AUTHOR COMMENTARIES - 2009

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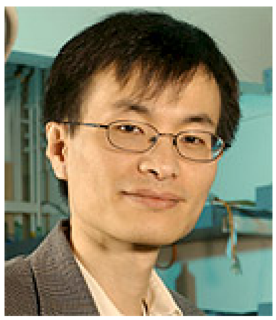


Peidong Yang

Featured Paper Interview

According to Essential Science IndicatorsSM *from Thomson Reuters, the paper currently ranked at #1 among Materials Science papers published in the past decade is "Room-temperature ultraviolet nanowire nanolasers" (Huang, MH,* et al.*, Science *292[5523]: 1897-9, 8 June 2001), with 2,849 citations to its credit up to February 28, 2009.*

The chief researcher behind this paper is Dr. Peidong Yang. Dr. Yang's record in the database includes 139 papers, mainly classified under either Materials Science or Chemistry, cited a total of 18,814 times. He is also a Highly Cited Researcher in Materials Science. Dr. Yang is the Miller Professor of Chemistry at the University of California, Berkeley, where he heads up his own research group. He is also an Associate Editor for the Journal of the American Chemical Society.

In the interview below, ScienceWatch.com *talks with Dr. Yang about this paper and its impact on the nanowire research community.*

SW: What factors led you to research room-temperature ultraviolet lasing?

Back in 1999, my research group at Berkeley initiated a research program centered around semiconductor nanowires. This program was about developing chemical processes for the rational synthesis and assembly of semiconductor nanowires and exploring their fundamental physical properties. My first postdoc fellow, Dr. Michael Huang (now a Chemistry Professor at National Tsinghua University, Taiwan), developed a simple vapor condensation process for the production of zinc oxide (ZnO) nanowires on substrates such as silicon. This nanowire growth process was first published in *Advanced Materials* in 2001 (Huang MH, *et al.*, "Catalytic growth of zinc oxide nanowires by vapor transport," 13[2]: 113-6, 16 January 2001). This paper is now also one of the highly cited papers in the nanowire research community.

Having a research background in epitaxial oxide thin-film growth during my Ph.D. training, a very natural next step was to examine the possibility of growing ZnO nanowires on an epitaxial substrate such as sapphire. This turned out to be a stunning success. Michael's first trial on nanowire growth on sapphire substrate yielded beautifully oriented, high-density, uniform ZnO nanowire arrays.

These nanowires have a perfect hexagonal cylindrical shape with atomically smooth side and end facets. The diameters of these nanowires are typically in the range of 80-200 nm. At the time, we realized that these hexagonal nanowires bear striking similarities to the conventional macroscopic laser cavity—only in this case, it is a much smaller nanoscopic version. This led to the first discovery of room-temperature UV nanowire nanolasers.

Figure 1: +details

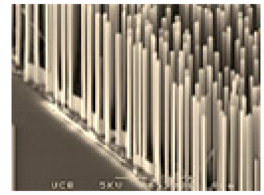
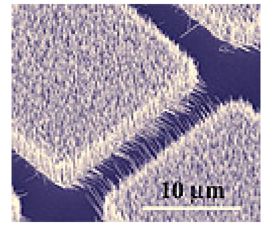


Figure 2:



SW: Would you sum up the paper—your methods, findings, etc.?

The 2001 *Science* paper on nanowire nanolasers reported the growth of high-quality, uniform ZnO nanowire arrays by combining a typical vapor-phase nanowire growth process with another common thin-film growth technique: epitaxy. The resulting nanowires have a perfect hexagonal cylindrical shape with atomically smooth side and end facets. The diameters of these nanowires are typically in the range of 80-200 nm. Since ZnO is a wide-bandgap material emitting in UV region and also has a relatively high refractive index, we reasoned that it is very much likely that these hexagonal nanoscopic cylinders could serve as a sub-wavelength laser cavity in the UV region (below 400 nm).

We went ahead and tested the idea using an optical pumping approach. We used the 4th harmonic output of a Nd:YAG laser (266 nm) as the excitation source and have clearly demonstrated that these highly oriented ZnO nanowire arrays indeed serve as an excellent nanoscopic laser cavity with a lasing wavelength of 380 nm. This is the first report of using semiconductor nanowires as a nanoscopic Fabry-Perot laser cavity.

