Characterization of ZnO–TiO₂-coated tapered fibres synthesized by a low-temperature hydrothermal method

¹Roslan F. S., ¹Saidin N., ²Hatta M. A. M., ¹Hasbullah N. F. and ³Thirunavakkarasu P. M.

¹ Department of Electrical and Computer Engineering, International Islamic

University Malaysia, 53100 Kuala Lumpur, Malaysia; norazlina@iium.edu.my

² Department of Science in Engineering, Kulliyyah of Engineering, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia

³ Communication Technology Section, University Kuala Lumpur – British

Malaysian Institute, Bt. 8, Jalan Sungai Pusu, 53100 Gombak, Selangor, Malaysia

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Abstract. We characterize ZnO-nanorod fibres doped with different concentrations of TiO₂ powder which is introduced on the final stage of synthesis of ZnO nanorods, using a low-temperature hydrothermal method. Their surface morphology, size of particles, behaviour of crystallites and optical properties are investigated using techniques of scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD) and an optical spectrometer. A presence of ZnO nanorods and a globular structure of TiO₂ are confirmed by the SEM analysis. The EDS spectra and chemical-element mapping reveals a presence of Ti incorporated into a globular surface, along with Zn. The XRD analysis testifies that ZnO doped with TiO₂ has a primary crystallite phase of ZnO. ZnO doped with 10 and 15 mM of TiO₂ shows a stronger and more expressed peak corresponding to (002) and (011) planes, which implies improved crystallinity of ZnO-TiO₂ system. Optical properties of ZnO-TiO₂ are studied by measuring the intensity of halogen-source light transmitted through the fibres. The ZnO & 15 mM TiO₂ fibre sample shows the lowest intensity of the transmitted light due to higher refractive index of a cladding layer coated under condition of high TiO₂ concentration. The increased light leakage in such a fibre can improve sensitivity of a relevant sensor, especially a gas one.

Keywords: zinc oxide, titanium dioxide, doping, ZnO–TiO₂, nanorods, hydrothermal method.

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1. Introduction

Zinc oxide, ZnO, represents a semiconductor metal oxide. It is widely used in many applications, especially in sensor fabrication and medical or cosmetics industries. A wide band gap (3.37 eV) and a large exciton-binding energy (60 meV) stipulate various applications of ZnO. In particular, due to its high excitation potential at the room temperature, low power consumption and long-term stability, ZnO has been employed as a material for different gas sensors [1]. Moreover, ZnO manifests a number of advantages in photovoltaic technology [2] and water treatment [3].

Numerous studies have revealed different properties of ZnO nanostructures. A successful synthesis of ZnO nanostructures in one- (1D), two- (2D) and three- (3D) dimensional patterns has been reported. Formation of ZnO nanorods, nanoneedles and hollow spheres can be observed in 1D structures, whereas nanopellets and dandelion patterns are available in either 2D or 3D structures [4]. By manipulating such synthesis parameters as a type of precursor ions [5],

precursor-ion concentration and a temperature of synthesis, different nanostructures can be obtained, which are suitable for different sensing requirements. In particular, ZnO nanorods demonstrate a well-aligned and highly oriented structure [6], which helps in trapping gas molecules between the nanorods. In the present work, we will obtain ZnO nanorods by applying a low-temperature hydrothermal method. This method is preferred due to its simplicity, cost-effectiveness and high sensing sensitivity [7, 8].

Recently a pure ZnO system has been applied in sensor technologies. A significant improvement of the corresponding characteristics can be attained via controlling the size and shape of ZnO or introducing catalytically active additives into a sensing layer, e.g., through doping or surface modification. Furthermore, addition of some catalysts to the sensing layer via doping can improve both the band gap and the exciton-binding energy of ZnO. Coupling of a ZnO-nanostructure system with another metal oxide has been found to increase the rate of photocatalytic reactions [5].

Titanium dioxide, TiO_2 , has long been known as a good catalyst, due to its high-temperature stability and high environmental tolerance [9]. In the study [10], TiO_2 has been coupled with the ZnO system basing on its ability to ease oxidation and reduction processes on a synthesized surface. All active sites of TiO_2 interact fully with reactants, thus providing a saturated change of resistance and contributing to a maximal sensitivity. Besides, the work [10] has reported good photocatalytic properties of TiO_2 resulting from irradiated light that facilitates the oxidation process. The process is initiated by photoinduced effect developed due to permanent generation of electron–hole pairs. This phenomenon supports the oxidation reaction and increases the conductivity of TiO_2 . Then the response time decreases and the sensitivity of sensor becomes enhanced [11].

