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Research Article

Photodetector Based on Titanium Oxide Nanoparticles Produced via Pulsed Laser Ablation

Ban A. Bader,[1] Iman H. Hadi,[2] Muna Y. Slewa,[1] Khawla S Khashan,[2] and Farah A. Abdulameer[3]

[1]*Department of Physics, College of Education, University of AI–Hamdaniya, AI–Hamdaniya, Nineveh, Iraq*
[2]*Applied Sciences Department, University of Technology, Baghdad, Iraq*
[3]*College of Health and Medical Techniques, Gilgamesh Ahliya University, Baghdad, Iraq*

Correspondence should be addressed to Khawla S Khashan; 100082@uotechnology.edu.iq

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TiO_2 nanoparticles (NPs) were produced via utilized nanosecond laser ablation of titanium in water. The description of these NPs was employed utilizing XRD, SEM, and UV-VIS. Then, optoelectronic properties were investigated via a drop-casting of TiO_2 NPs on the Si wafer substrate. XRD results show the formation of anatase TiO_2. The SEM exhibits a spherical shape with sizing changing from 5 nm to 50 nm. The bandgap was 3.6 eV which was determined from the Tauc chart. The IV characteristic of the TiO_2NPs/Si heterojunction showed good rectifying behaviour, with a maximum responsivity of about 0.7 A/W at 310 nm.

1. Introduction

Metal oxide nanostructure material is a very interesting nanomaterial owing to its unique electric, magnetic, optical, and chemical characterization [1]. These characterizations make them suitable to be applied in different application areas like solar cells, photodetectors, catalysts, antimicrobial sensors, and batteries [2–6]. TiO_2 nanostructure material is one of the excellent metal oxide semiconductor materials owing to its important features like high transparency, high refractive index, good chemical stability, relative hardness, and wide gap. These material oxides exist in three diverse structure systems: rutile (tetragonal), anatase (trigonal), and brookite (orthorhombic) [7–12]. Many techniques were applied to prepare TiO_2 nanoparticles like sol-gel, chemical vapor deposition, sputtering, and hydrothermal method [13–18]. Nanosecond pulsed laser ablation method in the fluid environmental process is a very appropriate procedure to produce TiO_2 NPs with different sizes, shapes, and forms depending on the laser ablation parameters like wavelength, fluence, number of laser pulses, and liquid medium. Recently, it has provided a good, simple, and low-cost procedure for the production of size-controlled nanoparticles in solution with a high purity of nanoparticles [19–24]. In this process, irradiation of a target, which is immersed in a liquid with a pulse, starts the foundation of plasma and removal of material. These plasmas have species like ions, atoms, and clusters. The species in the plume collide and react with molecules of the surrounding medium, generating new compounds including atoms from both the target and the solution. Moreover, due to high-density conditions, this method provides manufacturing of unique materials which are inaccessible using traditional methods [8, 9, 12]. Therefore, many researchers have utilized the production of nanoparticles such as metal oxide, nitride, carbon, metal, and metal carbide via laser ablation in liquid [25–29]. In this research, we prepare TiO_2 NPs using pulsed (ns) laser ablation in solution and investigate the optoelectronic features.

2. Materials and Method

The process of laser ablation was used to produce TiO_2NPs in deionized water. TiO_2NPs were produced by employing a 1064 nm Q-switched pulsed Nd: YAG laser (200 mJ, 7 ns) to ablate titanium plate immersed in (2 ml) deionized water (DIW), operated with 200 mJ and 150 pulses. A structure of

TiO_2 NPs was examined by X-ray diffraction (600-Shimadzu; CuKα = 1.54060 Å), the topography and nanosized of TiO_2NPs were determined via SEM from TESCAN, and the absorption was assessed via Shimadzu 1800 UV-VIS spectrophotometer. To measure the optoelectronic properties, the TiO_2 NPs were deposited on a silicon substrate by the drop-casting process. A dark current-voltage characterization was carried out using a Tektronix CDM 250 and power supply. The responsivity of the TiO_2 NPs/Si heterojunction photodetector was evaluated in a spectral range (200–500) nm employing a calibrated monochromator.

