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Special Topics : Graphene : Konstantin Novoselov Interview - Special Topic of Graphene

AUTHOR COMMENTARIES - From Special Topics

Graphene - December 2008
Interview Date: February 2009

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Konstantin Novoselov
From the Special Topic of Graphene

According to our Special Topics analysis on graphene research over the past decade, the scientist whose work ranks at #1 by total cites is Dr. Kostya Novoselov, with 33 papers cited a total of 2,895 times. He also ranks at #6 by number of papers and #2 by cites per paper. Five of his papers appear on the lists of the most-cited papers over the past decade and over the past two years.

Essential Science IndicatorsSM *from* Thomson Reuters*, Dr. Novoselov's record includes 49 papers, largely classified in Physics and Materials Science, cited 3,536 times between January 1, 1998 and October 31, 2008. Dr. Novoselov is a Royal Society Research Fellow in School of Physics & Astronomy at the University of Manchester.*

Below,* ScienceWatch.com *correspondent Gary Taubes talks with Dr. Novoselov about his pioneering work with graphene.

SW: Considering that graphene physics is an entirely new field of science, how did you get into it?

My background is in mesoscopic physics, studying fairly macroscopic objects that show some quantum effects. I did my Ph.D. with Andre Geim—first in Holland—and when he moved to the UK he invited me here as a post-doc. The style of Geim's lab (which I'm keeping and supporting up to now) is that we devote ten percent of our time to so-called "Friday evening" experiments. I just do all kinds of crazy things that probably won't pan out at all, but if they do, it would be really surprising. Geim did frog levitation as one of these experiments, and then we did gecko tape together. There are many more that were unsuccessful and never went anywhere (though I still had a good time thinking about and doing those experiments, so I love them no less than the successful ones).

This graphene business started as that kind of Friday evening experiment. We weren't hoping for much, and when I gave it to a student, it initially failed. Then we had what you could call a stream of coincidences that basically brought us some very remarkable results quite quickly—within a week or so. Then we decided to continue on a more serious basis.

SW: What was the original idea behind the graphene experiment?

Well, people talk about metal electronics a lot, substituting semiconductors for metal. There are many advantages to that, but nobody had really used graphite as a material for electronics. So we decided to see if that was possible. Basically, the idea was that we needed to get some very thin films of high-quality graphite; one of our students did it the first time by trying to file down thick graphite crystals and it didn’t work. We almost gave up after that.

At the same time we had a very experienced guy—Oleg Shkliarevskii—working here, building a low-temperature scanning tunneling microscope. He showed how the samples were prepared for an STM. The best sample is graphite—you can quite easily gain atomic resolution there. They clean graphite surface by peeling the top layer off with Scotch tape. It is a very standard technique, used everywhere. We knew about the method before, but everything is good in its own time, so one glance at it and we knew—that must be it. I tried it and within a few days we had a working device.

"Considering that the field is only four years old, we’ve made enormous progress."

SW: So this was serendipity, more so than any premeditation?

And it wasn’t the only time we got lucky. Graphene, which is a monolayer of carbon atoms, is really hard to see—you can only see it on a very special substrate. We didn’t know it at the time, but, coincidentally, we had exactly that substrate and it was what we used, purely by luck. I still don’t understand how that worked out, but the substrate we had was exactly the one required. This was a huge coincidence—just unbelievable. It was only a few months later that we understood how lucky we had been. If not for that, I'm sure we would be there anyway, but a bit later.

SW: Were you literally using Scotch tape, or is that just what you like to call it?

Yes, literally Scotch tape, at least initially. We later switched to a Japanese tape—Nitto tape—which is used in the semiconductor industry. I don’t know why we use Nitto tape; probably because the whole process is so simple and cheap we wanted to fancy it up a little and use this blue tape instead. Many people, though, are still using Scotch tape and it works equally well.

SW: What, in your view, are the most significant papers for the field?

There are quite a few significant papers by now. Still, the very first ones were the 2004 *Science* paper (Novoselov KS, *et al*., "Electric field effect in thin carbon films," 306[5696]: 666-9, 22 October 2004), and the *Nature* paper in 2005 (Novoselov KS, *et al*., "Two-dimensional gas of massless Dirac fermions in graphene," 438[7065]: 197-200, 10 November 2005). The paper by Philip Kim's group published back-to-back with our *Nature* paper is also key to the field. The *Science* paper started the field, demonstrating a method for obtaining high-quality graphene. The *Nature* papers developed the idea, demonstrating that the quasi-particles in this material have very weird properties—they’re massless, for instance—and it showed that the quality of the samples obtained is very high, so the quantum Hall effect could be readily observed.

SW: The *Nature* paper is the more highly cited of the two, even though it was a follow-up publication. Why do you think that is?

The interesting thing is that the first paper, the one in *Science*, was originally submitted to *Nature* and, of course, it was rejected, because…well, I don’t know why. The referee told us it was interesting, but we should measure this, that, and the other thing in addition, and then maybe they’d consider it for publication. It’s now three years later and all those requirements made originally by the *Nature* referee are still not measured. Nonetheless, we improved our paper a bit and then published it half a year later in *Science*.

