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Graphene: A Polish Success Story

We talk to Dr. Włodzimierz Strupiński about the two-dimensional form of carbon that is taking the world of high technologies by storm, Poland's role in its development, and the relationship between science and business

Academia: Graphene is a real buzzword at the moment – could you tell us what the material actually is?

Włodzimierz Strupiński: *Graphene is a form of pure carbon. There are many other forms – diamond, graphite, fullerenes, nanotubes – but the difference is that graphene is two-dimensional. Theoretical physicists long believed that two-dimensional carbon cannot exist due to the laws of thermodynamics. And yet it has been possible to isolate it! This was achieved by Professors Andre Geim and Konstantin Novoselov working at the University of Manchester using a very simple method: they used adhesive tape to isolate a single layer of carbon atoms – graphene – from graphite. Graphene is the thinnest possible form of carbon, forming layers just one atom thick. Atoms are arranged in a "chicken wire" (hexagonal) pattern. The extremely powerful bonds between them are responsible for graphene's high strength. The free fourth electron in carbon atoms is responsible for transporting electrical charge, giving graphene very attractive electronic properties. There are other materials with similar individual properties, but none combine them all. Graphene is unique in that respect: it has high mechanical strength, it conducts electricity, it is almost transparent, it has highly unusual light absorption properties, and it displays saturable absorption. All this inspires scientists to come up with completely new, creative applications.*

How did you first come across graphene?

I have always worked on semiconductor technologies and nanotechnologies. I was first introduced to graphene by Prof. Andrzej Wysmołek from the University of Warsaw. He came to see me after a conference, and asked if I'd be interested in trying to make graphene. It was late 2006 – just a year or two after the material was first isolated. In 2007, I started studying graphene systematically. The result was a research collaboration with Prof. Geim, and jointly we published a paper which appeared a week after he was awarded the Nobel Prize. This caused a major stir, especially in Polish scientific circles: suddenly I was a colleague of a Nobel laureate! Later, I attempted a different way of isolating graphene: everyone else was sublimating silicon from the surface of silicon carbide, while I was crystallizing graphene on the surface of silicon carbide. This proved to be a major challenge, and had I realized this, I may well have given up at the start. But I did manage to develop the method, and there was quite a bit of fuss about it. After all, it's not often that we are able to develop something in Poland – especially in nanotechnology – that's so far ahead of other research centers. And of course it wasn't just the case that I myself mixed three ingredients, happened to get the right proportions, and came up with a miracle elixir; it was all based on solid experimental, theoretical, and technological foundations and experience – my own, my team's, the Institute's. As a result, we have a Polish method of obtaining graphene on different surfaces, a Polish patent, and interest in the method from around the world. We have stood out and shown ourselves to be worthwhile partners, and as a country we have brought something innovative to the technological race for graphene. This is unique, since millions of dollars are spent globally on studying the material and its applications. And we were successful, even given our budget...

You didn't have millions of dollars...

We didn't, but what we did have was knowledge, experience and passion. And the team I trained. We were stubborn and persistent.

How big is your team?

We have a dozen or so people working on semiconductors, and five or six focusing on graphene. To begin with, I was the only one working on the material, then a couple of doctoral students joined us. Prof. Baranowski started supporting us at an early stage – not on the technological side, but in pure physics, measurements. This fruitful collaboration continues until the present day. There are now far more people working on graphene at the Institute. Alongside our own method, I am now working on all technologies for isolating graphene. We are now among the top fifteen research centers manufacturing graphene. We use various methods, and we have a fair amount of equipment. It all meshes together and generates funding. When we presented our results, we were able to obtain funding and interest from hardware manufacturers. This was followed by wider interest around the globe and participation in a prestigious European program. Now we face our next task: to develop applications for the material. We are constantly improving our graphene and matching it to different applications. And these aren't some tiny samples, so small as to be almost invisible. We are able to provide it in large quantities.

What applications are there?

Graphene is an incredibly difficult material. A single layer of atoms – how do you even handle it? How do you measure it? How do you use it? It's a new chapter in the history of technology. The problem lies in increasing scale. Individual flakes of graphene have parameters and properties that are almost unbelievable. But the graphene that is naturally present in graphite exists just as Mother Nature intended. Flakes extracted from graphite are so tiny that they are invisible to the naked eye, so we are trying to synthesize them and make them larger. We are already able to grow a single layer 50cm by 50cm. Now we have to improve its quality. The question is, how close are we to reaching perfection – graphene with properties identical to those of a tiny flake extracted from graphite?