The work [5] has analyzed photocatalytic properties of ZnO/TiO₂-composite powders produced by a combustion method with different percentage ratios. These properties have been assessed by monitoring discoloration of samples via absorbance measurements, which has been performed with a Jenway 6505 UV-Vis spectrometer at the light wavelength 618 nm. The highest catalytic activity has been observed for the ZnO/TiO₂ composite with the percentage ratio 90:10. The study [12] has reported on the synthesis of ZnO–TiO₂ nanocomposites using a polymerizablecomplex method. The authors of this work have examined ZnO–TiO₂ nanocomposite samples with different Ti⁴⁺ and ZnO concentrations such as pure ZnO, 99% ZnO and 1% Ti⁴⁺, 97% ZnO and 3% Ti⁴⁺, and 95% ZnO and 5% Ti⁴⁺. They have revealed that incorporation of 5% Ti⁴⁺ into ZnO system decreases the crystallite growth down to the size 16.89 nm, as compared with the size 24.48 nm found for the pure ZnO system. Moreover, the presence of Ti⁴⁺ increases the band gap (~ 4.86 eV), which must be compared with the value $E_g = 3.31$ eV typical for pure ZnO. This difference is due to exciton-absorption peak caused by the smallest nanoparticles associated with 5% Ti⁴⁺.

Trying to produce a doped ZnO system with better characteristics, in the present work we adopt a simple TiO_2 -doping method based upon TiO_2 powder as a catalyst. Namely, we have synthesized zinc-oxide nanorods into an optical fibre, using a low-temperature hydrothermal method. Some amounts of TiO_2 powder have been introduced on the final stage of the synthesis process. It has turned out that the presence of TiO_2 powder leads to higher concentration of native defects due to better oxidation and reduction processes occurring in the ZnO nanorods. Accumulation of impurities from the TiO_2 powder at the lattice sites can improve the charge-transfer mechanism. Likewise, doping of the ZnO nanorods with the TiO_2 powder increases

substantially the surface-to-volume ratio, thus making the material highly reactive to even small environmental changes.

It follows from the above literature analysis that no attempts have been made to built ZnO nanorods doped with TiO_2 powder in a tapered optical fibre. Although the mixture of zinc oxide and titanium dioxide is a well-known compound [3, 9], applications of $ZnO-TiO_2$ in optoelectronic devices and, in particular, in tapered fibres have not vet been demonstrated. The results obtained by us with a simple doping method can become a basis for a more detailed future characterization of the influence of TiO₂-doping concentration on the properties of tapered fibres coated with ZnO nanorods. In this initial study, we analyze surface morphology, particle sizes, crystallites behaviour and optical properties of the ZnO-TiO₂ nanorods, using standard techniques of scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD) and optical spectrometry. In particular, our investigation of light intensity depending on the concentration of TiO2 powder reveals some special features of the ZnO-TiO2 nanorods. The intensity of light propagating in the fibre decreases due to light leakage occurring at the core-cladding boundaries, which can be related to increased TiO₂-powder concentration and so higher concentration of native defects at the ZnO-lattice sites. As a result, our simple and costeffective doping procedures can promote manifold future applications of tapered ZnO-TiO₂-based fibres.

2. Experimental details

2.1. Preparation of fibre tapering

A standard multimode fibre with the core diameter $62.5 \,\mu\text{m}$ and the cladding diameter $125 \,\mu\text{m}$ ($62.5/125 \,\mu\text{m}$) was used in this work. The fibre was tapered using a Vytran GPX-3400 optical-fibre processor. The tapering profile was set to 5 mm up-taper, 5 mm down-taper and 10 mm waist length. The fibre was tapered to the waist diameter 20 μm . Tapering enhanced sensitivity of the fibre. Then the cladding layer was removed to expose the core. The latter intensified formation of evanescent field around the tapered region. We remind that this field corresponds to a small portion of propagating light that escapes a core–cladding boundary during total internal reflections [13] and, usually, a better sensing performance can be achieved with enhanced evanescent field.

