Editorial

TiO₂-Based Nanomaterials for Advanced Environmental and Energy-Related Applications

Xujie Lü,¹ Baoyu Xia,² Cunming Liu,³ Yefeng Yang,⁴ and Hao Tang⁵

¹Center for Integrated Nanotechnologies, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

²School of Chemical and Biomedical Engineering, Nanyang Technological University, Singapore 637459

³Department of Physics, University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620, USA

⁴Department of Materials Engineering, College of Materials and Textile, Zhejiang Sci-Tech University, Hangzhou 310018, China

⁵Chemistry Department, Rutgers University, 73 Warren Street, Newark, NJ 07102, USA

Correspondence should be addressed to Xujie Lü; xujie@lanl.gov

Received 15 February 2016; Accepted 17 February 2016

Copyright © 2016 Xujie Lü et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Titanium dioxide (TiO₂) is one of the most attractive transition-metal oxides because of its superior physical and chemical properties, which has been widely applied in environmental clean-up (photocatalytic pollution removal), energy conversion (hydrogen production and solar cells), energy storage (lithium batteries and supercapacitors), security (sensors), panel display (transparent conducting films), biomedical devices, and so forth [1–18]. The performance of TiO₂ in these applications highly depends on its structural, electronic, optical, and morphological as well as the surface properties (exposed facets). Great effort has been devoted to adjust these properties and apparent progress has been made on the synthesis of the 0-, 1-, 2-, and 3-dimensional nanostructured TiO₂ materials. Nevertheless, further investigations are required on the development of new synthetic methods and the understanding of its relationship between the intrinsic properties and performance, to facilitate the commercialization of TiO₂-based materials in advanced environmental and energy-related areas.

This issue includes original research articles and a review that cover the synthesis of TiO₂-based nanomaterials and their environmental and energy-related applications. We summarize the published articles as below.

In “Influence of Anodic Oxidation Parameters of TiO₂ Nanotube Arrays on Morphology and Photocatalytic Performance,” X. Zhao et al. present the influence of electrolyte, applied potential, and duration of oxidation process on

nanomorphology and photocatalytic property of titanium dioxide nanotube arrays (TNTAs). Compared to the glycol electrolyte, the TNTAs grown by using the DMSO electrolyte exhibit much better photocatalytic activity, but their nanomorphology is much worse. Longer time and higher oxidation voltage benefit the growth of TNTAs.

TiO₂-based catalysts for the selective catalytic reduction of NO are hotspots in environmental catalysis. X. Chen et al. in their paper entitled “Experimental Study on the Deactivating Effect of KNO₃, KCl, and K₂SO₄ on Nanosized Ceria/Titania SCR Catalyst” investigated the deactivating effect of potassium compounds on nanosized CeO₂/TiO₂ selective catalytic reduction catalyst. This study would provide useful insights for the application and life management of CeO₂/TiO₂ in potassium-rich environments such as biofuel-fired boilers.

Development of supported titanium dioxide- (TiO₂-) based nanomaterials would promote their performance. In “Preparation of Stellerite Loading Titanium Dioxide Photocatalyst and Its Catalytic Performance on Methyl Orange,” H. Chen et al. reported the photocatalytic decomposition of methyl orange (MO) over a stellerite modified-TiO₂ photocatalyst. This work would provide a promising strategy to explore highly efficient photocatalyst and thus promote their further application in environmental fields.

Volatile organic compounds have been identified as indoor and outdoor pollutants and the treatment of them

has been studied for decades. In “New Insights into Benzene Hydrocarbon Decomposition from Fuel Exhaust Using Self-support Ray Polarization Plasma with Nano-TiO₂,” T. Zhu et al. developed a new strategy of using nano-TiO₂ as the catalyst in the self-support ray polarization of nonthermal plasma. This strategy showed improved performance to remove benzene. Indeed, at electric field strength of 12 kV/cm, 99% of benzene was removed. Moreover, the final products are environmentally friendly with decreased residence of ozone. This study with advances in potential industrial application should be of interest to the community.

