nanomaterials

Editorial

Metal Oxide Nanomaterials: From Fundamentals to Applications

Yuanbing Mao [1,*] and Santosh K. Gupta [2,3,*]

[1] Department of Chemistry, Illinois Institute of Technology, 3101 South Dearborn Street, Chicago, IL 60616, USA
[2] Radiochemistry Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India
[3] Homi Bhabha National Institute, Anushaktinagar, Mumbai 400094, India
* Correspondence: ymao17@iit.edu (Y.M.); santoshg@barc.gov.in (S.K.G.);
Tel.: +1-312-567-3815 (Y.M.); +91-22-25590636 (S.K.G.)

Citation: Mao, Y.; Gupta, S.K. Metal Oxide Nanomaterials: From Fundamentals to Applications. *Nanomaterials* **2022**, *12*, 4340. https://doi.org/10.3390/nano12234340

Received: 22 November 2022
Accepted: 29 November 2022
Published: 6 December 2022

This Special Issue of *Nanomaterials*, "Metal Oxide Nanomaterials: From Fundamentals to Applications", highlights the development and understanding of different types of metal oxide nanoparticles and their use for applications in luminescence, photocatalysis, water–oil separation, optoelectronics, gas sensors, energy-saving smart windows, etc. The wide variety of applications covered by the 10 articles published here is proof of the growing attention that the use of metal oxide nanomaterials has received in recent years. Here, nanomaterials are defined, based on the October 2011 European Commission's definition, as materials with one or more external dimension in the range of 1–100 nm. As the surface area per mass of a material increases, a greater proportion of the material can come into contact with the surrounding materials, thus affecting reactivity [1,2]. Nanomaterials have indeed revolutionized the world due to their unique properties and growing applications in all spheres of humankind, encompassing energy, health, and the environment.

Within this Special Issue, Gupta et al. designed and demonstrated excitation energy tunable light emission from barium zirconium oxide crystals as color-tunable phosphors [3]. The authors tuned the emission light from $BaZrO_3$:Eu^{3+} crystals from orange to red based on the charge transfer and *f-f* transition excitation of an Eu^{3+} dopant, which is dictated by its magnetic and electric dipole transition probabilities. Enesca et al. showed the potential of $Cu_2O/SnO_2/WO_3$ heterostructure powder in the efficient removal of pesticides photocatalytically [4]. The photocatalytic mechanism corresponds to a charge transfer based on this three-component structure, where Cu_2O exhibited a reduction potential responsible for O_2 production and WO_3 had an oxidation potential responsible for OH· generation. Liang and his colleagues successfully decorated TiO_2 nanorods with a copper oxide layer through sputtering and post-annealing, which resulted in improved light absorption and photo-induced charge separations [5]. This led the composite nanorods to have enhanced photoactivity compared to the pristine TiO_2 nanorods.

Other fascinating properties of nanocomposite based on metal oxides nanoparticles, particularly from ZnO, were explored by several other research groups [6]. For example, Si et al. synthesized Fe_3O_4@ZnO nanocomposites (NCs) to improve the stability of the viscoelastic surfactant (VES) fracturing fluid [7]. At a loading of 0.1 wt.%, this NC-VES nanocomposite showed superior stability at 95 °C or at a high shear rate and good sand-carrying performance and gel-breaking properties. Designing a surface with special wettability is an important approach to improving the separation efficiency of oil and water. Liu and co-authors demonstrated superhydrophobicity in both oil and water from their stainless-steel metal fibers coated with sol–gel-derived ZnO nano-pillars [8]. They found that their ZnO-coated stainless-steel metal fibers had a static underwater oil contact angle of $151.4° \pm 0.8°$ and an underoil water contact angle of $152.7° \pm 0.6°$ and was a highly promising candidate for both water-in-oil and oil-in-water separation in the industry. Maevskaya et al. studied the effect of Cu_2O on the photo-induced alteration of the hydrophilicity of TiO_2 and ZnO surfaces [9]. The Cu_2O/TiO_2 and Cu_2O/ZnO heterostructures showed photo-induced decay of the surface hydrophilicity caused by both

UV and visible light irradiation. Simeonov and his group carried out defect engineering of ZnO by nitrogen doping [10]. They demonstrated that nitrogen doping in ZnO led to an abundance of oxygen and zinc vacancies and interstitials and contributed to enhanced electron transport properties in ZnO:N films. As another example demonstrating advancements in the roles of structure and morphology in material properties, Naszályi Nagy et al. prepared silica NPs with a diameter of 50 nm and covered them with a monoclinic/cubic zirconia shell using a green, cheap, and up-scalable sol–gel method [11]. They confirmed that these silica@zirconia core@shell NPs bind as muchas 207 mg of deoxynucleoside monophosphates on 1 g of this nanocarrier at neutral physiological pH while maintaining good colloidal stability.