2.2. Synthesis of ZnO nanorods

A hydrothermal method was implemented to synthesize ZnO nanorods on the 20 µm tapered region of the fibre. The fibre was attached to a holder template throughout the synthesis process to secure the tapered region of the fibre. Synthesis of ZnO nanorods involved the three following stages: seeding, annealing and growing.

A seeding solution was prepared using zinc acetate, sodium hydroxide and ethanol. About 1 mM of zinc acetate acting as a source of precursor ions was dissolved in 60 mL of ethanol and stirred vigorously on a magnetic hot plate at 50°C, in order to form a Zn precursor. Upon completing constant stirring for 30 min, the resultant mixture was cooled naturally down to the room temperature to produce a homogeneous solution. 1 mM of sodium hydroxide was separately dissolved in 60 mL of ethanol. The solution was stirred vigorously for 15 min and then set aside to cool. As the temperatures of both solutions had dropped to the room temperature, 60 mL of ethanol was stirred together with the Zn precursor. Subsequently, 2 mL of sodium ethoxide in the form of droplets was added to the Zn precursor. During this stage, pH of the ZnO precursor was regulated to be between 8 and 9, since this parameter might affect the morphology of ZnO nanostructures [14]. The ZnO precursor was ultrasonicated at 60°C for 2 h, using Crest

Ultrasonics. As a result, a cloudy solution was formed, thus indicating a presence of the ZnO precursor.

To prepare a ZnO-seed layer, the tapered fibre was immersed in the ZnO precursor so that only the tapered region was involved. The fibre was attached to the holder template to obtain fine deposition of ZnO on the tapered region, without affecting the fibre coating. The fibre was hanged and immersed vertically to form a uniform deposition. A seeding solution was slowly stirred at the ambient temperature to ensure homogeneous deposition of precursor ions on the surface of the tapered region. This slow stirred-immersion method was applied for 30 min, thus forming a ZnO root base on the fibre surface. This root base acted as a 'magnet' to attract ZnO particles into the growing solution later on.

The seeded fibre was annealed at 90°C for 3 h to improve crystallinity of the ZnO base. The final stage of this low-temperature hydrothermal method required a growth of ZnO-nanorod particles inside the seeded region. The growing solution was formed by mixing 10 mM of zinc nitrate hexahydrate, 10 mM of hexamethylenetetramine and 1000 mL of deionized water. The solution was stirred homogeneously. The fibre was immersed into the growing solution and placed in an oven kept at 90°C for 2 h. Finally, the fibre was withdrawn from the growing solution and rinsed with deionized water in order to remove excess impurities. All the seeding, annealing and growing procedures applied for obtaining the ZnO nanorods had been described in a more detail in Ref. [15].

Finally, TiO_2 powder was added to the host (ZnO-containing) growth solution. Different concentrations of dopant were applied to study the concentration effect on the surface morphology, crystallinity and the optical properties. TiO_2 dopants with the concentrations equal to 0.1, 1, 5, 10 and 15 mM were added to 10 mM of ZnO precursor. The corresponding concentration ratios for the ZnO and TiO_2 powders amounted to 1:0.01, 1:0.1, 1:0.5, 1:1 and 1:1.5, respectively.

2.3. Characterization of ZnO–TiO₂-coated fibres

Several fibre samples were prepared to study comprehensively the surface morphology and the characteristics of ZnO–TiO₂ nanorods. The samples were characterized using the SEM (JEOL JSM-IT100) at the magnification 10000×. Besides, the EDS was used to validate the presence of Zn and Ti elements in the fibre samples. Afterward, the XRD was applied to study the crystalline structure of ZnO and ZnO–TiO₂ nanorods, using PANalytical XPert Pro 3. Cu-K α radiation was used, the scanning speed was set to 0.05°C/s, and a 2 θ scan range was fixed from 30° to 70°. Finally, we studied the effect of TiO₂ concentration in the ZnO–TiO₂ nanorods on the light intensity, using an Avantes Starline AvaSpec 2048 spectrometer connected to a halogen light source (AvaLight-HAL-S-Mini). The wavelength range 350–1100 nm was probed.