3. Results and Discussion

Figure 1 indicates XRD pattern of TiO_2NPs produced in DIW by laser ablation at 200 mJ for 150 laser pulses. The spectrum exhibits peaks at $2\theta = 25.2^{\circ}$, 36.4°, and 38.9° which are assigned to (101), (103), and (112) phases that are matched to the crystal planes of anatase TiO2 (JCPDS 21-1272) [7]. The size of the TiO_2 nanostructure (D) was determined by the Debye-Scherrer equation [7]: $D = 0.94\lambda/\beta \cos\theta$, where λ is the X-ray wavelength, θ is the angle of Bragg's diffraction, and β is full width at half maximum. This data is shown in Table 1.

Figure 2 exhibits an SEM image of TiO_2NPs prepared via 200 mJ and 150 pulses. The image shows that the particles have a spherical-like shape and size changes from 5 nm to 50 nm. Also, there is an individual particle that can be seen with high aggregations owing to the electrostatic attractive force through nanoparticles. As a result of the interaction between laser radiation and the submerged titanium target, a very thin layer of Ti metal is heated to its melting point. The solvent layer near to the Ti metal warms up to a temperature which is substantially higher than the liquid's boiling temperature at atmospheric pressure as a result of the transfer of heat from the metal to the surrounding medium. The outcome is the formation of bubbles. TiO_2NPs is created as an effect of the reaction among the molten metal and the oxygen in the evaporated solvent. This technique was used to create nanoparticles of various shapes and sizes. For example, Fadhil et al. [6] prepared CuO NPs with a size change from 10 nm to 100 nm; Khashan and Abbas [19] used the same technique to create spherical-shaped Indium nitride (InN) nanoparticles with particle sizes in the range of 2–20 nm; as well as Khashan and Mahdi [21] to create ZnMgO nanocomposites with a flower-like hierarchical structure and a full array of about 2 μm. While, Hameed et al. [24] generated carbon nanoparticles separated long multiwall carbon nanotubes (MWCNT) with hollow core in different dimensions, larger in diameter (66–75) nm and other sizing about (25–30) nm. Khashan el al. [29] produced silicon carbide nanoparticles with spherical shape and average size ranging from 25 nm to 55 nm.

Figure 3 exhibits the relationship between $(\alpha hv)^2$ and (hv) of TiO_2 nanoparticles, while the insert in the figure demonstrates the change of absorption per a wavelength. The bandgap was determined from extrapolating the linear part in Figure 3, and it was found to be 3.6 eV. The larger energy gap for TiO_2NPs compared to its bulk value (3.2 eV)

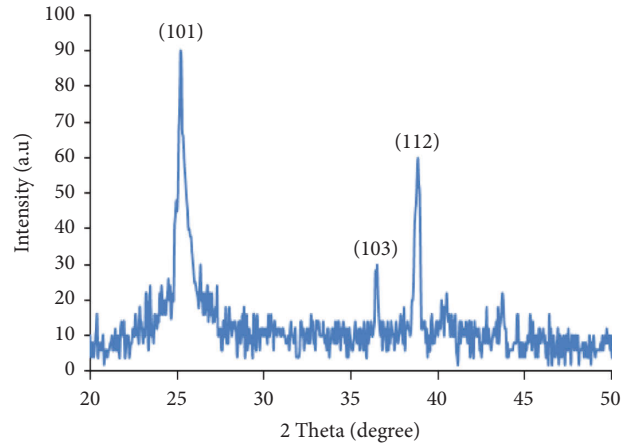

Figure 1: XRD pattern of TiO_2NPs.

may provide confirmation for the quantum size effects. As an outcome, the effectively synthesized TiO_2 NPs in this study were given distinction for the blue shift value of about 0.4 eV, which was associated to the phase structures, crystal size, crystallinity, and quantum size effects [30].

