

Theme issue: inorganic nanotubes and nanowires

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Nanotubes, nanowires and nanobelts are important one-dimensional (1D) nanomaterials that are the foundation for nanoscience and nanotechnology (Fig. 1a). 1D nanomaterials have important applications in electronics, optoelectronics, sensors, biomedical science, environmental science, green energy and advanced defence technologies. This themed issue on inorganic 1D nanomaterials gathers papers about the synthesis, characterization and novel applications of 1D nanomaterials, which gives a broad overview about the on-going cutting-edge research in the forefront of the field.

Among the 1D nanomaterials being studied, carbon nanotubes, silicon nanowires and zinc oxide nanowires/nanobelts are the dominant materials systems (Fig. 1). Among the 27 papers published in this issue, we have 7 feature articles that

give a comprehensive review on some of the important facets of research in the field, 7 papers on ZnO, 6 papers on complex oxides, 5 papers on Si, Ge, GaN and GaAs. The contents of these papers can be summarized as follows.

Development of novel synthesis techniques is an active research field in 1D nanomaterials. Chenguo Hu *et al.* gave a comprehensive introduction about a composite hydroxide-mediated approach for synthesizing a wide range of nanostructures in the categories of complex oxides, hydroxides, simple oxides, sulfides, selenides, tellurides, fluorides and metals. Shu-Hong Yu's group has introduced a general approach for synthesis of a family of functional inorganic nanotubes such as TiO₂, Fe₂O₃, SnO₂, ZrO₂, and SnO₂@Fe₂O₃ composite using highly active carbonaceous nanofibres as templates. Hassel's group reports an unusual but exciting structure of single crystalline gold nanobelts. Yu Huang's group reported fluid assisted assembly of one-dimensional nanoparticle arrays inside inorganic nanotubes, providing a new approach for integrating nanoparticles with nanotubes. C. N. R. Rao's group reported covalent functionalization of nanowires of TiO₂, ZnO and Al₂O₃.

ZnO is a material that is attracting a lot of research interest. Sishen Xie's lab has synthesized periodic ZnO nanorod arrays and observed their blue shift in photoluminescence. Gyu-Chul Yi's group reported controlled epitaxial growth modes of ZnO nanostructures using different substrate crystal planes. Willander *et al.* report their up to date chemical synthesis of zinc oxide nanowires and their applications in electrochemical and light emitting diodes (LEDs).

Beyond binary oxides, synthesis of 1D nanostructures of complex oxides and oxides with unique crystallographic structures is a new trend in nanomaterials synthesis. Hong Jin Fan *et al.* gave a review on the synthesis of 1D nanomaterials of spinel structured materials,

such as Al₂O₃, Ga₂O₃, Fe₂O₃, Sb₂O₃, TiO₂, and SnO₂. Using ZnO nanowire arrays as sacrificial templates, Kuang and Xie reported the fabrication of aligned SnO₂ nanotube arrays, which are great candidates for gas and chemical sensors. Shihe Yang's group described a general surfactant-free synthesis of MTiO₃ (M = Ba, Sr, Pb) perovskite nanostrips. Xiaodong Li's group introduced low temperature, organic-free synthesis of 1D nanostructures of complex hydroxides and oxides. Pu-Xian Gao *et al.* described synthesis, characterization, and photocatalytic properties of ZnO/(La,Sr)CoO₃ composite nanorod arrays.

Among all, 1D nanostructures of silicon, germanium and III-V compound semiconductors are a forefront research field. Jing Zhu's group has reviewed the recent progress in syntheses, properties and applications of Si, ZnO, metal, and heterojunction nanowires. Heigoldt *et al.* presented a long range epitaxial growth of prismatic heterostructures on the facets of catalyst-free GaAs nanowires for receiving branched heterojunctions. Holmes's group described a single step synthesis of Ge-SiO_x core-shell heterostructured nanowires. Chockla and Korgel reported a seeded germanium nanowire synthesis in solution, which provides a new route for scale-up production of Ge nanowires. Lauhon's group presented a sub-eutectic vapor-solid-solid (VSS) growth of Si and Ge nanowires together with new studies of Mn-mediated Ge and Si nanowires to assess the generality of sub-eutectic nanowire growth and highlight key requirements. Song Jin's group presented epitaxial growth of hierarchical PbS nanowires.

Besides synthesis and structure analysis, in-situ characterization of the physical properties of individual nanostructures is of vital interest for understanding their unique performance. Golberg and Bando introduced properties and engineering of individual inorganic nanotubes using in-situ transmission electron microscopy, which

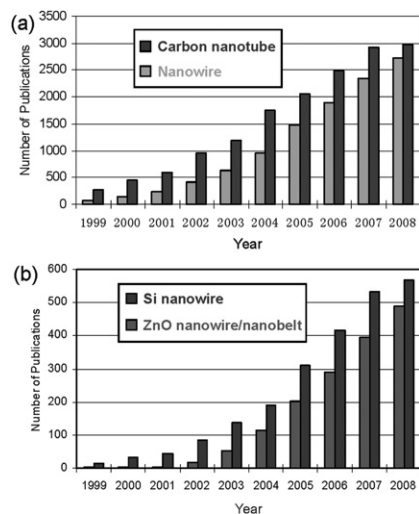


Fig. 1 Publication statistics on (a) carbon nanotubes and inorganic 1D nanomaterials (nanowire, nanorod, nanobelt, nanofiber, or nanotip), and (b) ZnO and Si 1D nanomaterials (nanowire, nanorod, nanobelt, nanofiber, or nanotip). The plotted data were received on Dec. 28, 2008 using the database from Institute of Scientific Information by searching the listed key words that appear in the title, abstracts and keywords.

provides a direct correlation between the measured property and the observed structure. X. D. Bai and E. G. Wang's group studied the bending effect of individual zinc oxide nanowires on photoconducting behavior of individual ZnO nanowires, and they found an improved photoresponse performance of the nanowires as a result of bending. The result supports the mechanism proposed for piezotronics.

Novel applications of 1D nanomaterials are the core of the current research. Guozhen Shen and Chongwu Zhou's groups have presented devices and chemical sensing applications of metal oxide nanowires. Kuei-Hsien Chen and Li-Chyong Chen's groups reported functionalized GaN nanowire-based electrodes for direct label-free voltammetric detection of DNA hybridization. Younan

Xia's group has reported synthesis and application of RuSe₂ nanotubes as a methanol tolerant electrocatalyst for the oxygen reduction reaction. Guozhong Cao's group reported carbon monoxide annealed TiO₂ nanotube array electrodes for efficient biosensor applications. Moon-Ho Jo and Seunghun Hong's groups gave a review about three promising strategies for the massive assembly of inorganic nanowires on solid substrates for their device applications. This is an important step towards nanomanufacturing. Huibiao Liu, Yuliang Li and colleagues reported the enhanced field emission properties of ZnO nanoparticles and CuTCNQ (copper 7,7,8,8-tetracyanoquinodimethane) nanowires.

I anticipate that this themed issue not only presents to our readers an overview about the current on-going research

worldwide, although it is not a complete list from all of the active groups, but also serves as a guidance about the near future development directions in the field.



Zhong Lin (Z. L.) Wang, Georgia Institute of Technology, USA, Guest Editor