AUTHOR COMMENTARIES - 2010

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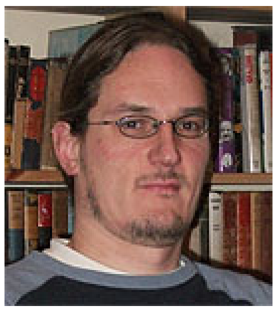

Jonathan Coleman

Featured Scientist Interview

According to Essential Science Indicators^SM *from* Thomson Reuters, *the work of Professor Jonathan Coleman ranks in the top 1% in both Chemistry and Materials Science. His full record in the database includes 97 papers cited a total of 3,019 times between January 1, 1999 and August 31, 2009.*

Professor Coleman is Director of Postgraduate Studies, Associate Professor of Physics, and a Principal Investigator of CRANN, the Centre for Research on Adaptive Nanostructures and Nanodevices, all at Trinity College in Dublin, Ireland.

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

SW: How did you get into nanotechnology research and how did that in turn bring you to your highly cited 2003 research on super-tough carbon-nanotube fibers?

I started working in nanotechnology in the area of polymer nanotube composites back in 1995-96. If you add nanotubes to polymers, you get plastics in composite form that are much stronger and stiffer. So we learned to make these stiff strong plastics.

Then in 2002, I was working in Dallas as a visiting researcher with Ray Baughman. His group was trying to make composite fibers with polymers and nanotubes. That was my background and so I was able to contribute to that work, but I want to make it absolutely clear that I was not the lead author on that work or the lead researcher. Professor Baughman was the undisputed leader of that work.

Ray had a DARPA project to develop artificial muscles, and one of the things we needed for that was fibers that would have a very high stiffness—this was the goal driving that work. This was very focused research. They were making fibers, and although we knew they were good fibers, they were just not stiff enough. It was a matter of going to the books, the literature, to see what we could learn.

Then Joe Razal, a student in the lab, came to me and said, "Look, I think this is good for something else." He showed me a paper on the toughness of spider silk, which is fantastically tough material. People had been trying to make fibers as tough as that for a long, long time, without a lot of success. This student said, "I think our fibers are quite tough," and we calculated the toughness and they were much tougher than spider silk.

SW: How do you calculate toughness?

You measure the stretch-strain curve. You stretch it and measure the force by which it pulls back. So you're measuring the force as a function of expansion, of how much you stretched it to begin with. Then you calculate the quantity called toughness from the area under the curve.

SW: So how tough is spider silk is and how much tougher were the fibers made in Professor Baughman's laboratory?

I can't be precise, because there are many different spiders and they make different types of silk with different mechanical properties. But tough spider silk would be around 150 megajoules per gram and our material was about 500. Ergo, ours was something like a factor of three tougher. So these polymer nanotube composite fibers were pretty strong and pretty tough—they were the toughest materials known to man at the time. And that was the work we published in *Nature*, the highly cited paper, "Super-tough carbon-nanotube fibres—these extraordinary composite fibres can be woven into electronic textiles," (Dalton AB, *et al.,* 423[6941]: 703, 12 June 2003).

"When you work on a new field like graphene, you're apt to get very, very excited."

SW: What did you do after you measured it and realized how tough it was?

I think we went to the pub. Well, okay, we also had to reproduce it—that was key. We spent a lot of time rebuilding and improving the apparatus so we could make the stuff reproducibly. That took a lot of time. That was the not-very-exciting part of the research: when you have something interesting but you have to turn it from a one-off result to a reproducible one.

SW: Did you expect the paper to have the impact it did or was that a surprise?

We certainly knew we had something, and well, Ray Baughman made the decision that we would submit it to *Nature*. With submissions to *Nature*, you know you have only a very small chance of being successful. We knew with this one that there was a good chance it would be accepted. To be honest, I think when most people submit to a journal like *Nature*, all they're thinking about is getting it accepted. They don't think too far beyond that—citations, etc. We were just excited about having something we knew had a real chance of getting into the top journal.

SW: Your second most-cited article is the 2006 *Advanced Materials* paper, "Mechanical reinforcement of polymers using carbon nanotubes," (Coleman JN, Khan U, Gun'ko YK, 18[6]: 689-706, 17 March 2006). What prompted you to write that paper and why do you think it's been so highly cited?

That's a review paper, an invited review paper. I had done quite a lot of work on reinforcing polymers with carbon nanotubes. We had really published a number of papers on this—maybe 10—so we were well known in the area. Out of the blue I was invited to write this review with a collaborator, and it was the sort of thing that when you agree to do it, you don't really realize what you're getting into. It was a huge amount of work; it ruined my life for about three months. All I did was read literally hundreds of papers trying to digest them all and distill the information. But the thing about a review is that you know if you do it right, you're going to get a lot of citations. I did put a lot of effort into that and I think I got it right and it's been quite highly cited.