Still, some applications are already possible, even in Poland. Our colleagues at the Wrocław University of Technology are using graphene to make saturable absorbers, used to guide femtosecond lasers. We are working on making detectors, sensors, and transistors. We have created demonstrators which are the first step towards "flexible" electronics. These involve graphene applied to ordinary plastic foil – flexible and transparent. It's invisible, and yet it conducts electricity. In South Korea, scientists are working on graphene-based touchscreens to eliminate the use of expensive and hazardous indium.

Working with the Faculty of Physics at the University of Łódź, we have determined that graphene works as an anti-corrosion coating. It

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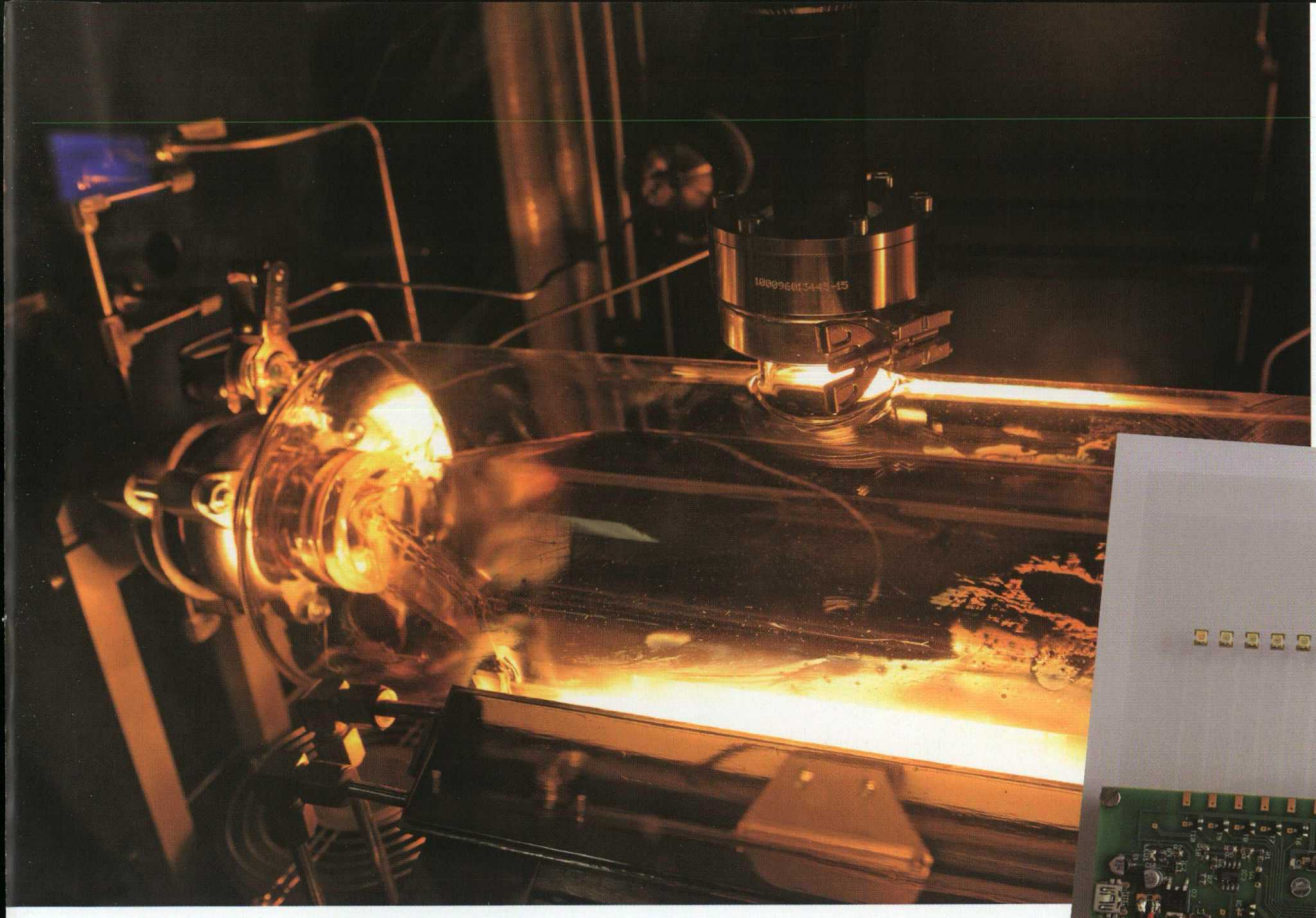
has a high resistance to chemical compounds, which means it protects surfaces against corrosion from environmental and other sources. Independent research at the Warsaw University of Life Sciences (SGGW) and at medical schools shows that graphene prevents bacterial growth. Its bactericidal properties are also being studied. Graphene membranes are being considered as artificial heart valves and parts of other organs, such as retinas. Of course we don't know at this point which research direction will be the most successful. But even if just 5% of these ideas can be brought to life, that's a major breakthrough. At our Institute, we also make graphene in powder form – as the Nobel laureates did. But here we don't use adhesive tape, and the process is on an industrial scale. We can make it in batches of several kilograms. It turns out that a kilo of graphene powder added to substances such as polymers, plastics, completely changes their properties – their electrostatic, electronic, thermal, but also mechanical and tensile properties. So the range of applications for graphene is vast. In Poland, I'm trying to encourage several institutions to use graphene: firstly, in materials engineering – the development of anti-corrosive protective coatings – and secondly, in polymers as a modifier of their properties. In electronics, it can be used to make invisible, flexible conductive paths as well as sensors and detectors. This is a Polish domain which we are able to develop using our background and infrastructure. We are also involved in a new European project in the area of associating silicon technologies with graphene.

