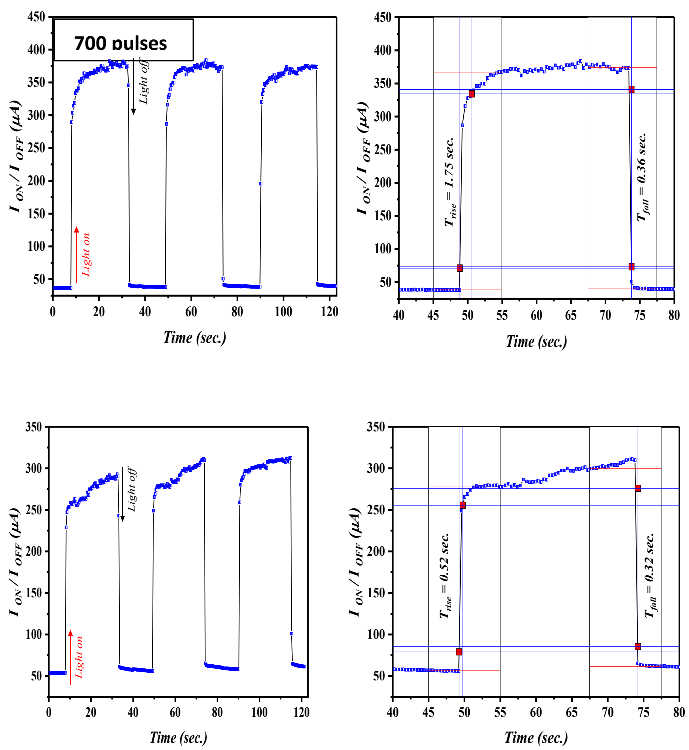


Figure 6 Switching behavior of ZnO/ZnTe/Si photodetectors fabricated at different laser pulses with response/recovery time.

Figure 7 shows the spectral responsivity curves as a function of wavelength for the manufactured ZnO/ZnTe/Si detectors. The spectral responsivity of the detector was studied at the wavelength range of 300–800 nm. Figure 7a shows the presence of two peaks for the spectral responsivity. The first peak was caused by the absorption edges of ZnO and ZnTe and the second peak by the absorption edge of the silicon substrate [14].

The detector manufactured at 900 pulses (Figure 7b) had a higher spectral responsivity. Its value reached 35.758 µA/mW at the wavelength of 460 nm, and this finding was due to the film having the highest internal building voltage and the longest life among the minority carriers and the great conductivity of the ZnO/ZnTe/Si film; this region had a high efficiency in separating the doublets (e - h) generated by the internal electric field and the lack of recombination processes, and thus, the spectral responsivity was the highest possible in this region [15].



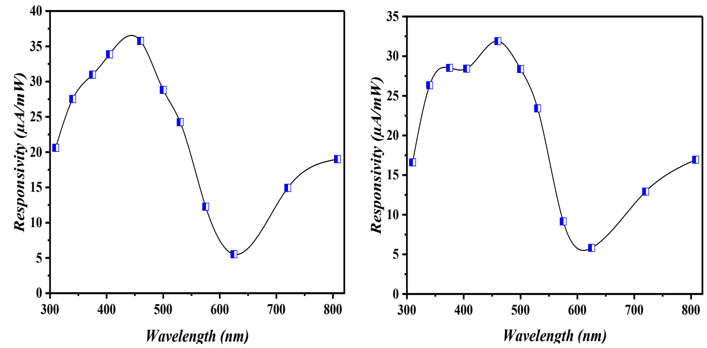


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Figure 7 Photoresponsivity of the fabricated ZnO/ZnTe/Si photodetector at 180 MJ and different laser pulses. (A) 700 and (B) 900 pulses

Figure 8 shows the detectivity spectrum of the manufactured Zno/ZnTe/Si detector. The detectivity value was calculated using the relationship $D^* = \frac{R_\lambda (A)^{\frac{1}{2}}}{\sqrt{2e}\, I_d}$ [16]. The detectivity spectrum of the detector manufactured at 700 pulses (Figure 8A) contained the detection peaks of 2.92×1017 and 3.26×1017 Jones at the wavelengths of 375 and 460 nm, respectively. These peaks formed due to the presence of two peaks in the spectral responsivity of this detector at the same wavelengths.

When the number of laser pulses increased (Figure 8B), the detectivity of this detector decreased, which can be attributed to an increase in the noise current and led to a decrease in the detectivity of the Zno/ZnTe/Si detector. The highest detectivity value for this detector was 2.34×10^{17} Jones at a wavelength of 460 nm.

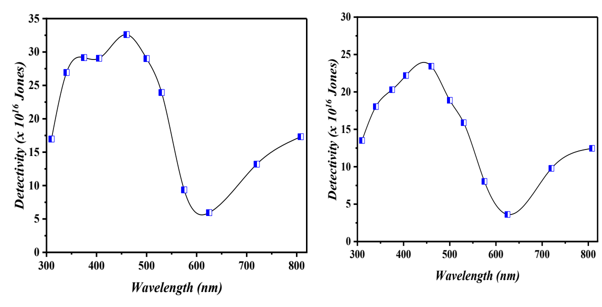

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Figure 8. Photodetectivity of the fabricated ZnO/ZnTe/Si photodetector at 180 MJ and different laser pulses. (A) 700 and (B) 900 pulses.