SW: Now that it's three years later, is there anything you would go back and change?

I think I captured a pretty good snapshot of where the field was at the time. One thing, though, is that paper had a page limit. There were things I would have liked to do with the data that I didn't have the space for. You can always do a better job within an infinite amount of space. Still it's cited a lot, and I meet people that mention it to me. I'm quite happy with it.

SW: How has the field itself evolved in the three years since you wrote that review?

Well, real progress is starting to be made. I've noticed a number of papers lately where the mechanical properties of composites have really started to get places. One of the things we suggested in that review, and many people knew this, is that the chemical treatment of nanotubes to make them bond better to polymers was really the way to go. Recently a number of papers have reported doing that and it has worked. People have shown they can make really, really strong composites.

SW: What are you working on now?

Well I don't really work on that stuff at all. What we're doing a lot of work on now is graphene. Graphene is a single carbon layer and it was shown around 2004 that it had these phenomenal properties. But people couldn't make it in any large-scale way. The way people have made it is they take a single layer of graphene off a graphite crystal, and they do it one flake at a time. Last year, we were able to show that we could make graphene in liquids—very, very high yield, and very, very large throughput. We can make a billion layers in parallel at the same time in solution. That's quite a big advantage.

This work was published in *Nature Nanotechnology* in 2008 ("High-yield production of graphene by liquid-phase exfoliation of graphite," Hernandez Y, *et al*., 3[9]: 563-8, September 2008). Since then it's had more than 50 citations. That's quite a lot for one year. This for me is where my future is, so I'm not really doing much nanotube work anymore.

SW: What's the next step then, for your graphene work?

"...the thing about a review is that you know if you do it right, you're going to get a lot of citations."

Right now the graphene flakes we make are limited to about one micrometer in size. We'd like to have them bigger. We want to make graphene flakes that are really quite large.

SW: Do you have a strategy for doing that?

Well, yes and no. We've found out what controls the size. Once you know that then you at least have some hope of getting around it, but we certainly don't have a successful strategy yet.

SW: Other than making bigger flakes, what do you consider the biggest challenge or obstacle in the graphene research?

I think it's having self discipline. When you work on a new field like graphene, you're apt to get very, very excited. You think you're doing something new and you're going to change the world and get lots of high-impact papers. It's very easy to get carried away. But that's not what science is about. It should be about really doing good work and keeping your head down and making sure you're doing things right, making sure what you're doing is reproducible and measuring things again and again, just doing good science. I'm not saying you forget how to do that, but it's easy to get carried away because of how exciting you tell yourself your work is. It's always important to keep your feet on the ground. That's what I very consciously have to do.

SW: What unexpected or serendipitous events arose in the course of your research?

I'm not sure we've had any truly serendipitous moments but we've had some surprising results, not amazing in the scientific sense, but interesting, almost amusing. One of my students found out that graphene can be dissolved and exfoliated using a chemical, a liquid that turned out to be liquid ecstasy. We got little bit of a surprise there. We knew what molecules worked, and we were just choosing molecules with a similar structure from a catalog. We tried to order this material and we got some serious emails back, asking us to explain exactly why it was we needed this chemical. I wondered why, so I asked a chemist—I'm a physicist, I don't know what these chemicals are—and this chemist said, "My God, that's liquid ecstasy. Why do you need that?"

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

Exfoliating of graphene. There's no doubt about that and I can tell you why. We were trying to exfoliate carbon nanotubes, because we knew we could make better composites that way. Nanotubes tend to stick together. That's their problem. If we can separate them from one another, we should have better composites. At some point, I said, "Hold the composites, and let's solve this problem of nanotubes sticking together."

We worked quite hard on that for quite some time, and we found we could only unstick these nanotubes by using special solvents. We had done some theory work as well as experiments, and we found solvents that worked and they did so—and I'm going to get technical here for a moment—because their surface energy matched the surface energy of the nanotube. And if that's the case, we thought, well, graphene has the same surface energy as nanotubes, so it should also work for graphene.

We went off and bought this new material, graphite. We'd never worked with it before, but simply on the basis of this prediction from this theoretical model, we tried it and it worked the first time. It really illustrated the value of really understanding what you're doing, understanding the theory, and then making connections with other things. I think that is science in a microcosm.

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Jonathan Coleman's current most-cited paper in *Essential Science Indicators*, with 372 cites:

Dalton AB, *et al*., "Super-tough carbon-nanotube fibres—these extraordinary composite fibres can be woven into electronic textiles," *Nature* 423(6941): 703, 12 June 2003. Source: *Essential Science Indicators* from Thomson Reuters.

KEYWORDS: CARBON NANOTUBES, COMPOSITE FIBERS, ELECTRONIC TEXTILES, POLYMER NANOTUBE COMPOSITES, SPIDER SILK, GRAPHENE, GRAPHITE, FLAKE SIZE.

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