ZnO-TiO$_2$ nanocomposite materials: fabrication and its applications

K Kusdianto, D F Nugraha, A Sekarnusa, S Madhania, S Machmudah, and S Winardi*
Department of Chemical Engineering, Institut Teknologi Sepuluh Nopember, Kampus ITS Surabaya 60111, Indonesia

*swinardi@chem-eng.its.ac.id

Abstract. Zinc oxide (ZnO) is one of the most commonly used semiconductor materials for various applications, namely as photocatalysts, gas sensors, antimicrobial substances, and photovoltaic cells. The performance of the particles is greatly influenced by the morphology and the optical properties of the particles itself. To improve the performance of ZnO, one method which can be applied is by doping support with other semiconductor materials, such as TiO$_2$. This is caused by electron transfers between ZnO and TiO$_2$ which are able to enhance the stability of ZnO and the electron mobility of TiO$_2$. Therefore, the electron-hole recombination can be inhibited by this mechanism. Fabrication of ZnO-TiO$_2$ can be prepared by several methods, which is gas or liquid phases and solid phase. Spray pyrolysis, chemical vapor deposition, micro-arc oxidation, electrospinning and electron beam evaporation are preparation method for gas-phase synthesis, while sol-gel, hydrothermal, precipitation, solution combustion, pulse plating, and wet impregnation are for liquid phases. In this study, the fabrication methods of ZnO-TiO$_2$ and its application have been reviewed as well as the factors that affect the morphology, performance, and the stability of ZnO-TiO$_2$ nanocomposite. This review is conducted by comparing the analysis results with their performances. It is clearly found that there is an optimum condition for obtaining the best photocatalytic performance by adjusting the ratio of ZnO to TiO$_2$. Furthermore, ratio of ZnO:TiO$_2$ concentration on antimicrobial activity shows a linear performance, and it is obviously observed that the ZnO-TiO$_2$ nanocomposite shows a better performance compared to the pristine ZnO or TiO$_2$ in various applications. We believe that this review will provide valuable information and new insights into possible fabrication methods of ZnO-TiO$_2$ nanocomposite materials, which can be used in many applications.

1. Introduction
The development of nanoparticles fabrication is expanding among the scientists since nanoparticles improve the existing technologies and propose solutions to various problems, such as the environment, energy sources, electronic devices, and gas sensors. Nanoparticles are defined as tiny particles sized 1 nm to 100 nm. There are many advantages that nanoparticles offer, such as wide applications in various fields, high efficiency, low cost, reusable, easy to be modified on physical, chemical, electronical, and optical properties, so that the materials can be adjusted to be lighter, stronger, more durable, or reactive. One of the most developed nanoparticles is semiconductor nanoparticles. Semiconductors nanoparticles are nanosized materials which have properties in between conductors and isolators. The applications of semiconductor nanoparticles are photocatalysts for dye degradation [1-4], antimicrobial materials [5-7], and gas sensors [8-11]. TiO$_2$ and ZnO are a semiconductor
material which are extensively used in various fields because of high photocatalytic performance, high photo stability, low toxicity, cheap, and a wide band gap (for anatase TiO$_2$ is $\sim 3.2$ eV and ZnO is $\sim 3.37$ eV) [12]. Unfortunately, the performance of pristine ZnO or TiO$_2$ is inhibited by electron hole-recombination.

Improvement of semiconductor material can be done through several modifications. For instance, the addition of transition metal ions (Cr, Zr, Mn, Mo), doping (altering the electrical and optical properties of semiconductors) with non-metals (N, S, C) and noble metals (Ag, Pt, Au), and the fabrication of hybrids (ZnO-TiO$_2$, TiO$_2$-SiO$_2$) [13]. On the other hand, modification of crystal structure is also reported as a promising candidate to enhance the photocatalytic performance [14,15]. It is reported that the mixture of anatase-rutile with anatase content approximately 80% and rutile 20% shows the best performance. To be honest, this conclusion may still debatable, because some references mention that anatase give the best photocatalytic performance [16]. However, there are many parameters affected the photocatalytic performance, not limited to the crystal structure. The mechanism of the photocatalytic performance affected by crystal structure of TiO$_2$ nanoparticle can be seen in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Illustration of photocatalytic performance with different crystal structure of TiO$_2$, which is a mixture of anatase-rutile, anatase, dan rutile.

