DOI 10.5162/IMCS2012/8.4.1

Hybrid Nanofabrication for Multifunctional Nanowire Sensor Applications

Inkyu Park[1*], Daejong Yang[1], Donghwan Kim[1], Young Wook Lee[2], Sang Woo Han[2], and Zhiyong Li[3]
[1] Department of Mechanical Engineering, KAIST, 291 Daehak-ro, Yoosung-Gu, Daejeon, Korea
inkyu@kaist.ac.kr
[2] Department of Chemistry, KAIST, 291 Daehak-ro, Yoosung-Gu, Daejeon, Korea
[3] Intelligent Infrastructure Lab, Hewlett Packard Laboratory, 1501 Page Mill Road, Palo Alto, CA, USA

Abstract

We introduce two novel hybrid nanofabrication methods for the facile synthesis and integration of functional nanomaterials towards highly sensitive physical and chemical sensors. The first method is thermally-driven local synthesis of metal oxide nanostructures where localized temperature field enhances mass transport of precursor materials and endothermal reaction at selected regions. The second method is template-based synthesis of metal nanotubes based on heterogeneous nucleation of metal atoms along sacrificial metal oxide nanowire templates and in-situ dissolution of templates.

Key words: nanowires, nanotubes, local synthesis, template-based synthesis, gas sensors

Introduction

Recently, nanomaterials such as nanoparticles, nanowires, nanotubes, and their composites are actively researched for sensor applications. Representative examples include silicon nanowires for the detection of pH level [1], ZnO nanowires for the detection of UV illumination [2], and carbon nanotubes for the detection of toxic gases [3]. Although nanomaterials have proven to exhibit an outstanding performance, they are still far from practical and industrial applications due to poor controllability, repeatability, high manufacturing cost, and throughput. The major bottleneck for these barriers is an extreme difficulty of reliable integration of these nanomaterials on functional sensor devices [4]. Here, we introduce two novel methods for easy, controllable, reliable, eco-friendly, inexpensive, and high-throughput fabrication and integration of nanomaterial-based sensors.

Principles and Experimental Results

The first method is thermally-driven local synthesis of metal oxide nanostructures [5]. Here, we use an array of microheaters for the control of local temperature field in microscale space. By applying an electrical bias across selected microheater, local temperature rise is induced and this creates continuous convective mass transport of fresh precursor chemicals towards heated region. Then, nanomaterials are synthesized by endothermal reaction at these hot regions (see Fig. 1a). Since the nanomaterials are grown from the pre-deposited seeds coated on the hot region, they are directly integrated to the device electrodes. In the present work, we have fabricated sensor devices based on ZnO nanowire network (see Fig. 1b). Due to the photosensitivity of ZnO nanowires, they could be used for the UV sensors (see Fig. 1c). Myriad nano-junctions between locally grown ZnO nanowires create connection between neighboring electrodes that is highly sensitive to the photo-illumination.

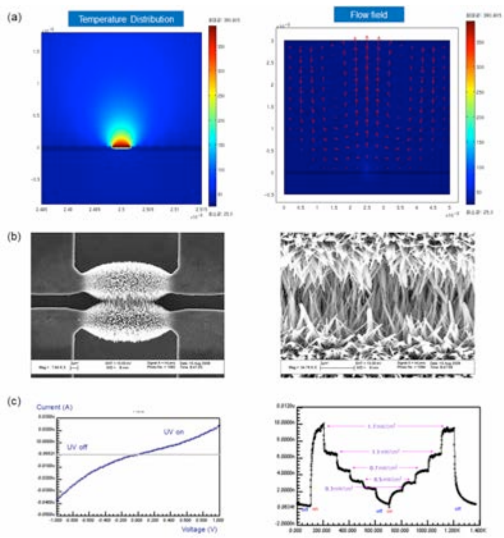

Fig. 1. Thermally-driven local synthesis of metal oxide nanostructures and UV sensor applications

DOI 10.5162/IMCS2012/8.4.1

Another application of locally grown ZnO nanowires is gas sensors. The reaction of reducing gases such as H_2 and H_2S with oxygen ions (O^{2-}) at the surface of ZnO nanowires modulates the depletion layer thickness and electrical conductivity of ZnO nanowire network (see Fig. 2a). Localized heating can be further used for the selective surface decoration of ZnO nanowires with catalytic metal nanoparticles such as Pd or Pt. Heterogeneous nucleation of these metal nanoparticles along the surface of ZnO nanowires allows a facile coating and modification of nanowire surfaces with these particles. (see Fig. 2b) The decoration with catalytic nanoparticles results in enhanced sensitivity, selectivity, and response speed. As compared to the pristine ZnO nanowires, nanowire sensors decorated with catalytic nanoparticles show higher sensitivity by orders of magnitude (see Fig. 2c).