3. Results and discussion

Fig. 1 illustrates the surface morphology of ZnO and ZnO–TiO₂ deposited on the tapered fibres with the hydrothermal method. One can see that the morphology of the ZnO nanorods remains homogeneous and dense, with the average size being equal to 394 nm. The addition of TiO₂ to ZnO modifies the surface morphology of the nanorods so that globular TiO₂ structures are randomly distributed, resulting in agglomerated clusters of TiO₂ particles. As seen from Fig. 1b–f, the fact that the globular TiO₂ structure is being formed becomes more obvious with increasing dopant concentration. Besides, the average length of the nanorods increases (to respectively 639 nm and 440 nm) when relatively low TiO₂ concentrations (0.1 and 1 mM) are added to ZnO. However, growing ZnO nanorods become distorted with further increase in the dopant



Fig. 1. Surface morphology of nanorods composed of (a) ZnO, (b) ZnO & 0.1 mM TiO₂, (c) ZnO & 1 mM TiO₂, (d) ZnO & 5 mM TiO₂, (e) ZnO & 10 mM TiO₂, and (f) ZnO & 15 mM TiO₂, as observed using SEM at the magnification $10000\times$.

concentration from 5 to 15 mM. This observation is consistent with the results reported earlier by Zhu et al. [16] and Ayed et al. [17]. The reason might be reactions taking place between the ZnO precursor and the TiO₂ powder. In general, matching of the ionic radii of Ti⁴⁺ and Zn²⁺ ions is needed. [Notice that the corresponding parameters are equal to 0.068 and 0.074 nm, respectively [16]]. Matching the ionic radii would enable the situation when TiO₂ reacts with the Zn precursor and substitutes the Zn²⁺ ions. The reaction of TiO₂ and ZnO occurs alongside the grain boundaries, where Ti elements diffuse into the grain bulk of ZnO. Therefore, a small amount of TiO₂ would promote the growth of ZnO and provide longer ZnO nanorods. Nevertheless, higher concentrations of TiO₂ at the ZnO boundaries distort significantly the growth of the ZnO grains. Therefore, formation of ZnO nanorods is restrained as the TiO₂ concentration increases.

Our further analysis performed with ImageJ software aims at finding the maximum diameter and the area the TiO₂ particles cover on the ZnO nanorods. The appropriate results are summarized in Table 1. As the TiO₂ concentration increases from 0.1 to 15 mM, the maximal deposited diameter of TiO₂ also increases. Hence, the coverage area A_{TiO2} of the globular TiO₂ particles then increases, too (see Table 1). Increasing TiO₂ concentration increases the surface-to-volume ratio for our fibre sensor, which should improve the resulting sensing response of the ZnO–TiO₂ nanorods.

Table 1. Summary of some morphologic measurements made for ZnO and TiO_2 .					
Sample	Average length of ZnO nanorods $L_{av, ZnO}$, nm	Average diameter of globular TiO ₂ structure, nm	$\underset{\times 10^{-12}}{A_{\text{TiO2}}}\text{m}^2$		
ZnO	394	_	_		
ZnO & 0.1 mM TiO ₂	639	1.738	5.189		
ZnO & 1 mM TiO ₂	440	2.363	16.133		
ZnO & 5 mM TiO ₂	287	3.420	25.310		
ZnO & 10 mM TiO ₂	269	3.641	31.010		
ZnO & 15 mM TiO ₂	237	5.663	59.489		

The EDS spectra have been analyzed for validating elemental composition of the samples synthesized by us. As seen from Fig. 2a, the elemental analysis of the ZnO–TiO₂ samples confirms that all the relevant constituents (i.e., Zn, O and Ti elements) are present within the inspection spot, with Zn being the most abundant. Here a presence of additional Au and Pd peaks is due to sputtering of an Au–Pd thin film, which is done for enhancing conductivity in the SEM measurements. The atomic percentages recorded for our ZnO–TiO₂ samples are as follows: 21.33% (Ti), 37.18% (O) and 41.19% (Zn).



Fig. 2. Panel (a) shows EDS spectrum obtained for $ZnO-TiO_2$, with the ordinate axis corresponding to count number per second per electron-volt (cps/eV) and the abscissa axis to energy in keV. Panels (b)–(e) illustrate EDS chemical-element mapping made for TiO₂ (b), Ti, Zn, and O (c), Ti (d) and Zn (e).

Spatial distribution of Zn, Ti and O elements has been further analyzed using the SEM–EDS mapping technique (see Fig. 2b–f). The EDS mapping has detected compositional zoning of chemical elements in our ZnO–TiO₂ samples, thus confirming the presence of O (67%), Zn (21%) and Ti (12%). These findings imply successful incorporation of TiO₂ into the basic ZnO compound. We emphasize that this is the first study revealing successful formation of the globular TiO₂ structure based on direct synthesis of the TiO₂ powder in the ZnO-nanorod structure.

