AUTHOR COMMENTARIES - From Special Topics

Mesoporous Materials - June 2008
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Professor Osamu Terasaki
From the Special Topic of Mesoporous Materials

According to our Special Topics analysis of mesoporous materials research over the past decade, the work of Professor Osamu Terasaki ranks at #6 by total cites, by number of papers, and by cites/paper, with 64 papers cited a total of 2,910 times to date. Three of his papers also appear on the list of the 20 most-cited papers in this Topic over the past decade.

In Essential Science Indicators*SM from Thomson Reuters, Professor Terasaki's citation record includes 170 papers, mainly found in the fields of Chemistry and Materials Science, cited a total of 6,314 times between January 1, 1998 and June 30, 2008.*

Professor Terasaki is the Head of Structural Chemistry, in the Department of Physical, Inorganic & Structural Chemistry at the University of Stockholm in Sweden, a position he has held since 2003.

In the interview below, ScienceWatch.com *correspondent Gary Taubes talks with Professor Terasaki about his highly cited work.*

SW: How did your research on mesoporous materials begin?

I was in the physics department at Tohoku University in Japan, in the late 1990s, studying microporous crystals called zeolites. I came across a paper from Shinji Inagaki on the mesoporous material FSM-16 and I thought it was something I should study—especially its crystal symmetry and growth procedure. I contacted Inagaki, and together we worked on and published a paper in the journal *Microporous and Mesoporous Materials* suggesting that the "folded sheet mechanism" he had discussed in his original paper had to be modified. We've continued to collaborate ever since.

SW: Your most-cited article discusses nanoporous arrays (Joo SH, *et al*., "Ordered nanoporous arrays of carbon supporting high dispersions of platinum nanoparticles," *Nature* 412[6843]: 169-72, 12 July 2001). What's the connection there with mesoporous materials?

We were interested in arrayed nanostructured materials within crystals. "Mesoporous" means the material has pores 20 to 100 angstroms in diameter. These materials are crystals, which mean the pores are imbedded in amorphous silica and are arranged periodically. Then we can study entirely new materials, like nano-network materials, synthesized in the pores of the mesoporous crystal.

SW: When you published the paper on nanoporous materials in *Nature*, were you aware of how significant it was?

Well, it is embarrassing that I wasn't aware of the importance of carbon, which is what we were using in that paper. Ryong Ryoo is a very clever guy and he knows about the actual requirements in the real world. He was the one who developed nano-casted carbon, synthesized composite with Pt nano-particles and thought this paper was important. So, no, I never suspected this paper would be so highly cited.

"These materials can be used or can be useful for drug delivery and biomedical applications."

On the other hand, our 1999 *JACS* paper with Inagaki (Inagaki S, *et al*., "Novel mesoporous materials with a uniform distribution of organic groups and inorganic oxide in their frameworks," *JACS* 121: 9611-4, 1999), that one I thought from the very first would get a lot of attention. This was unfortunately rejected by *Nature* but *was* accepted by JACS within a month. I cannot understand why after our paper appeared in *JACS, Nature* published a paper on the same topic.

SW: Why do you think they rejected yours?

They said it was too specialized; that *Nature* is a general interest journal and this was paper was of narrow interest. It seems from their latter publication that they changed their mind.

SW: Why did you choose *Nature* to begin with?

Because it is a general interest journal. If we were successful with *Nature* we'd attract many more readers, and, to be honest, that's quite helpful in receiving a research grant. We published one paper in *Nature*—Sakamoto Y, *et al.,* "Direct imaging of the pores and cages of three-dimensional mesoporous materials," *Nature* 408(6811): 449-53, 23 November 2000—followed by a few more *Nature* papers. These helped me a lot in raising research grants.

SW: What do you consider the most challenging aspects of research on mesoporous and nanoporous materials?

Personally, I am not good at making these materials. I worked with a Ph.D. student in Yokohama University named Shunai Che who can do this, and she is now a Cheung Kong Professor in Shanghai and one of my most important material suppliers. Ryong, Inagaki, and Dong Yuan Zhao can also make the novel materials, and my group extends the method to solve/characterize the structures of new crystals and then we publish together.