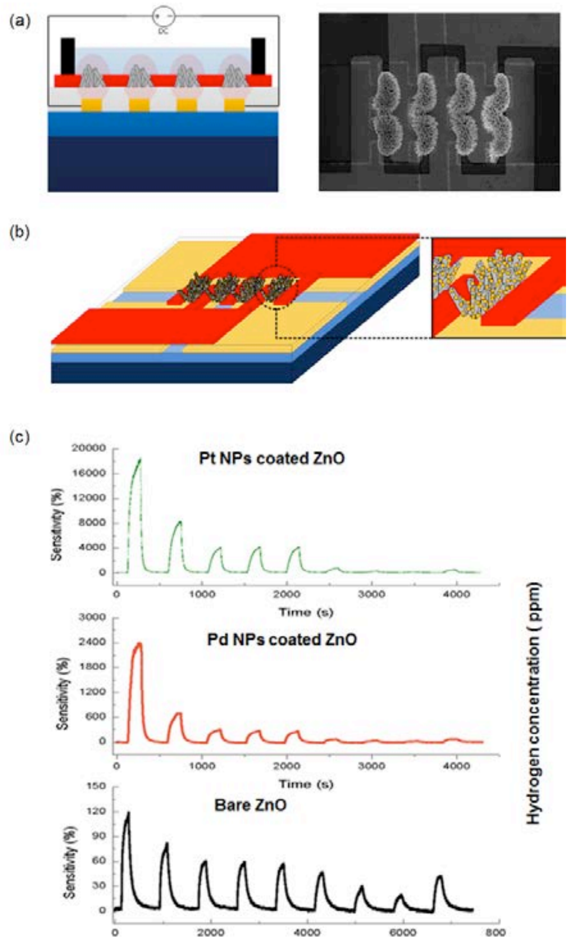

Fig. 2. Gas sensor application of locally synthesized nanowire network and effect of surface decoration with catalytic nanoparticles on their surfaces

The second method we are introducing is a template-based synthesis of metal nanotubes by using a heterogeneous nucleation of metal atoms along sacrificial metal oxide nanowire templates (see Fig. 3) [6]. First, ZnO nanowire templates are synthesized by low-temperature hydrothermal reaction. Then, metal nanoparticles are synthesized along the ZnO nanowire templates by reduction of metal precursors with sodium citrate. The formation of tubular nanostructures can be explained by in-situ dissolution of ZnO nanowire templates due to lowered pH level during the metal nanoparticle synthesis. Therefore, this method alleviates the problems of conventional methods for metal nanotube fabrication in terms of multiple processes, toxic chemistry, additional procedures for template removal, and difficulties of device integration. Synthesis condition such as low-temperature and mild chemistry allows the fabrication of metal nanotubes on a variety of substrates including silicon, glass, and flexible polymer substrate.

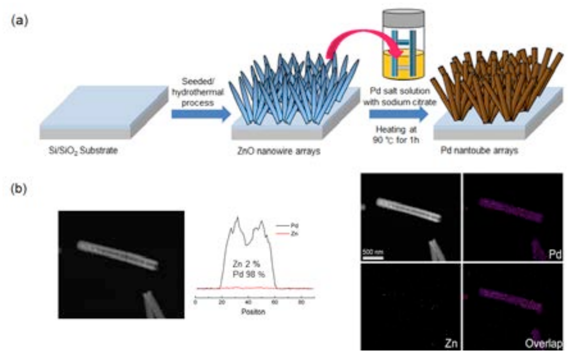

Fig. 3. Template-based synthesis of metal nanotubes by heterogeneous nucleation of metal atoms along sacrificial metal oxide nanowires and in-situ dissolution of nanowires

By using this method, we could successfully demonstrate highly sensitive and flexible H_2 sensors based on Pd nanotube arrays. Due to the large surface area by tubular morphologies of fabricated structures and porous network of nanoparticles constituting the nanotubes, extremely high sensitivity and high response speed to the H_2 gas were observed (see Fig. 4a). In addition, the flexible H_2 sensors based on Pd nanotube arrays exhibited excellent mechanical bendability and durability (see Fig. 4b). Therefore it is expected that these sensors would be extremely useful for the applications in various systems that demands highly sensitive chemical sensing with light weight, mechanical flexibility, and robustness.