Two review articles are also included in this Special Issues. In the first review, Li et al. comprehensively discussed the development of two-dimensional (2D) nanomaterials with metal oxide nanoparticles for gas sensing applications [12]. They further emphasized recent advances in the fabrication of gas sensors based on metal oxides, 2D nanomaterials, and 2D material/metal oxide composites with highly sensitive and selective functions. In the second review article, Kim et al. presented recent advances in fabricating flexible thermochromic VO_2(M) thin films using vacuum deposition methods and solution-based processes and discussed their optical properties for potential applications in energy-saving smart windows and several other emerging technologies [13].

In summary, this Special Issue presents just the tip of the iceberg of the broad, dynamic, and active fundamental research and applications in the developing field of metal oxide nanomaterials by collecting a few examples of the latest advancements. We hope that the readers enjoy reading these articles and find them useful for their research.

Author Contributions: Both authors have contributed equally. All authors have read and agreed to the published version of the manuscript.

Funding: Y.M. thanks the financial support by the IIT startup funds. S.K.G. thanks the United States-India Education Foundation (USIEF, India) and the Institute of International Education (IIE, USA) for his Fulbright Nehru Postdoctoral Fellowship (award #2268/FNPDR/2017).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gupta, S.K.; Mao, Y. A review on molten salt synthesis of metal oxide nanomaterials: Status, opportunity, and challenge. *Prog. Mater. Sci.* **2021**, *117*, 100734. [CrossRef]
2. Gupta, S.K.; Mao, Y. Recent Developments on Molten Salt Synthesis of Inorganic Nanomaterials: A Review. *J. Phys. Chem. C* **2021**, *125*, 6508–6533. [CrossRef]
3. Gupta, S.K.; Abdou, H.; Segre, C.U.; Mao, Y. Excitation-Dependent Photoluminescence of $BaZrO_3$:Eu^{3+} Crystals. *Nanomaterials* **2022**, *12*, 3028. [CrossRef] [PubMed]
4. Enesca, A.; Andronic, L. UV-Vis Activated $Cu_2O/SnO_2/WO_3$ Heterostructure for Photocatalytic Removal of Pesticides. *Nanomaterials* **2022**, *12*, 2648. [CrossRef] [PubMed]
5. Liang, Y.-C.; Li, T.-H. Sputtering-assisted synthesis of copper oxide–titanium oxide nanorods and their photoactive performances. *Nanomaterials* **2022**, *12*, 2634. [CrossRef] [PubMed]
6. Gupta, S.K.; Mohan, S.; Valdez, M.; Lozano, K.; Mao, Y. Enhanced sensitivity of caterpillar-like ZnO nanostructure towards amine vapor sensing. *Mater. Res. Bull.* **2021**, *142*, 111419. [CrossRef]
7. Si, X.; Luo, M.; Li, M.; Ma, Y.; Huang, Y.; Pu, J. Experimental Study on the Stability of a Novel Nanocomposite-Enhanced Viscoelastic Surfactant Solution as a Fracturing Fluid under Unconventional Reservoir Stimulation. *Nanomaterials* **2022**, *12*, 812. [CrossRef]
8. Liu, X.; Feng, S.; Wang, C.; Yan, D.; Chen, L.; Wang, B. Wettability Improvement in Oil–Water Separation by Nano-Pillar ZnO Texturing. *Nanomaterials* **2022**, *12*, 740. [CrossRef] [PubMed]
9. Maevskaya, M.V.; Rudakova, A.V.; Emeline, A.V.; Bahnemann, D.W. Effect of Cu_2O substrate on photoinduced hydrophilicity of TiO_2 and ZnO nanocoatings. *Nanomaterials* **2021**, *11*, 1526. [CrossRef] [PubMed]
10. Simeonov, S.; Szekeres, A.; Spassov, D.; Anastasescu, M.; Stanculescu, I.; Nicolescu, M.; Aperathitis, E.; Modreanu, M.; Gartner, M. Investigation of the Effects of Rapid Thermal Annealing on the Electron Transport Mechanism in Nitrogen-Doped ZnO Thin Films Grown by RF Magnetron Sputtering. *Nanomaterials* **2021**, *12*, 19. [CrossRef]

11. Naszályi Nagy, L.; Dhaene, E.; Van Zele, M.; Mihály, J.; Klébert, S.; Varga, Z.; Kövér, K.E.; De Buysser, K.; Van Driessche, I.; Martins, J.C. Silica@zirconia Core@shell Nanoparticles for Nucleic Acid Building Block Sorption. *Nanomaterials* **2021**, *11*, 2166. [CrossRef]
12. Li, T.; Yin, W.; Gao, S.; Sun, Y.; Xu, P.; Wu, S.; Kong, H.; Yang, G.; Wei, G. The combination of two-dimensional nanomaterials with metal oxide nanoparticles for gas sensors: A review. *Nanomaterials* **2022**, *12*, 982. [CrossRef] [PubMed]
13. Kim, J.; Paik, T. Recent advances in fabrication of flexible, thermochromic vanadium dioxide films for smart windows. *Nanomaterials* **2021**, *11*, 2674. [CrossRef] [PubMed]