SW: How was the paper received by the community?

This paper has been very well received by the community, judging by the large number of citations in the past decade. In retrospect, this work could be considered as one of the milestones in the nanowire research field. Back in 1999-2000, only very few research groups had concentrated efforts on nanowire research. Since nanowire research was still at its early stage, much of the research efforts at that time were targeted for rational growth and assembly, not so much on functionalities.

The discovery of lasing in semiconductor nanowires led to a flurry of research into photonic properties of nanowires. For example, the nanowire lasing concept was later quickly adopted in many other nanowire materials, including CdS and InSb, with lasing wavelengths spanning from UV to IR. By now, nanowire photonics has become a very important subfield within the nanowire research community.

SW: You mention the potential applications in the paper—have any of them been realized?

After our first discovery of UV lasing in ZnO nanowires, several other research groups quickly demonstrated lasing in other material systems with lasing wavelength from UV to IR. In addition, this research has further evolved into a much larger research effort along the line of nanowire photonics, with a purpose of miniaturizing optical devices using nanowires as potential building blocks.

The development of these nanoscopic light sources could be very important for applications such as data storage and optical computing, as well as on-chip chemical/biological detection. At this point, the sensing application seems to be most promising, part of which has already been demonstrated in my lab (See Sirbuly DJ, *et al*., "Multifunctional nanowire evanescent wave optical sensors," *Adv. Mater*. 19[1]: 61 +, 8 January 2007 and Sirbuly DJ, *et al*., "Optical routing and sensing with nanowire assemblies," *Proc. Nat. Acad. Sci.* 102[22]: 7800-5, 31 May 2005).

SW: Where have you taken this work since 2001, and where do you hope to take it in the next several years?

Since the first nanowire laser report in 2001, we have devoted significant effort to understanding the optical processes at the single nanowire level. This has led to several important pieces of work within the field, including, for example, the demonstration of subwavelength waveguiding in a single nanowire (See Law M, *et al*., "Nanoribbon waveguides for subwavelength photonics integration," ***Science,*** 305[5688]: 1269-73, 27 August 2004); non-linear optical mixing within a single nanowire (Nakayama Y, *et al*., "Tunable nanowire nonlinear optical probe," *Nature*, 447[7148]: 1098-U8, 28 June 2007).

"The discovery of lasing in semiconductor nanowires led to a flurry of research into photonic properties of nanowires."

All of these studies represent important steps towards a functional, integrated photonic system using our nanowire building blocks. I believe that these subwavelength structures represent a new class of semiconductor materials for investigating light generation, propagation, detection, amplification, and modulation.

For the near future, I believe that there are two very important directions for this research. First, these single crystalline oxide or nitride nanowires could be used for the development of high-efficiency light-emitting devices with different wavelengths, including white light sources. Secondly, at the single-nanowire level, these nanoscopic light sources could be used to probe individual living cells in a non-invasive manner. Such single-cell endoscopy will rely on the use of these nanoscopic light sources and allow us to monitor *in-vivo* biological processes within single living cells with high spatial resolution.

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Peidong Yang's current most-cited paper in *Essential Science Indicators*, with 2,849 cites:

Huang MH, *et al*., "Room-temperature ultraviolet nanowire nanolasers," *Science* 292(5523): 1897-9, 8 June 2001. Source: *Essential Science Indicators* from Thomson Reuters.

Additional Information:

- **May 2008**
  Peidong Yang is a Professor of Chemistry at the University of California, Berkeley. In this podcast interview, he discusses his lab’s interdisciplinary research in semiconductor nanowires. Yang is a Current Classics scientist (Mat. Sci.) from Apr. 2008.
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KEYWORDS: ROOM-TEMPERATURE ULTRAVIOLET NANOWIRE NANOLASERS, ZNO NANOWIRE ARRAYS, GAN NANOWIRE ARRAYS, VAPOR PHASE, THIN FILM GROWTH TECHNIQUE, EPITAXY, REFRACTIVE INDEX, NANOSCOPIC FABRY-PEROT LASER CAVITY, NANOWIRE PHOTONICS, NANROWIRE-LEVEL OPTICAL PROCESSES, LIGHT EMITTING DEVICES, SINGLE-CELL ENDOSCOPY, APPLICATIONS.

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