The current-voltage (I–V) measurement for the TiO_2NPs/Si heterojunction photodetector was shown in Figure 4. It was noticed that the junction has good rectification and also noticed that the transport features were dominated via diffusion or recombination within the junction at low voltage, while the space charge limited impact became the main transport mechanism at higher bias. The value of turn-off voltage was 3.2 V. This high value was related to the high value of resistivity of TiO_2 film. The leakage currents in the reverse direction are low and voltage-independent and no breakdown was shown in the heterojunction for bias voltage <8 V. By using the semi-log I–V characteristic for the forward bias and the equation: $n = (q/KT)(\Delta V/In(I/I_s))$, where q is the charge of an electron, T is the temperature, k is a Boltzmann constant, and I_s is the saturation current, the ideality factor was valued and found to be 1.2, which demonstrates that the heterojunction offers the best junction assets.

Figure 5 presents the responsivity of the TiO_2NPs/Si photodetector measured at 2 volt bias. As shown, a quick rise in spectral responsivity (R) was illustrated at wavelength range (210–310) nm. The maximum value was 0.71 A/W @ 310 nm owing to absorption edge of TiO_2 nanomaterial [31–33] film, and the additional response peak was observed in the range of 790–860 nm, related to an absorption of the substrate. Therefore, it's a good device for utilization in UV detection. Furthermore, the quantum efficiency (η) for TiO_2NPs/Si detectors is demarcated as the ratio of the number of produced electrons to the number of incident photons and it's determined using the formula: $\eta = 1240R_\lambda/\lambda\,(nm)$, which was found to be 2.84 at 310 nm. Owing to the broadening of the depletion width brought on by raising the reverse bias, the value is greater than unity. This finding suggests that at this reverse, the photodetector is completely exhausted, leading to effective carrier collection from photogenerated light. In addition, by absorbing photons and producing the photomultiplication effect, the

Table 1: XRD data for TiO_2 nanostructure.

2θ (degree)	Grain size (nm)	Orientation (hkl)
25.2	8	101
36.4	28	103
38.9	17	112

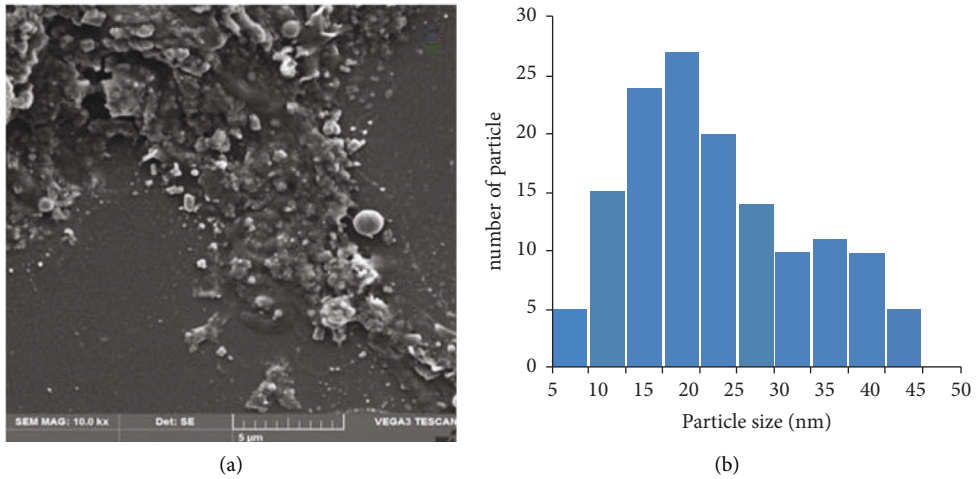

Figure 2: (a) SEM image of TiO_2NPs and (b) size distribution.