Carbon materials have been extensively investigated and have been well incorporated with TiO₂ materials to improve the performance of their composites. In “Modified Sol-Gel Synthesis of Carbon Nanotubes Supported Titania Composites with Enhanced Visible Light Induced Photocatalytic Activity,” Q. Wang et al. report a multiwalled carbon nanotube enhanced TiO₂ nanocomposites for photocatalytic degradations. The nanocomposites possess good absorption properties not only in the ultraviolet but also in the visible light region. Under irradiation of ultraviolet lamp, the prepared composites have the highest photodegradation efficiency of 83% within 4 hours towards the degradation of methyl orange (MO) aqueous solution. The results indicate that the carbon nanotubes supported TiO₂ nanomaterials exhibit high photocatalytic activity and stability, showing great potentials in the treatment of wastewater.

In a paper entitled “Enhanced Adsorption and Removal of Ciprofloxacin on Regenerable Long TiO₂ Nanotube/Graphene Hydrogel Adsorbents,” J. Ma et al. reported the investigation of regenerable long TiO₂ nanotube/graphene oxide hydrogel adsorbent for antibiotic pollutants, which would attract the attention of environmental science, materials, and nanotechnology community to development a safe and sustainable society.

In “Preparation of TiO₂/Activated Carbon Composites for Photocatalytic Degradation of RhB under UV Light Irradiation,” J. Cao et al. used a sol-gel method to prepare TiO₂/activated carbon (AC) composites and they have found that the loading cycles of TiO₂ precursor play an important role in controlling the morphological structure and photocatalytic activity of TiO₂/AC composites. The porosity parameters of these composite photocatalysts such as specific surface area and total pore volume decrease whereas the loading amount of TiO₂ increases. The TiO₂/AC composite synthesized at two loading cycles exhibits the highest photocatalytic activity.

TiO₂ is a kind of promising anode material because of its low cost, excellent structural stability, small volume expansion, and good safety performance due to its high discharge plateau potential (about 1.5–1.8 V versus lithium) that would not decompose the organic electrolyte, large exposed surface offering more lithium-insertion channels. However, the poor electronic conductivity and low lithium ion diffusivity of TiO₂ result in poor cycling stability and lithium ion depletion at high current rates. A review entitled “Recent Progress of TiO₂-Based Anodes for Li Ion Batteries” by Y. Liu and Y. Yang is specifically focused on the recent progress in enhancing the lithium ion batteries (LIBs) performance of TiO₂ with

various synthetic strategies and architectures control, such as designing hollow structure to form more open channels and active sites for Li ion transport, coating or combining TiO₂ with metal to improve its electronic conductivity, or incorporating carbonaceous materials such as active carbon, CNTs, and graphene to enhance its capacity and cycling stability.

The guest editors hope that this special issue will inspire further research in the field of TiO₂ nanomaterials and their applications in advanced environmental and energy-related areas.

Acknowledgments

The editors gratefully thank the authors for their contributions to this special issue and the reviewers for their constructive comments.