In this study, we only focus on the fabrication method of ZnO-TiO$_2$ nanocomposite as well as their applications. Generally, ZnO-TiO$_2$ nanocomposite can be prepared by three different processes, which is liquid-, solid-, dan gas-phases. Finally, the aims of this review are to determine some parameters that affecting the characteristics of the particles and to compare the performance between ZnO-TiO$_2$ and pristine ZnO or TiO$_2$ nanoparticles. To obtain these results, the characteristics of synthesized ZnO-TiO$_2$ were reviewed in different aspects, such as synthesis methods, calcination temperature, pH of added solution, solvents used, and concentration ratio of precursors. Furthermore, the performance of ZnO-TiO$_2$ nanocomposites were also reviewed, which is photocatalytic, antimicrobial, and gas-sensing.

2. **Fabrication Method**

As mentioned in the previous part, there are three processes commonly used for fabrication of ZnO-TiO$_2$ nanocomposites, which is liquid-, solid-, dan gas-phases. Detail explanation of those processes are described in the following.

2.1 **Liquid phase**

There are many types of fabrication methods in liquid phase, such as sol-gel, hydrothermal, wet impregnation, and precipitation.
Sol-Gel is one of the well-known fabrication methods, since it is very easy to prepare and does not require certain condition. This method is basically a reaction process of precursor material then turns becoming sol and gel and finally solid by calcination process.

Hydrothermal is one of the nanoparticles synthesis methods using high temperature to gain the particles through reaction. It is also one of the most prominent methods because of the simplicity and easy to control. However, the higher temperature or certain pressure requirements makes this method requires higher energy [17].

Wet impregnation is a method where solid containing active phase material is contacted with precursor solution and then dried to obtain the desired particles. This method consists of two important steps, the nucleation and agglomeration. Wet impregnation method can be used to mixed catalyst, which in this case are ZnO and TiO₂ [18].

Precipitation method is a well-known method to prepare catalyst by combining two phases reaction, which are the aqueous phase of metal salt and alkali solution to get insoluble metal hydroxide or carbonate. This method also easily controlled by its pH, evaporation, and the concentration of the material [18].

2.2. Gas phase

Chemical Vapor Deposition (CVD), spray pyrolysis, and spray drying are classified as gas-phase fabrication methods.

Chemical Vapor Deposition or CVD is a synthesis method which the deposition process occurs on vapor phase due to the decomposition of the heated substrate surface or a chemical reaction between the substrate and precursor gases inside a chamber [19].

Spray pyrolysis is a fabrication method which the deposition process occurs inside a furnace with spraying process of the precursor solution on the heated substrate surface. There are three parameters affecting the characteristics of the synthesized composites, which are the composition of precursor solution, the production and transfer of aerosol, and the synthesis process [20].

Spray drying is a method which dry powders are made through the fluid atomization process with the assistance of hot gas flow. The stages of this synthesis method are atomization of fluid into droplets which then altered into particles, and the collecting process of particles [21]. The major difference between spray drying and spray pyrolysis is there is no decomposition and chemical reaction in spray drying method.

2.3. Solid phase

Mechanochemical is the example of solid phase fabrication methods using mechanical forces to alter the chemical and physicochemical properties of the aggregated materials. There are two main processes in this method, which are primary process and secondary process. Primary process is the reactivity enhancement of the composites, meanwhile secondary process happens spontaneously during or after milling process [22]. Table 1 shows the advantages and disadvantages of these methods.

| Synthesis Methods | Advantages | Disadvantages | Reference |
|-------------------|------------|---------------|-----------|
| Sol-Gel           | Does not require vacuum condition and high temperature | High contamination and impurities |          |
| Hydrothermal      | High yield, uniform particles, simple process | Requires an autoclave, difficult to observe the particle growth | [17]     |
| Precipitation     | Simple and fast fabrication process, low cost | Nucleation and growth process of particles occur at the same time thus making it difficult to observe the particle growth | [18]     |
| Wet impregnation  | Low operation cost and temperature, high homogeneity | High amount of precursor is required and not suitable for high concentrated solution | [18]     |
**3. Results and Discussion**

In this part, we discuss two sub-sections regarding with ZnO-TiO$_2$ nanocomposite, the first is characterization of the produced nanocomposites and another one is performance of the nanocomposite in several applications. These characteristics including the crystallinity, morphology, and size of the materials.

### 3.1. Characteristics of ZnO-TiO$_2$ nanocomposites

There are several factors affecting the characteristics of ZnO-TiO$_2$ nanocomposite, which are pH of solution, types of solvents used, the concentration of precursors, as well as the fabrication methods and thermal treatment.