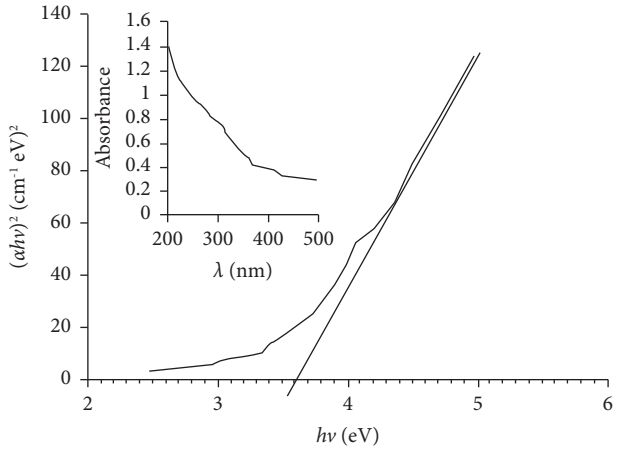

Figure 3: The relation between $(\alpha h\nu)^2$ and $(h\nu)$ of TiO_2 NP.

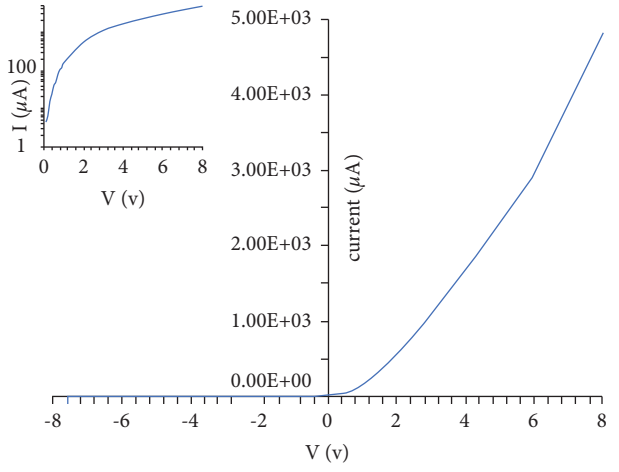

Figure 4: I_{dark}–V features of the TiO_2NPs photodetector. In the insert figure, Semi-log I_f–V scheme.

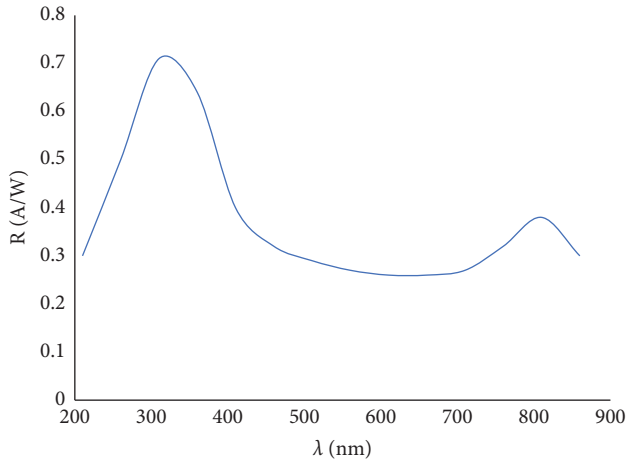

Figure 5: Responsivity of TiO_2NPs/Si photodetector.

supplied bias dramatically raises quantum efficiency by encouraging charge injections and creating free carriers.

4. Conclusion

We have a good synthesis of TiO_2NPs based UV photodetector using simple pulsed Nd-YAG laser ablation of Ti metal in water. XRD results show the formation of anatase TiO_2. Spherical-like shapes and sizing changes from 5 nm to 50 nm were investigated from SEM. The bandgap was 3.6 eV which was determined from the Tauc chart. The IV characteristic of the TiO_2NPs/Si heterojunction showed good rectifying behavior, with the maximum responsivity of approximately 0.71 A/W at 310 nm, this method is extremely promising, simple, and low-cost for fabricating photodetectors.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

All authors contributed equally to this study.

Acknowledgments

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