Even for the chemists, it's not easy to create highly crystalline materials. These materials inevitably contain various kinds of defects. They're also electron-beam sensitive, which means they are easily damaged during the electron microscope observation. If you use X-ray diffraction you can only detect a few reflections, so it's impossible to obtain enough information for structural solution from the X-ray powder diffraction. We can do it with our method, and, as far as I know, we're the only ones to ever solve three-dimensional mesoporous structures.

SW: How does your method work?

I think it's deceptively simple. We take high-resolution electron microscope images, and from these images we obtain Fourier diffractograms—like electron diffraction patterns, but these also contain the phase information of structure factors. This phase information is essential to solving the structure—that's our advantage. Once we're able to get the phase information, then we can obtain unique structural solutions. This is the method we described in the 2000 *Nature* paper.

SW: How rapidly has the state of knowledge in your field evolved since your 1999 paper with Inagaki?

I think we built a lot of the conceptual framework when I was in Japan, before 2003. After that, we've received interesting new materials, so we've been extending the method further to new materials. Recently Miyasaka and I developed quite a big step; however, this was rejected by *Nature*. We'll submit it to another high-ranking journal.

SW: What was the new step?

In our previous method described in *Nature* in 2000, we solve the structure with the help of gas adsorption data, therefore we can solve only after the surfactant is removed. Now we have proposed a way to solve the structure and to provide pore volume and surface area with the surfactant intact. That means we can solve it in its synthesized state. As prepared, these crystals contain a lot of surfactant, and when you want to use these mesoporous materials—for drug delivery, for example—then an existence of the surfactant is important. It can stabilize/protect a drug or peptide in

"...as far as I know, we're the only ones to ever solve three-dimensional mesoporous structures."

these materials. It can contribute to slow delivery of the drug, so you want the structure with the surfactant, ideally.

SW: I hate to ask this question, but why did *Nature* reject it?

Again, they said this was too specialized for them.

SW: Where do you see your research going in the next few years?

I have to retire in one and a half years and I hope to contribute a little to society before I do. These materials can be used or can be useful for drug delivery and biomedical applications. In the one and a half years I have left until retirement, I want to be able to show the potential of these materials for those kinds of purposes—that they can really be useful for society. One and a half years can be a short time or a long time—it's all in your perspective. Since I only moved here five and a half years ago, I hope I will be able to do this and make it truly productive.

SW: Why did you leave Japan for Stockholm and do it so late in your career?

I worked as an academic staff in the same place, Department of Physics, Tohoku University for more than 36 years. A big change in the Japanese university system had started, and I thought this would be the last chance for me to restart. During my career, I spent time at Cambridge for one and a half years, and also 15 years ago I was a guest professor at Lund University in Sweden. Cambridge is extremely active in science; however, from my perspective, Sweden was the most attractive country. I wanted to start from the beginning with young scientists, and Sweden was ideal. So when this position was announced, I applied for it and I am happy to say that I got it.

SW: Which of your professional achievements brings you the most satisfaction?

I think this *Nature* paper with Sakamoto. This is unique. As I told you, all mesoporous crystal structures that have ever been solved were solved by us. The method itself is very simple. Everything is described in this *Nature* paper, and I hope many scientists will use the method on a daily basis. So the development of this methodology to solve structure of mesoporous crystals is the most satisfying.

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Professor Osamu Terasaki's current most-cited paper in *Essential Science Indicators*, with 565 cites:

Joo SH, *et al*., "Ordered nanoporous arrays of carbon supporting high dispersions of platinum nanoparticles," *Nature* 412(6843): 169-72, 12 July 2001. Source: *Essential Science Indicators* from Thomson Reuters.

Keywords: mesoporous materials, nanoporous arrays, carbon, pores, cages, imaging, three-dimensional mesoporous structures, highly crystalline materials, high-resolution electron microscopy, Fourier diffractograms.