#### 3.1.1. The effect of pH to the characteristics of ZnO-TiO$_2$

For ZnO-TiO$_2$ synthesis, some chemical compounds will be added into the precursor solution, which are acidic or alkaline compounds such as HCl, KOH, NaOH, and acetic acid. There are some characteristics influenced by the compound, which are the crystalline phase, the size of the particles, and the morphology. In acidic condition, the crystalline phase of TiO$_2$ is mainly rutile, while in alkaline condition is mainly brookite. Anatase phase is formed at pH between 4.4-6.8 [26]. This means that the more acidic the solution is, the crystalline phase of TiO$_2$ is dominated by the rutile phase and the optimum pH must be reached to obtain anatase phase. This is because in the process of forming TiO$_2$, the hydrolysis of the titanium cation occurs under acidic conditions and [Ti(OH)(OH$_2$)$_3$]$^{2+}$ will be formed, but because there is a positive charge and a hydroxyl group, condensation will not occur. When condition is not too acidic to stabilize the precursor solution used, deprotonation will form a new species namely [Ti(OH)$_2$(OH$_2$)$_3$]$^{2+}$, but condensation also will not occur due to spontaneous intramolecular oxidation in [Ti(OH)$_2$(OH$_2$)$_3$]$^{2+}$. Thus, a pH in the range 4.4-6.8 is required to form the desired anatase phase. This occurs when the pH conditions deprotonate titanium to [Ti(OH)(OH$_2$)$_4$]$^+$, which can lead to intramolecular deoxolation of [Ti(OH)(OH$_2$)$_3$]$^{2+}$. Meanwhile, if the conditions are too acidic, the reaction mechanism will be the opposite and it will generate a rutile phase [27]. Similar tendency has been reported by previous studies using acetic acid [28], acetic acid [29,30], polyethylene glycol [31] with anatase-rutile as the dominant phase, while researches using acetic nitrate [32] only shows rutile phase. These researches were conducted in acidic condition for TiO$_2$. Meanwhile the morphology of TiO$_2$ is affected by its surface charge which depends on the pH, where the higher the pH, the particle shape tends to aggregate but smaller. In acidic conditions, strong surface charges tend to be present which reduce clumping, so that the particle shape is less aggregated and bigger [27].

Whereas in the formation of ZnO at an acidic pH (less than 7), the results of XRD analysis usually indicates no intense peak is formed, because the amount of H$^+$ ions is higher than the OH$^-$ ion, where ZnO itself will be formed under conditions with excess OH$. At neutral pH, various peaks are found at XRD results, whereas at high pH value, the peaks produced are more intense indicating the crystal formed is hexagonal wurtzite. These are accordance with previous researches using NaOH [2,3,32-35],

### Table: Synthesis Methods

| Synthesis Methods     | Advantages                        | Disadvantages                                     | Reference |
|-----------------------|-----------------------------------|---------------------------------------------------|-----------|
| Chemical vapor deposition | Easy to control, flexible, high purity and deposition rate | By-product is usually toxic (CO, H$_2$, HF), requires volatile precursor thus high material cost | [19]      |
| Spray pyrolysis       | Simple process, low equipment cost, does not vacuum condition and high-quality precursor | Energy requirement is high since the operating temperature is high, low yield and rate of deposition | [23,24]  |
| Spray drying          | Fast process, continuous system, flexible, does not require additional drying process | Low yield on lab scale, not suitable for nanocomposites fabrication | [25]      |
| Mechanochemical        | Products, easy to control the size and nucleation process | High contamination | [22]      |
NH₃ [13], NH₂OH [36], and KOH [37]. Besides that, in the formation of ZnO, the shape of ZnO itself is influenced by the aging time during the reaction. In this process, there are two important things that occur, which are particle aggregation and coarsening and they are very dependent on pH. The higher the pH is, then the resulting particle shape is spherical with tendency to agglomerate. This happens because the reaction moves from supersaturated to saturated with Zn(OH)₂⁺ species [38].