The crystalline structures of ZnO and ZnO–TiO₂ have been characterized using the XRD. According to Fig. 3, ZnO demonstrates the orientation analogous to that of a standard reference JCPDS 98-018-1039, whereby the five major peaks are detected at the diffraction angles 32.2356° , 34.9381° , 36.7607° , 47.0922° and 57.3728° , with an obvious preferred orientation (002). These angles correspond respectively to the reference planes (010), (002), (011), (012) and (110), which are typical for the hexagonal wurtzite structure of ZnO.



Fig. 3. XRD characterization of ZnO and ZnO–TiO₂ with different TiO₂ contents.

The diffraction peaks detected for ZnO doped with different TiO₂ concentrations (0.1, 1, 5, 10 and 15 mM) can be attributed to the reflections from the same planes (010), (002), (011), (012) and (110). These results confirm that the wurtzite structure is formed again, with the absence of any secondary phase. This further suggests that the ZnO lattice sites are successfully doped with TiO₂ and the original phase is retained. Focusing attention on the experimental curve observed for ZnO & 15 mM TiO₂, one can see that the peak position becomes slightly shifted in the (110) plane (from 47.0922° to 48.3389°) when 15 mM TiO₂ is added to ZnO. The shift in the diffraction angle indicates that the lattice parameter of ZnO changes due to incorporation of Ti⁴⁺ into the ZnO lattice, which imposes some lattice distortion. In addition, the diffraction peaks for ZnO doped with 10 mM and 15 mM TiO₂ become sharper and more intense (especially inside the (002) and (011) planes), thus indicating that TiO₂ could improve crystallinity of the ZnO structure.

The lattice spacing d has been calculated using the Bragg relation

$$d = \frac{\lambda}{2\sin\theta} , \qquad (1)$$

where θ is the angle between the normal of diffraction plane and the incident X-ray direction and λ denotes the wavelength of the Cu- $k\alpha$ radiation (i.e., 1.54060 Å). Following from the lattice spacing, the lattice parameters *a* and *c* can be calculated with the relations valid for the hexagonal system:

$$\frac{1}{d^2} = \frac{4}{3} \left(\frac{h^2 + hk + k^2}{a^2} \right) + \frac{l^2}{c^2} \,. \tag{2}$$

Finally, the crystallite size D and the microstrain M of the crystalline structure have been obtained using the lattice parameters and the Scherrer's formula:

$$D = \frac{k\lambda}{\beta\cos\theta} , \qquad (3)$$

$$M = \frac{\beta \cos \theta}{4} \,. \tag{4}$$

As seen from Table 2, addition of TiO₂ up to 15 mM increases both the lattice parameter and the size of crystallites. This increase can be associated with matching of the ionic radii of Ti⁴⁺ and the host Zn^{2+} ions. Note that the increase in the crystallite size found by us contradicts the findings of Refs. [16] and [17]. However, our results agree with the data by Bachvarova-Nedelcheva et al. [5] who have reported the same effect observed when the concentration of TiO₂ incorporated into ZnO becomes higher. Besides, the microstrains get reduced when TiO₂ of the highest concentrations corresponding to 15 mM is added. A minimal microstrain, 114.60×10^{-3} , is achieved at the 15 mM TiO₂ doping, which is approximately 27.9% lower than that peculiar for pure ZnO. It is likely that this effect is caused by a reduction of lattice defects occurring due to addition of a small amount of dopant (see also Ref. [18]).

Table 2. Summary of crystalline measurements made for ZnO and ZnO-TiO₂.

TiO ₂ ,	Lattice p	arameters	Crystallite size	Microstrain
mM	<i>a</i> , Å	<i>c</i> , Å	D, nm	$M \times 10^{-3}$
ZnO	3.210	5.132	2.178	159.13
0.1	3.218	5.129	2.828	122.57
1	3.219	5.126	2.354	147.26
5	3.224	5.131	2.765	125.37
10	3.224	5.153	2.946	117.65
15	3.224	5.134	3.025	114.60

A simple optical setup has been used to analyze the optical properties of ZnO and ZnO–TiO₂, which is based on a halogen light source emitting light at the wavelengths 350-1100 nm. More specifically, we have detected the intensity of light propagating through the coated fibre, using the spectrometer. Our main purpose has been to study the effect of TiO₂-dopant concentration on the intensity of light transmitted through the coated fibre. Fig. 4a displays the intensity curves corresponding to the overall visible range, 350-1100 nm. The curves in the narrower wavelength region 550–620 nm (see Fig. 4b) demonstrate that the light intensity under test decreases gradually at the TiO₂ concentrations 5, 10 and 15 mM. The highest light intensity is detected for the ZnO & 5 mM TiO₂ sample.