Figure 9 shows the quantum efficiency curves as a function of wavelength for the manufactured Zno/ZnTe/Si detector. The highest value of quantum efficiency was 96.057% at the wavelength of 340 nm for the detector manufactured at 700 pulses. Figure 9b reveals that the quantum efficiency of the detector increased when the number of laser pulses increased to 900 as the quantum efficiency reached 103.695%. This finding was due to the increase in the amount of absorption coefficient in the depletion region and the decrease in reflectivity. Consequently, the spectral responsivity and detectivity in this region increased because quantum efficiency is linked to the spectral responsivity through the equation $\eta = R\,[h\nu\,(eV)]$ [17].

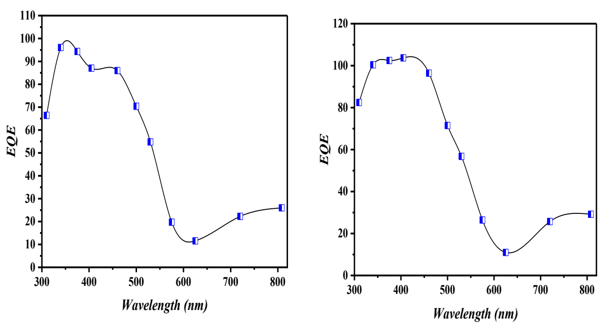

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Figure 9 External quantum efficiency of the fabricated Zno/ZnTe/Si photodetector at 180 MJ and different laser pulses. (A) 700 and (B) 900 pulses.

Conclusion

GaN/ZnO films were deposited on silicon and FTO glass substrates at different laser pulses via a PLD technique. These films were annealed in an oven at a temperature of 400 °C. The results on XRD characteristics show that ZnTe/ZnO films had a hexagonal and cubic structure. The ZnTe/ZnO films deposited on Si indicated that the crystalline quality was high with the use of the ZnTe buffer layer. FE-SEM measurement of the thin films unveiled a homogeneous structure without cracks and spherical and condensed nanoparticles. The white particles were ZnO particles randomly distributed on the black background. Good results were achieved when the ZnTe film was introduced as a buffer layer. EDX measurement revealed the absence of impurities in the ZnTe/ZnO films. Detector characteristics revealed good response/recovery times, which decreased with the increase in laser pulses for the thin films. The spectral responsivity improved with the increase in the number of laser pulses, and the quantum efficiency increased from 96.057 to 103.695 when the number of laser pulses increased from 700 pulses to 900 pulses

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تصنيع أغشية رقيقة من ZnO/ZnTe/Si باستخدام تقنية الترسيب بالليزر النبضي لتطبيقات الكواشف الضوئية

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الملخص:

تم ترسيب الأغشية الرقيقة ZnTe/ZnO ذات التراكيب النانوية بواسطة تقنية الترسيب بالليزر النبضي لتطبيقات الكاشف الضوئي. تم ترسيب الأغشية على ركائز من السيليكون من النوع n وزجاج FTO عند طاقة (180 MJ) وعدد نبضات ليزر (٧٠٠ و٩٠٠) نبضة. تم دراسة الخواص التركيبية للأغشية المحضرة بواسطة أنماط حيود الأشعة السينية، وتبين أن الغشاء يحتوي على تراكيب سداسية ومكعبة متبلورة. تم التعرف على التركيبات الأولية لأغشية ZnTe و ZnO الرقيقة من خلال تحليل الأشعة السينية المشتتة للطاقة (EDX). أظهرت فحوصات المجهر الالكتروني الماسح ذو تأثير المجال FE-SEM أن الاغشية تظهر تجانس جيد للجسيمات الموزعة على السطح وأن متوسط حجم الجسيمات يزداد مع زيادة عدد نبضات الليزر. تم ترسيب أقطاب الفضة (Ag) على أغشية ZnTe/ZnO/Si وتم إجراء فحوصات الكاشف، بما في ذلك خصائص (I-V) في حالة الاضاءة والظلام. أظهرت فحوصات الحساسية الضوئية أن أقصى استجابة للكاشف كانت μA/mW ٣١.٨٩٢ عند الطول الموجي 460 nm. وان أعلى قيم للكشفية النوعية والكفاءة الكمية الخارجية كانت Jonse 3.26×10^{17} و% ٩٦.٠٧٥ ،على التوالي. تم إجراء فحص التشغيل/الإيقاف للتحقق من وقت الاستجابة/الاسترداد للكواشف الضوئية المصنعة.

الكلمات المفتاحية: أغشية ZnO/ZnTe الرقيقة، تقنية الترسيب بالليزر النبضي، الكواشف الضوئية.