In the aspect of particles size, the size of TiO₂ particles at acidic condition is smaller than at alkaline condition due to the more controlled hydrolysis process. This is caused by the protonation from Ti(OH)₄ to [Ti(OH)₂]⁺ and it triggers the depolymerization process and produces hydrophilic oligomers of the complex titanium hydroxy groups caused by the intermediate repulsion positive charges. Thus, the polycondensation process occurs rapidly and causes TiO₂ particles to be smaller [39]. In contrast, the particle size tends to increase when the condition is more alkaline, where at pH 6.8, the crystal size is 21.02 nm and as the pH is reduced to 5, the size becomes 7.77 nm [26]. Moreover, ZnO is an amphoteric compound, meaning it can be formed at either acidic or alkaline conditions. However, on various experiments, ZnO tends to form under alkaline conditions in the presence of excess OH⁻. This occurs when the precursor dissolves and dissociates into Zn²⁺ and OH⁻, which will increase the thermal energy required for the reaction. This causes the nucleation process and smaller particles are formed, because it is a slow reaction and requires a lot of energy. This result is also similar with the research [36] when the synthesis of ZnO-TiO₂ nanoparticles were conducted in alkaline condition and the size of the particles are getting smaller with the increase of the pH.

3.1.2. The effect of solvent to the characteristics of ZnO-TiO₂
Solvent is a very important aspect in the fabrication of ZnO-TiO₂. Some solvents will greatly influence the rate of nucleation of ZnO-TiO₂ particles. The choice of solvent in TiO₂ will affect the morphology of the resulted particles. For instance, TiO₂ particles synthesized under atmospheric conditions are amorphous and thermal treatment is needed, both calcination and annealing to form the desired crystal phase. Therefore, using some selected solvents without thermal treatment will not produce a certain TiO₂ phase [40]. While the phase of ZnO particles tends to be influenced by the size of the particles formed. When the size of the fabricated ZnO particles is smaller because of the longer formation reaction, then the results of the XRD analysis show wider and more intense peaks, such as hexagonal or wurtzite [41].

Furthermore, the size of crystal is affected by the degree of polarity of the solvent. The more polar the solvent is, then the higher the nucleation rate will be. Apart from the degree of polarity, the boiling point of the solvent will also speed up the reaction rate which resulted in a larger particle size, because the longer the duration of reaction is, the size will be larger. Thus, the most common solvents used are methanol and ethanol due to their high polarities, lower alcohol chains, and their boiling point are lower than water (below 100°C) [40]. Meanwhile, the influence of solvent to the morphology is not determined yet, because the same solvent is able to form varied shapes of ZnO-TiO₂ nanocomposites, therefore it can be concluded that there is no significant effect of certain solvent on the shapes of the particles.

3.1.3. The effect of concentration of precursors to the characteristics of ZnO-TiO₂
The crystal phase of the particles is influenced by the ratio of the precursors, whether it is mass, molar, or volume ratio. Fabricated nanomaterials with insignificant difference in ratio of ZnO and TiO₂ will have zincite or wurtzite phase ZnO and anatase or rutile for TiO₂, while significant difference in ratio of ZnO and TiO₂ resulted in particles which tend to follow the dominant pure particles [8].

Most of the ZnO-TiO₂ nanoparticles size decrease when the TiO₂ ratio increases due to the radius of the Ti³⁺ ion is smaller than Zn²⁺, where the radius are 0.042 – 0.074 nm and 0.06 – 0.09 nm, respectively [42]. Not only reacting with ZnO and forming Zn₂TiO₄, TiO₂ in low concentration is also able to diffuse into the ZnO lattice, substituting Zn²⁺ ions, and causing increased ZnO activity. This increment in ZnO activity causes the size of the nanoparticles to increase. However, when the TiO₂ concentration is high, the formation of Zn₂TiO₄ and the presence of TiO₂ on the ZnO surface prevents the growth of nanoparticle, thus reducing its size [43].
3.1.4. The effect of fabrication method and thermal treatment to the characteristics of ZnO-TiO₂

Other aspects that will influence the morphology of ZnO-TiO₂ particles are the fabrication methods and thermal treatment, whether it is annealing or calcination. The fabrication methods are categorized into three phases, which are gas phase, liquid phase, and solid phase. The influence of thermal treatment and fabrication method cannot be distinguished because thermal treatment itself is a part of fabrication process to get the desired nanoparticles. The synthesis methods in solid and gas phases are capable of producing crystalline nanoparticles without thermal treatment, meanwhile in liquid phase, it requires calcination in the temperature range of 100-600°C in order to obtain the desired crystals. This is because the ambient condition in liquid phase synthesis method forms amorphous particles. The range temperature of calcination to produce amorphous TiO₂ crystals is above 222°C, anatase at about 500°C, anatase-rutile at above 650°C, and rutile at above 785°C [44]. Moreover, insufficient temperature at spray drying process will not produce the TiO₂ crystal.