Xujie Lü
Baoyu Xia
Cunming Liu
Yefeng Yang
Hao Tang

References

- [1] B. O'Regan and M. Graetzel, “Low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO₂ films,” *Nature*, vol. 353, no. 6346, pp. 737–740, 1991.
- [2] R. Asahi, T. Morikawa, T. Ohwaki, K. Aoki, and Y. Taga, “Visible-light photocatalysis in nitrogen-doped titanium oxides,” *Science*, vol. 293, no. 5528, pp. 269–271, 2001.
- [3] J. Wang, D. N. Tafen, J. P. Lewis et al., “Origin of photocatalytic activity of nitrogen-doped TiO₂ nanobelts,” *Journal of the American Chemical Society*, vol. 131, no. 34, pp. 12290–12297, 2009.
- [4] J. Zhang, Q. Xu, Z. Feng, M. Li, and C. Li, “Importance of the relationship between surface phases and photocatalytic activity of TiO₂,” *Angewandte Chemie*, vol. 120, no. 31, pp. 1790–1793, 2008.
- [5] X. Lü, X. Mou, J. Wu et al., “Improved-performance dye-sensitized solar cells using Nb-Doped TiO₂ electrodes: efficient electron injection and transfer,” *Advanced Functional Materials*, vol. 20, no. 3, pp. 509–515, 2010.
- [6] M. Sathish, B. Viswanathan, R. P. Viswanath, and C. S. Gopinath, “Synthesis, characterization, electronic structure, and photocatalytic activity of nitrogen-doped TiO₂ nanocatalyst,” *Chemistry of Materials*, vol. 17, no. 25, pp. 6349–6353, 2005.
- [7] B. Naik, S. M. Kim, C. H. Jung, S. Y. Moon, S. H. Kim, and J. Y. Park, “Enhanced H₂ generation of Au-loaded, nitrogen-doped TiO₂ hierarchical nanostructures under visible light,” *Advanced Materials Interfaces*, vol. 1, no. 1, Article ID 1300018, 2014.
- [8] X. Lü, F. Huang, X. Mou, Y. Wang, and F. Xu, “A general preparation strategy for hybrid TiO₂ hierarchical spheres and their enhanced solar energy utilization efficiency,” *Advanced Materials*, vol. 22, no. 33, pp. 3719–3722, 2010.
- [9] H. Ren, R. Yu, J. Wang et al., “Multishelled TiO₂ hollow microspheres as anodes with superior reversible capacity for lithium ion batteries,” *Nano Letters*, vol. 14, no. 11, pp. 6679–6684, 2014.

- [10] W. Li, F. Wang, Y. Liu et al., "General strategy to synthesize uniform mesoporous TiO₂/graphene/mesoporous TiO₂ sandwich-like nanosheets for highly reversible lithium storage," *Nano Letters*, vol. 15, no. 3, pp. 2186–2193, 2015.
- [11] X. Lü, J. Li, X. Mou et al., "Room-temperature ferromagnetism in Ti_{1-x}V_xO₂ nanocrystals synthesized from an organic-free and water-soluble precursor," *Journal of Alloys and Compounds*, vol. 499, no. 2, pp. 160–165, 2010.
- [12] C. Sotelo-Vazquez, N. Noor, A. Kafizas et al., "Multifunctional P-doped TiO₂ films: a new approach to self-cleaning, transparent conducting oxide materials," *Chemistry of Materials*, vol. 27, no. 9, pp. 3234–3242, 2015.
- [13] X. Lü, S. Ding, Y. Xie, and F. Huang, "Non-aqueous preparation of high-crystallinity hierarchical TiO₂ hollow spheres with excellent photocatalytic efficiency," *European Journal of Inorganic Chemistry*, vol. 2011, no. 18, pp. 2879–2883, 2011.
- [14] B. Liu, H. M. Chen, C. Liu, S. C. Andrews, C. Hahn, and P. Yang, "Large-scale synthesis of transition-metal-doped TiO₂ nanowires with controllable overpotential," *Journal of the American Chemical Society*, vol. 135, no. 27, pp. 9995–9998, 2013.
- [15] X. Lü, F. Huang, J. Wu, S. Ding, and F. Xu, "Intelligent hydrated-sulfate template assisted preparation of nanoporous TiO₂ spheres and their visible-light application," *ACS Applied Materials & Interfaces*, vol. 3, no. 2, pp. 566–572, 2011.
- [16] T. Leijtens, G. E. Eperon, S. Pathak, A. Abate, M. M. Lee, and H. J. Snaith, "Overcoming ultraviolet light instability of sensitized TiO₂ with meso-superstructured organometal trihalide perovskite solar cells," *Nature Communication*, vol. 4, article 2885, 2013.
- [17] X. Lü, W. Yang, Z. Quan et al., "Enhanced electron transport in Nb-doped TiO₂ nanoparticles via pressure-induced phase transitions," *Journal of the American Chemical Society*, vol. 136, no. 1, pp. 419–426, 2014.
- [18] J. T.-W. Wang, J. M. Ball, E. M. Barea et al., "Low-temperature processed electron collection layers of graphene/TiO₂ nanocomposites in thin film perovskite solar cells," *Nano Letters*, vol. 14, no. 2, pp. 724–730, 2014.