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Editorial

Novel ZnO-Based Nanostructures: Synthesis, Characterization and Applications

Yamin Leprince-Wang [1,*], Guangyin Jing [2] and Basma El Zein [3]

1 ESYCOM Lab, CNRS, Université Gustave Eiffel, F-77454 Marne-la-Vallée, France
2 School of Physics, Northwest University, Xi'an 710127, China
3 Department of Electrical Engineering, University of Business and Technology, Jeddah 21432, Saudi Arabia
* Correspondence: yamin.leprince@univ-eiffel.fr

The Special Issue "Novel ZnO-Based Nanostructures: Synthesis, Characterization and Applications" is a collection of 13 papers, including 3 review papers and 10 original articles dedicated to both experimental research works and numerical simulations on ZnO nanostructures.

On one hand, as a multifunctional material, ZnO possesses unique outstanding properties, such as a wide direct bandgap; high electron mobility; piezoelectric, antibacterial, photocatalytic, and thermoelectric properties; as well as chemical and thermal stability and biocompatibility. On the other hand, ZnO nanomaterials can be obtained using easy and low-cost growth techniques including green synthesis methods, with easy morphological control altering seedlayer composition and/or varying growth conditions. It should be emphasized that ZnO nanostructures can be doped to enhance different physical and chemical properties. These assets make nanostructured ZnO one of the most fascinating nanomaterials, leading to the development of many promising applications around the ZnO nanostructures, as presented in this Special Issue.

Knowing that the properties are closely related to the nanostructures, the study of nanostructures' growth mechanism is important for the desired material properties and the targeted applications. In the case of the widely used classical two-step sol-gel hydrothermal method for ZnO nanoarray growth, the morphology of nanoarrays, such as the number density of the nanorod array and the diameter of nanorods, is often tuned by changing the composition ratio of the seed solution. Li et al. [1] investigated the tuning growth of ZnO nanoarrays by the controlled spreading of gel layer based on the dewetting process. The proposed new mechanism can not only help deepen the understanding of the formation and evolution of the seedlayer, but also provide a new method for the controllable growth of nanomaterials. Continuing with the growth mechanism study, Huang et al. [2] investigated the controlled synthesis and the growth mechanism of two-dimensional (2D) ZnO by surfactant-assisted ion-layer epitaxy (SA-ILE), by controlling the growth parameters, such as the amounts of surfactant, temperature, precursor concentration, and growth time. Their work might guide the development of SA-ILE and pave the way for practical applications of 2D ZnO on photodetectors, sensors, and resistive switching devices.

The green synthesis of ZnO nanoparticles (NPs) has recently gained considerable interests because it is simple, environmentally friendly, and cost-effective. The paper of Jaithon et al. [3] therefore aimed to synthesize ZnO NPs by utilizing bioactive compounds derived from waste materials, mangosteen peels, and water hyacinth crude extracts, and investigated their antibacterial and anticancer activities. This study demonstrated the possibility of using green-synthesized ZnO NPs in the development of antibacterial or anticancer agents. Furthermore, this research raised the prospect of increasing the value of agricultural waste. On the same topic, Ali et al. [4] investigated another green synthesis method for ZnO nanostructures (NS) using Pyrus pyrifolia fruit extract. The obtained ZnO NS demonstrated significant antibacterial activity analyzed by metabolic activity analysis

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and disc diffusion assay against *Escherichia coli* and Staphylococcus aureus. Furthermore, ZnO NS achieved good photocatalytic activity of organic dye decolorizing. The research findings from this study could offer new insights for developing potential antibacterial and photocatalytic materials.

Regulating the swimming motility of bacteria near surfaces is essential to suppress or avoid bacterial contamination and infection in catheters and medical devices with wall surfaces. In their work, Yan et al. [5] showed that ZnO nanowire arrays could reduce the swimming motility of *Escherichia coli*, thus significantly enhancing the trapping ability for motile bacteria. Additionally, thanks to the wide bandgap nature of ZnO, the UV irradiation rapidly reduces bacterial locomotion due to the production of hydroxyl radicals and singlet oxygen. The authors' findings not only demonstrated the detailed motility of bacterial swimming on nanostructured surfaces, but also provided means for antibacterial applications of ZnO nanomaterials.

ZnO is an excellent photocatalyst able to mineralize a large amount of organic pollutants in water under UV irradiation that can be enlarged to the visible range by doping. With high surface/volume ratio, the ZnO nanostructures showed an enhanced photocatalytic efficiency. Le Pivert et al. [6] investigated the photocatalytic activity of ZnO NSs grown on different substrates, both in classic mode and microfluidic mode. All tests showed the notable photocatalytic efficiency of ZnO NSs with remarkable results obtained from a ZnO-NSs-integrated microfluidic reactor, which exhibited an important enhancement of photocatalytic activity by drastically reducing the photodegradation time. The simultaneous real-time PCR followed by UV-visible spectrometry and high-performance liquid chromatography, coupled with mass spectrometry (HPLC-MS), could reveal both the photodegradation efficiency and the degradation mechanism of the organic dye.

In their study, Mendoza-Sánchez et al. [7] used an accessible thermal oxidation technique to synthesize the nanostructured ZnO arrays. Two different morphologies were achieved, ZnO grass-like and ZnO cane-like nanostructures, allowing them to study the influence of ZnO nanostructure morphology on the functionalization efficiency of nanostructured arrays with hemoglobin for CO_2 capture. After functionalization with hemoglobin, they found that the ZnO grass-like structures exhibited the best efficiency for CO_2 capture, with 98.3% of the initial concentration after 180 min.