The ZnO-TiO₂ nanoparticles produced by hydrothermal method at temperatures of 450°C and 800°C have a round (granular) shape as shown in Figure 2 (a) [45], while at lower temperature (220°C), the resulting particles are a mixture of tetragonal TiO₂ and hexagonal ZnO as shown in Figure 2 (b) [32]. Both conditions formed agglomerated particles. Sol-gel method at low calcination temperatures (100–150°C) produces rod-shaped particles for ZnO and spherical for TiO₂ (see Figure 2 (c)) [3], at moderate calcination temperatures (200 to below 500°C), the shape is irregular as depicted in Figure 2 (d) [29], and at high calcination temperature (500°C) the resulting particles are spherical and agglomerated rods (Figure 2 (e)) [33]. This shows that in terms of morphology, sol-gel method is best carried out at low calcination temperatures in the range of 100–150°C to remove water content and higher calcination temperatures cause defects. Precipitation method with calcination temperatures at 250–1000°C produces a spherical, agglomerated particle as shown in Figure 2 (f) [46]. Irregular shapes can be found in nanoparticles synthesized by other methods in the liquid phase, for example wet impregnation, as shown in Figure 2 (g) [47]. Furthermore, methods which are able to generate uniform particles without any agglomeration and cracking are chemical vapor deposition or CVD and spray pyrolysis, while in solid phase, the resulted particles are asymmetric and in liquid phase, the particles tend to agglomerate due to the formed colloid that will lead to agglomeration.

![Figure 2](image-url)

Figure 2. Morphology of ZnO-TiO₂ nanoparticles prepared by various methods, (a) hydrothermal (reprinted from [45]), (b) hydrothermal (reprinted from [32]), (c) sol gel (reprinted from [3]), (d) sol-gel (reprinted from [29]), (e) sol-gel (reprinted from [33]), (f) precipitation (reprinted from [46]), and (g) wet impregnation (reprinted from [47])

In terms of size, when small nanoparticles (under 10–100 nm) are desired, it can be fabricated through both liquid phase and mechanochemical synthesis method, because the size of the nanoparticles produced in gas phase synthesis method is still quite large (100–600 nm) compared to the aforementioned methods. Even though the particles formed in liquid phase are agglomerated, they still have smaller size compared to the particles produced in gas phase. This is because large
aggregates tend to stick to porous surfaces [48], so it is likely that the aggregations or agglomerations found in nanoparticles with liquid phase fabrication have more pores and cause their size to be smaller.

Another morphological characteristic impacted by methods of fabrication is particle distribution. Nanoparticles which are fabricated through the gas phase method has the best and uniform distribution due to the fact that nanoparticles fabricated using the liquid phase synthesis method tend to form agglomeration and it has a clogging effect which can lead to poor particle distribution [49].

3.2. Performance of ZnO-TiO₂ nanocomposites

The various performance of ZnO-TiO₂ nanoparticles in several applications, such as photocatalytic activity, antimicrobial activity, and gas-sensing will be discussed in this paper.

3.2.1. Photocatalytic performance of ZnO-TiO₂

Photocatalytic activity is one of the prominent applications of ZnO-TiO₂ nanoparticles. So far, these bicomponent nanocomposites can be used to degrade various dyes and organic compounds, such as reactive black 5 [12], brilliant golden yellow [13], methylene blue [50], rhodamine B [28,51], pentachlorophenol [4], benzene, xylene, and toluene [52], bentazon [3], malachite green [5], 4-nitrophenol [47], and methyl orange [34]. The parameter to determine the degradation performance is the concentration of dye left in the solution after the addition of catalysts. The greater the performance is, then the remaining dyes are less. The degradation performance of these nanoparticles is higher (75%–100%) under either UV or visible lights compared to pure ZnO or TiO₂ (below 70%) [3,4,13]. This indicates that mass-scale production of ZnO and TiO₂ leads to positive impacts in environmental issues, especially in dye waste degradation. The performance of photocatalysts is affected by the size, where the smaller the size is, then the larger specific surface area is available to enhance the adsorption of organic compounds or dye [1]. Another factor affecting the photocatalytic performance is light absorption, which can be found in the experiment from Ferrari-Lima, et al [52] where the red-shift on visible light will improve the photocatalytic performance because red-shifted particles absorb longer wave (400 nm to 700 nm). This is also accordance with experiment of Araujo, et al [51] where the blue-shifted particles can absorb shorter light wave, thus the UV light absorption improved. ZnO-TiO₂ particles are able to be reused during its photocatalytic process thrice until 6 times [3,4,34,50]. This shows a great stability of these composites.