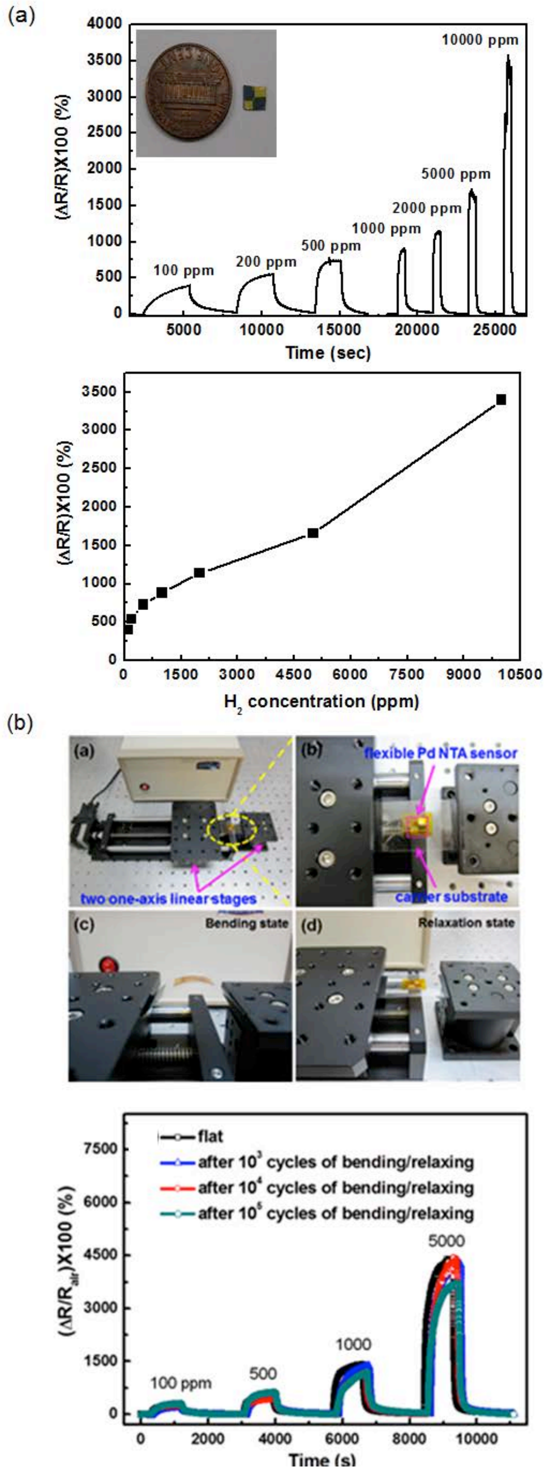

Fig. 4. H2 gas sensing performance of Pd nanotube sensors fabricated by template-based synthesis and mechanical robustness test

Conclusion

In this paper, we introduced two novel hybrid nanofabrication methods for the facile fabrication of nanowire-based sensors for various environmental parameters. These methods are thermally-driven local synthesis of nanowires and template-based synthesis of nanotubes. We believe that both of these methods would be very useful for the fabrication of a variety of high performance environmental sensors.

Acknowledgements

This work was supported by Basic Science Research Program (2010-0015290), Smart IT Convergence System Research Center (Global Frontier Project, 2011-0031870) through the National Research Foundation (NRF) funded by the Korean government (MEST), and Open Innovation Research Program of Hewlett Packard (HP) Company, USA.

References

[1] I. Park, Z. Li A. P. Pisano, and R.S. Williams, Top-down Fabricated Silicon Nanowire Sensor for Real-time Chemical Detection, *Nanotechnology* 21, 015501 (2010)

[2] J. Suehiro, et al., Dielectrophoretic Fabrication and Characterization of a ZnO Nanowire-based UV Photosensor, *Nanotechnology* 17, 2567-2573 (2006)

[3] T. Zhang, et al., Electrochemically Functionalized Single-Walled Carbon Nanotube Gas Sensors, *Electroanalysis* 18, 1153-1158 (2006)

[4] S. Jin, et al., Scalable Interconnection and Integration of Nanowire Devices without Registration, *Nano Letters* 4, 915-919 (2004)

[5] I. Park, et al., Focused Energy Field Method for Nanomaterial Synthesis and Integration, in preparation

[6] M. Lim, D. Kim, C-O. Park, Y. Lee, S-W. Han, Z. Li, R.S. Williams, and I. Park, A New Route Towards Ultra-sensitive, Flexible Chemical Sensors: Metal Nanotubes by Wet-Chemical Synthesis along Sacrificial Nanowire Templates, *ACS Nano* 6, 598-608 (2012)