As for citations, I think it’s now within five or ten percent of the second paper, which was published in *Nature*. But the word "graphene" isn’t in the title of the original. So people probably overlook it a little bit. And it doesn’t have all that fancy stuff that’s in the *Nature* paper, all the fancy words in the title, like Dirac fermions in graphene. That sounds a lot more exciting. It talks about the quantum Hall effect. It speaks to all possible communities at once. The material scientists like graphene. The theorists like the Dirac fermions, then there’s quantum Hall people, who also cite it. It’s really, really interdisciplinary.

The first paper, the *Science* paper, really lays out the background—how to prepare the films; it proves it exists, but it’s not as all-around appealing. It’s quite easy to overlook. And it’s not really the new material that makes this exciting—it’s what you can do with this material, and that’s all in the *Nature* paper. For us it was quite exciting that you can get this field effect and have an ambipolar transistor effect. You start with something very simple—a piece of graphite—and you can get a working field-effect transistor by this very simple technique. Nobody was working with this before.

To attract people to a new field of research, to make them change the direction of their research, you have to show them really something that is 10 times more exciting than what they’re doing now. If it’s only twice as exciting, nobody is going to change. And, of course, seeing a phenomenon like that in a system as simple as this is really 10 times more exciting than anyone else. That’s also probably why this 2005 *Nature* is more appealing.

SW: What were the greatest challenges in performing and presenting your work?

"…there are so many interesting features to study with graphene and we’re trying to work on them all."

That there was no related work at that time at all. We had to develop all the techniques from scratch, and we had to do so having no background of any kind working with carbon. So we had to dig out an enormous amount of literature trying to understand what’s going on. Also, as I said, it’s multidisciplinary work. We knew we’d have people from carbon, quantum Hall, and mesoscopics communities interested. So we had to make the paper understandable and interesting to all of them.

SW: What are you focusing on now in your research?

Well, we’ve really diversified our research quite dramatically. It’s all graphene, but there are so many interesting features to study with graphene and we’re trying to work on them all. I hate the fact that we don’t have time anymore to do Friday evening experiments now, except those with graphene. We do some crazy stuff with graphene, but nothing else. So we’re now working on quantum dots on graphene. That’s one of the directions were going, and that’s for future transistor applications. Even a few months ago, I was pessimistic about that, but now I’m really starting to believe it might be used for applications in the future.

Another area we’re working on is chemical derivatives of graphene. One possibility is to look at graphene as a two-dimensional crystal. Another is to look at it as a huge organic molecule that can be chemically modified. By doing that, we can fine-tune its electronic properties by altering the chemical bonds and chemical environment. We are working a lot on that at the moment.

Another thing we’re doing, which is very down to earth, is very much about applications. Graphene can be used not only for transistors but also for other applications like transparent conductive coating—like the display on your computer screen. The layer that is on your computer screen is indium oxide; graphene can replace it quite happily and there are many other such places, like solar cells, touch screen displays, etc. We are developing this direction as well.

The funny thing is, with this transistor application, you have to produce a few wafer-scale mono-crystals of graphene. Until a few months ago, I was skeptical we could do this. Now I’m more positive. The liquid crystal displays, though, don’t need mono-crystals of graphene; several crystals interconnected with each other works equally well. We already have the technology to produce those devices. In this respect, it’s ready for applications now.

SW: How would you describe the current state of affairs in your field and its prospect for the future?

The field is developing extremely fast. Considering that the field is only four years old, we’ve made enormous progress. Virtually every month, it seems, someone comes up with an entirely new observation and so a completely new area of research on graphene. There’s also ever-increasing interest from industry, which helps to develop the field even further. Now it’s clear that graphene is a very promising material for practical applications.

SW: If you performed your research again, or published your paper again, what, if anything, would you do differently and why?

You have to realize that we were working on graphene for at least a year, probably a year and a half, before we published our first paper. So, yes, if we could go back and do it again, we’d do a lot of things differently; we’d know enough to cut the sharp corners and avoid the dead ends. But that’s just hindsight. At the time, we needed to accumulate a critical mass of knowledge and experience and the only way to do that was trial and error. I don’t think that stage can ever be eliminated in scientific research.

SW: What would you like to convey to the general public about your work?

That science should be fun, and you don’t always need to do expensive multi-million dollar experiments to be on the cutting edge of research.

Dr. Kostya Novoselov
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Konstantin Novoselov's current most-cited paper in *Essential Science Indicators*, with 888 cites:

Novoselov KS, *et al.*, "Two-dimensional gas of massless Dirac fermions in graphene," *Nature* 438 (7065): 197-200, 10 November 2005. Source: *Essential Science Indicators* from Thomson Reuters.

Related information:

- Read an interview and two commentaries with Andre Geim: 1 ¦ 2 ¦ 3

Keywords: graphene, thin films, quantum Hall effect, Dirac fermions, anisotropic space, applications, transistors, transparent conductive coating.

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