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AUTHOR COMMENTARIES - From Special Topics

Photonic Crystals - October 2008
Interview Date: November 2008

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Prof. Steven Johnson

From the Special Topic of Photonic Crystals

According to our Special Topic on photonic crystals, the work of Professor Steven Johnson ranks at #8 by total citations, based on 29 papers with "photonic crystal" in the title cited a total of 1,751 times. In Essential Science IndicatorsSM *from Thomson Reuters, Professor Johnson's record includes 95 papers, the majority of which are classified in the field of Physics, cited a total of 3,668 times between January 1, 1998 and June 30, 2008.*

Johnson is Assistant Professor of Applied Mathematics at MIT. In the interview below, he talks with ScienceWatch.com *about his work with photonic crystals.*

SW: Please tell us a little about your research and educational background.

I received three bachelor-of-science degrees in 1995 from MIT, in physics, mathematics, and computer science, and got my Ph.D. in the MIT physics department in 2001. I joined the MIT applied mathematics faculty in 2004 after postdoctoral positions at MIT and Harvard.

My research, since my days as a graduate student with Prof. John Joannopoulos at MIT, has centered around nanophotonics—electromagnetism in materials that have structures on the same scale as the wavelength. This can make light behave in very unusual ways compared to how it propagates through a mostly uniform medium like air or solid glass. Even though the basic physical laws of electromagnetism are well understood, their consequences can be complex and unexpected in the context of such structures. The challenge is twofold: first, to develop techniques, both involving large computers and involving pencil-and-paper analysis, to understand the behavior of light in these circumstances; and second, to design structures that lead to new phenomena and devices.

SW: What first interested you in photonic crystals?

My interest in physics has always centered on things that you can see and touch, and in the ways that combining simple interactions can lead to surprising effects. Even though the equations of classical electromagnetism have been around since the work of Maxwell in 1865, it is amazing to see that they can have so many unexpected consequences in nanostructured materials. And it is an area where you can literally see the results, from iridescent butterfly wings and peacock feathers in nature to synthetic materials that are leading to exciting new applications such as medical fibers, more efficient solar cells, or ultra-bright LEDs.

SW: A key paper in your publications is the 2001 *Optics Express* paper, "Block-iterative frequency-domain methods for Maxwell's equations in a planewave basis," (8: 173-90, 2001). Would you talk about the significance of this paper for photonic crystals?

That paper describes an efficient computational technique to find the allowed behaviors of light in a complicated three-dimensional structure, such as a three-dimensional photonic crystal or a traditional dielectric waveguide. A large part of the impact of this paper is due to the fact that it is paired with a free/open-source software package called "MPB" that I developed as an MIT graduate student. MPB has enabled many researchers to enter this field and begin doing calculations quickly, without having to develop a simulation tool themselves or purchase a commercial package that they cannot modify to suit their needs.

"...I think that nanophotonic control of light has taken on a new urgency, with a focus on discovering the fundamental limits of optical design."

SW: Your most-cited paper in our analysis is the 1999 *Phys. Rev. B* paper, "Guided modes in photonic crystal slabs," (60[8]: 5751-8, 15 August 1999). Would you talk a little bit about this paper's methods, findings, and conclusions? Actually, quite a few of your papers deal with photonic crystal slabs. Would you talk about what these are, and any advantages they possess?

Photonic crystals, in general, are periodic arrangements of two or more optical materials (e.g., glass and air). One of the exciting properties that a photonic crystal can possess is a photonic band gap, a range of wavelengths in which light cannot penetrate the crystal—it acts like a kind of "optical insulator." In order to obtain a true photonic band gap in three dimensions, however, one needs to build a complicated structure that has periodic patterns in all three dimensions. Although this is possible, and amazing progress has been made in three-dimensional nanofabrication, it is still challenging. A photonic-crystal slab is a simpler structure, a thin slab of material with only a two-dimensional pattern, which is much easier to fabricate using traditional lithography (like the processes used to make computer chips), while still approximating some of the useful properties of a three-dimensional crystal.

"My interest in physics has always centered on things that you can see and touch, and in the ways that combining simple interactions can lead to surprising effects."

In the 1990s, many researchers were interested in photonic crystals fabricated via two-dimensional patterns, but there was a lot of confusion about the properties and designs of such structures, especially in how they compared to simple two-dimensional models (in which light propagating vertically is not considered). My 1999 paper was one of the early theoretical papers to describe the correct three-dimensional analysis of photonic-crystal slabs, and gave a thorough survey of their properties and design principles. Some of my later papers extended this work to include "defects" designed into the slab to introduce waveguides and resonant cavities.

SW: How far has this work come since you entered the field? Where do you see it going in the next decade?

Offhand, I can think of more than half a dozen start-up companies that have been founded since I joined the field, all based in one way or another on ideas from photonic crystals. Here in Cambridge, I've been directly involved with one called OmniGuide, making a new kind of fiber that carries high-power lasers for endoscopic surgeries; it's been immensely gratifying to have some of my theoretical work directly translated into technology that is literally saving lives.

The sheer number of people now working in this field is staggering; it used to be possible to personally know almost every principal scientist working on photonic-crystal problems, but now there are far too many groups to keep track of.

There is an increasing shift in the electronics industry from focusing on speed to focusing on power. In optical devices, this translates into increasing concern with slowing down and trapping light via nanostructures to achieve more efficient nonlinear modulation, light emission, and light absorption—even pushing towards considerations on a single-photon scale. All of these concerns were present in past work, but I think that nanophotonic control of light has taken on a new urgency, with a focus on discovering the fundamental limits of optical design.

SW: What should the "take-home" lesson be about your research?

Instead of finding exotic materials to achieve some particular optical property, the problem is now to take existing materials and find new geometries that have the properties we need. Many of the limits imposed by natural materials are removed, and replaced by only the limitations of our imaginations.❏

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Steven Johnson's current most-cited paper in *Essential Science Indicators*, with 711 cites:

> Johnson SG, Joannopoulos JD, "Block-iterative frequency-domain methods for Maxwell's equations in a planewave basis," *Opt. Express* 8(3): 173-90, 29 January 2001. Source: *Essential Science Indicators* from Thomson Reuters.

Keywords: photonic crystals, dielectric waveguides, nanostructured materials, light behavior, computational techniques, MPB, photinuc crystal slabs, photonic crystal fibers, nanophotonic control of light.

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