Based on the experiments described, the photocatalytic performance of ZnO-TiO₂ is higher when compared to pure ZnO and pure TiO₂. This is due to the presence of TiO₂ which can increase the stability of ZnO, thereby reducing electron-hole recombination, while ZnO also increases the electron mobility of TiO₂ (see Fig. 3). The photocatalytic reaction starts when light energy or photon is absorbed by the components, thus causing excitation of holes (h⁺) in valence band and electrons (e⁻) in conduction band. In valence band, oxidation occurs and causing the moisture in air (OH⁻) to become hydroxyl radicals (OH), meanwhile in conduction band, reduction occurs and causing the oxygen in atmosphere (O₂) to become superoxide anions (O₂⁻). The two active oxygen species (hydroxyl radicals and superoxide anions) bind the organic substance or dye and alters it into CO₂ and H₂O which are more simple and easier to degrade [12].

![Figure 3. Mechanism of ZnO-TiO₂ photocatalytic activity](image-url)
3.2.2. Antimicrobial activity of ZnO-TiO₂

ZnO-TiO₂ particles also can be used as antimicrobial materials. Several experiments conducted by researcher using gram-positive and gram-negative bacteria, such as S. aureus and E. coli. According to the previous results [5-7,30], ZnO-TiO₂ nanocomposites can be used as an antimicrobial agent, due to the photocatalytic activity of ZnO and TiO₂ which produces radical superoxide anion or O₂⁻. O₂⁻ binds H⁺ and forms HO₂⁻, then HO₂⁻ which reacts with e⁻ and H⁺ will produce H₂O₂ molecules. These molecules are capable to penetrate the bacterial cell membrane and it causes changes in the structure of lipids, peptidoglycans, proteins, and DNA from bacteria, so that the bacteria cannot survive [6]. Besides that, the combination of ZnO-TiO₂ inhibits bacterial growth better than pure TiO₂ or ZnO. ZnO-TiO₂ can significantly reduce bacterial adhesion and cell density, as well as destroy bacterial morphology. The emitted Zn ion reacts with the plasma membrane so that it enters the cell and causes damage to the intracellular balance of bacteria.

3.2.3. Gas sensing performance of ZnO-TiO₂

ZnO-TiO₂ can be utilized as a gas sensor for acetone and ethanol [8], O₂ [9], and ammonia [10]. The addition of ZnO in TiO₂ in low concentrations and vice versa is proven to improve the performance of pure compound nanoparticles. This is because ZnO has a higher conductivity than TiO₂ and ZnO has a higher free electron content, so it is able to bind more toxic gases. Even so, ZnO is a semiconductor with low gas selectivity and tends to require high temperatures to be able to perform gas sensors, so the addition of TiO₂ is necessary. If ZnO-TiO₂ gas sensor is being compared to pure ZnO or pure TiO₂, these bicomponent nanocomposites show higher performance. This is evidenced by the experimental results using ammonia [10] and ethanol [11]. According to Chaiyo et al. [10], the sensitivity of ZnO-TiO₂ was higher than the pure components. Moreover, Gui et al. [11] also reported a higher stability of ZnO-TiO₂ which can be used for up to 6 months, while ZnO can only be used 4 times (1800 seconds). This is due to the resulting ZnO particle is in the form of rods so that it is more prone to breaking, while the resulting ZnO-TiO₂ structure is more rigid.

4. Conclusion

Based on our summary in the previous part, it can be concluded that the morphology of ZnO-TiO₂ was significantly controlled by fabrication method, while the dominant crystal phase is occupied by wurtzite and anatase phase. ZnO-TiO₂ is more superior than pure ZnO or TiO₂ in photocatalytic, antimicrobial agents, and gas sensing applications because of the higher performance and stability. In photocatalytic reaction, the degradation performance reaches 75–100% for ZnO-TiO₂, meanwhile pure compounds only reach less than 70% of degradation. The stability of ZnO-TiO₂ is proven both in photocatalytic and gas-sensing activities because of the high reusability, which are thrice until 6 times for the former and up to 6 months for the latter.

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