Chemistry and Physics of Nanowires

By *Younan Xia** and *Peidong Yang**

It has been our greatest pleasure to put together this special issue that is intended to cover all major aspects of research devoted to the chemistry, physics, and materials science associated with nanowires. Nanostructures (i.e., structures with at least one dimension in the range of 1–100 nm) have attracted steadily growing interest due to their peculiar, fascinating properties, as well as their unique applications complementary to the bulk materials. The ability to generate such small structures is central to the advance of many areas in modern science and technology. There are a large number of opportunities that could be realized by making new types of nanostructures, or by down-sizing currently existing structures into the nanoscale regime. In comparison with zero-dimensional (0D) nanostructures (or the so-called quantum dots or nanoparticles), 1D nanostructures (including wires, rods, belts, and tubes) provide a better model system for investigating the dependence of electronic transport, optical, and mechanical properties on size confinement and dimensionality. Nanowires, in particular, should play an important role as both interconnects and active components in fabricating nanoscale electronic and photonic devices. Until very recently, the advance in the utilization of nanowires had been relatively slow, probably due to difficulties associated with the synthesis of such nanostructures with well-controlled size, phase purity, crystallinity, and chemical composition. Solutions to these synthetic challenges require a detailed, fundamental understanding and good control of the nucleation and growth processes at the nanometer scale, whether it is in the solution or vapor phase. Due to the lack of nanowires with excellent monodispersity, it has also been difficult to draw conclusions on the structure–property correlations for this class of nanostructures, and to fully exploit their potential in fabricating new types of functional devices. These challenges and opportunities have motivated many groups to launch research projects specifically focused on the synthesis, characterization, and utilization of nanowires.

This special issue includes contributions from many leading figures in this area. Xia and Yang give a comprehensive review on recent research activities that involve the synthesis, characterization, self-assembly, physical properties, and applications of nanowires. The rest of the articles cover four important research themes: i) vapor-phase routes to the synthesis of nanowires; ii) solution-based methods for forming nanowires; iii) templated-directed synthesis of nanowires; and iv) self-assembly with nanowires as the building blocks and new physics associated with 1D nanostructures.

In the first theme, involving vapor phase growth, Yang and co-workers discuss how several simple processes could be adopted to grow nano- and microscale hierarchical structures based on ZnO nanorods; Wang presents a brief overview of recent work related to the synthesis of metal oxide nanobelts and nanowires; Liu and co-workers describe a new method for preparing tungsten oxide nanowires as 2D arrays on solid substrates; and Yu and co-workers report an improved procedure for the formation of uniform GaN nanowires. In the second theme, concentrating on solution-phase synthesis, Yu and Buhro describe a solution–liquid–solid approach to the synthesis of GaAs nanowires with well-controlled diameters approaching the quantum confinement size; Hanrath and Korgel review their recent work on the growth of semiconductor nanowires in supercritical fluids with alkanethiolate-capped gold colloids as seeds; Qian and co-workers examine the potential of solvothermal technique in synthesizing various types of 1D nanostructures; Peng briefly reviews recent progress on the shape-controlled synthesis of CdSe nanostructures; Cheon and co-workers illustrate how the shape of nanostructures could be controlled by changing thermodynamic and kinetic parameters; and Vayssieres describes the use of controlled hydrolysis in generating supported arrays of ZnO nanorods and nanowires. In the third theme, dealing with template-directed synthesis, Penner and co-workers report the use of step edges and nanowires in guiding the formation and assembly of nanoparticles; Cao and Limmer illustrate how electrophoresis and templating against porous membranes could be combined to provide an effective route to the synthesis of oxide nanorods having complex compositions; Murphy and co-workers demonstrate how structures assembled from surfactant molecules could be used to obtain metal nanorods with controlled aspect-ratios; Wang and Li summarize their recent work on the synthesis of metal nanowires and nanotubes by templating against lamellar structures assembled from surfactants; and Xie and co-workers describe a new templating route to the synthesis of Ag nanowires by sandwiching the silver ions between ferrocene molecules before the reduction step.

It is clear that within a relatively short period of time, major advancements have been made with regard to the chemical synthesis of 1D nanostructures from both vapor and solution phases. Intriguing physics associated with this new class of

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  0935-9648/03/0503-0351 $ 17.50+.50/0

ADVANCED MATERIALS

nanostructures has also begun to be unfold. A grand challenge resides in the *hierarchical integration* of these nanoscale building blocks into *functional assemblies* and ultimately to a *complex*, *multi-functional* system. Unlike traditional lithographic processing where precise placement of certain elements or devices is embedded in the design process, the precise placement of nanoscale building blocks in the right place with right configuration and with exceedingly high densities remains to be a daunting task for those working in this area. Progress has recently been made along this direction and prototype devices have also been demonstrated. For example, the microfludic channel-assisted integration and the Langmuir–Blodgett technique both hold promise as effective routes to the assembly of nanowires into high-density arrays. In this regard, the last theme of this special issue covers those articles that dealt with the self-assembly and integration of 1D nanostructures, as well as their unique properties and potential applications. Mallouk and co-workers report their measurements on the diffusion constants of gold nanorods on various functional surfaces; Li and Alivisatos discuss the self-organization of CdSe nanorods into various liquid crystalline phases both in liquid dispersions and on surfaces of solid supports; Wirtz and Martin briefly review the electrochemical and molecular sieving properties of gold nanowires and nanotubes that could be easily prepared by templating against porous membranes; Park and co-workers discuss the ferroelectric properties of $BaTiO_3$ nanowires and their implication for information storage; El-Sayed and co-workers describe their spectroscopic studies on the electron coupling dynamics associated with gold nanorods and arrayed tetrahedrons; and Keating and Natan describe the synthesis of striped metal nanowires with well-defined dimensions and compositions by sequential deposition in porous membranes, as well as their potential use as the building blocks for nanoscale electronics and as "barcodes" for both biological and non-biological tagging applications.

It is hoped that this special issue will be able to provide the readers some representative and exciting snapshots regarding the synthesis, characterization, and utilization of nanowires. Due to the highly dynamic nature of this fast-evolving field, it is impossible to cover every aspect of this class of new materials, especially those accomplishments that were most recently achieved by research groups not involved in the preparation of this special issue. There is no doubt that this new field will continue to develop strongly, with contributions from chemists, physicists, material scientists, and engineers. It is also hoped that readers of this special issue will enjoy the mix of topics presented here and perhaps find the inspiration to push this field a step further toward commercial importance.

  0935-9648/03/0503-0352 $ 17.50+.50/0