A broadband thin-film plasmonic metamaterial absorber (MMA) nanostructure with a multi-dielectric layer operating in the frequency range from 100 GHz to 1000 GHz is introduced and analyzed in the paper presented by Emara et al. [8]. In this work, the ZnO layer was added as a substrate on the top of an Au back reflector to enhance the absorption. The MMA had an average absorption of 84%, with a maximum absorption of 100% and a minimum absorption of approximately 65.9%. The optimized MMA showed good angular stability, as the effect of the incident angle of the electromagnetic wave on the MMA absorption is so small and the absorber is insensitive to polarization for both normal and oblique incidence conditions.

The quick development of wireless sensor networks has required sensor nodes to be self-powered. Driven by this goal, in their work, Serairi and Leprince-Wang [9] demonstrated a ZnO nanowire-array-based piezoelectric nanogenerator (NG) prototype, which can convert mechanical energy into electricity. The NG-device, with an effective area of 0.7 cm^2, was based on high-quality single crystalline ZnO nanowires with an aspect ratio of approximately 15. The NG's performance was tested both in compression mode and in vibration mode, giving the output power density of ~38.47 mW/cm^3 and ~0.9 mW/cm^3, respectively.

Aiming at the problem of a lack of data on the nonlinear morphology to divide uneven grain boundary in bulk ceramics, Shen et al. [10] developed a unique approach of the local three-dimensional characterization of nonlinear grain boundary length within bulk ZnO, using a nanorobot in SEM. SEM can generate an image of the contour shapes of the targeted grain boundaries in the X-Y plane, while the Z-directional relative height differences at different positions can be sequentially probed by the nanorobot. Further, by quantifying the Z-directional relative height differences, it can be verified that irregular characteristics exist in the three-dimensional grain boundary length, which can extend the depth effect on nonlinear bulk conductance. In addition, this method can also obtain nonlinear quantitative topographies to divide grain boundaries into an uneven structure in the analysis of bulk polycrystalline materials.

Today, living organisms are more susceptible to exposure to metallic NPs due to these NPs' constant evolution and applications. ZnO-NPs are one of the most used metallic NPs due to their various interesting properties and large application fields. Therefore, understanding the molecular effects of ZnO-NPs in biological systems is extremely important. Patrón-Romero et al. [11] presented a systematic review that aimed to include the most recent scientific evidence concerning the cytotoxic effect of ZnO-NPs in biological models, with special attention paid to mitochondrial damage. Since mitochondria are among the most complex and relevant organelles for cellular homeostasis, it is indispensable to define the most relevant mechanisms leading to cell dysfunction/death. The contribution and usefulness of ZnO-NPs in medical oncology is of great interest; in particular, their contribution in the therapeutic area is increasingly relevant due to their immense potential in the public health sector. This is because cancer remains among the leading causes of death worldwide. Tumor cells show a different cytotoxic effect compared to healthy cells of the same lineage, and the response varies depending on the exposure time, size, and shape of ZnO-NPs. Furthermore, ZnO-NPs can act as anti-cancer agents against different tumor lines resistant to conventional chemotherapeutic treatments; they provide a talented substitute approach to chemotherapies. This systematic review provides information on correlation and the impact on future research.

ZnO also possesses promising potential in thermoelectric applications, enabling the conversion of waste heat to electrical energies with high thermoelectric performance, due to its high physicochemical stability, tunable properties, and high abundance. ZnO thermoelectric devices can operate at higher temperatures; they have higher conversion efficiency and reliability, and the advantage of costless production. In the review presented by Sulaiman et al. [12], the authors attempted to oversee the approaches to improving ZnO thermoelectric properties, where nanostructuring and doping methods were assessed. The outcomes of the reviewed studies are analyzed and benchmarked in this Special Issue, in order to obtain a preliminary understanding of the involved parameters' influences. According to the extant literature, several strategies have been reported to enhance the thermoelectric properties of ZnO, including nanostructuring synthesis techniques and the doping of foreign particles in ZnO.

Today, antibiotics are pervasive contaminants in aqueous systems that pose an environmental threat to aquatic life and humans. The prolonged and excessive use of antibiotics in our society has led to the presence of excessive amounts of non-biodegradable medicines such as antibiotics, and anti-inflammatory, anti-depressive, and contraceptive drugs in hospital and industrial wastewater, which marks a significant threat to the ecosystem. According to the literature, 33,000 people die directly from drug-resistant bacterial infections in Europe annually, which costs EUR 1.5 billion in health care and productivity losses. Consequently, it is an absolute necessity to develop a sustainable method for effective antibiotic removal from wastewater. In their critical review, Mohamed et al. [13] present and discuss recent advances in the photocatalytic degradation of widely used drugs by ZnO-based nanostructures: namely, (i) antibiotics; (ii) antidepressants; (iii) contraceptives; and (iv) anti-inflammatories. This study endows a comprehensive understanding of the degradation of antibiotics using ZnO-based nanomaterials (bare, metal- and non-metal-doped, as well as nanocomposites) for the effective treatment of wastewater containing antibiotics. In addition, the operational conditions and mechanisms involved during the photocatalytic degradation process are systematically discussed. Finally, particular emphasis is devoted to future challenges and the corresponding outlook with respect to toxic effects following the utilization of ZnO-based nanomaterials.

We hope that this collection of papers will meet the expectations of readers seeking the synthesis methods, enhanced properties, and applications of novel ZnO-based nanostructures; and we hope that this collection can also create inspiration for further research works on the related topics included in this Special Issue.

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