It is interesting that ZnO & 15 mM TiO₂ shows a lower intensity in the spectrum than that of pure ZnO. This decrease in the light intensity is caused by influence of titanium defects on the ZnO lattice, which follows from easier oxidation and reduction processes in the coated layer. It is believed that high concentrations of TiO₂ particles agglomerated at ZnO nanorods increase absorption of the material and improve charge-transfer mechanism, thus promoting leakage of light at the core–cladding boundaries of the fibre. Note that higher TiO₂ concentrations in the ZnO nanorods increase the refractive index of the cladding; hence, the light absorption in the material also increases [19]. As a consequence, the light intensity inside the core experiences higher



Fig. 4. Spectra of light intensity transmitted through the fibre made of $ZnO-TiO_2$ with different TiO_2 concentrations, as detected at 350–1100 nm (a) and 550–620 nm (b).

attenuation. This reduces the light intensity for the doped sample with 15 mM of TiO_2 , if compared to the light intensity typical for pure ZnO.

4. Conclusions

Homogeneous and uniform ZnO nanorods have been synthesized in the fibre samples. We have characterized the ZnO nanorods doped with TiO_2 and synthesized by the hydrothermal method onto fibre samples, using the SEM, XRD and EDS analyses. In particular, the surface morphology, the size of particles and the characteristics of crystallites have been studied for the case of ZnO– TiO_2 fibre samples The optical properties of the ZnO– TiO_2 nanorods have also been investigated, using the spectrometry technique.

A high enough concentration of TiO_2 dopant (e.g., 15 mM) distorts a process of ZnOnanorod growth but increases the area of coverage by TiO_2 globules. A presence of Ti incorporated into the Zn lattice confirms the globular structure, which is obtained with our simple direct doping technique. The XRD peaks detected for doped ZnO testify that the resulting material maintains the primary phase of ZnO, while the size of crystallites increases with increasing dopant concentration.

The intensity of light propagating through the ZnO & 15 mM TiO₂ fibre is lower when compared to that observed for pure ZnO. This is due to greater leakage of light occurring at the core–cladding boundaries and greater light absorption of TiO₂. It is also worthwhile that our data of characterization of the ZnO–TiO₂ nanorods can serve as a benchmark for future development of this material. Besides, the fibre samples synthesized by us can be further explored as sensors.

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Анотація. Охарактеризовано волокна на основі наностержнів ZnO, леговані різними концентраціями порошку ТіО₂, введеного на кінцевій стадії синтезу наностержнів ZnO за низькотемпературним гідротермальним методом. Вивчено морфологію їхньої поверхні, розміри частинок, поведінку кристалітів та оптичні властивості за допомогою методів сканувальної електронної мікроскопії (СЕМ), енергодисперсійної рентгенівської спектроскопії (ЕРС), дифракції рентгенівських променів (ДРП) і оптичного спектрометра. Наявність наностержнів ZnO і глобулярну структуру ТіO₂ підтверджено СЕМ-аналізом. Спектри ЕРС, а також картування хімічних елементів засвідчили присутність Ті, поряд із Zn, у глобулярній поверхні. Рентгенівський аналіз фаз засвідчив, що ZnO, легований TiO₂, має первинну кристалітну фазу ZnO. ZnO, легований 10 і 15 мМ ТіО₂, виявляє сильніший і більш виражений пік, що відповідає площинам (002) і (011). Це засвідчує досконалішу кристалічність системи ZnO-TiO₂. Оптичні властивості ZnO-TiO₂ досліджено шляхом вимірювання інтенсивності світла від галогенного джерела, що пройшло крізь волокно. 3разок волокна ZnO із $15\,$ мM TiO $_2$ виявляє найнижчу інтенсивність пройденого світла через вищий показник заломлення шару оболонки, сформованої за умови високої концентрації TiO2. Збільшений витік світла у такому волокні може підвищити чутливість відповідного сенсора, особливо газового.