Finding applications involves academic research, but also business. For example, there is the company called Nano Carbon aiming to manufacture graphene.

Nano Carbon isn't our company – it was founded on the initiative of the Industrial Development Agency. I should take the opportunity to congratulate the Agency's former president Wojciech Dąbrowski, who made the move at the right time. The company has made several investments, including purchasing a range of equipment. This is a very serious undertaking – the company will have extensive technological abilities in terms of graphene production. By working in collaboration with the Institute, it is guaranteed access to its research potential, and, in turn, the Institute is able to commercialize its findings through the company. I'd say it's a good example of industry and research in symbiosis. We also have support from the Marshal's Office of the Mazowieckie Voivodship, through which certain EU funding is channeled. Marshal Struzik decided to invest in a Graphene Centre, whose construction has already begun. During the first phase, we will be provided with additional measurement equipment. During the second stage, a separate building will be constructed to house the research and technology department. The collaboration between the Marshal's Office and the Industrial Development Agency also seems to be expanding. We are starting to see specific outcomes, which in turn mean our own options are being expanded. On the business side, the National Centre for Research and Development has initiated the Graftech program, aiming to support the development of new applications. Applied research is reasonably well organized in Poland; what is missing is support for basic research. Until now, almost all such studies have been conducted as part of a single project, individual research and with the Institute's own funds. Subsidies from the Education Ministry have been very limited. Secondary ion mass spectrometry has also been removed from the ministry's list of subsidized projects, although fortunately it will be co-financed by the Marshal's Office. Our participation in a European project carries the risk that we might rush into applied research while forgoing basic research. This must not happen – the technology continues to develop! If we abandon basic research, we will be overtaken. But that said, I think that both Poland and Europe should focus most of their efforts on applied research into graphene; that's key.

You described the current situation – setting up a company. How did that come about? Was the business world seeking a way in?

The business world is generally quite in tune. When I turned out to be co-author of an article written with a Nobel laureate, that we are patenting a new method, that we are at the forefront of R&D into graphene, industry quickly became interested. In most cases, it was rather basic – offers of small investments meant to turn a quick profit. This wasn't for us. But one day, Dąbrowski called me personally and asked to meet me. He came over to the Institute... and things went from there. Another good example is the equipment manufacturer SECO-WARWICK (a Polish company despite the name). A representative called and said that the company wanted to enter the market for making equipment for graphene. We were able to start working together through the Graftech



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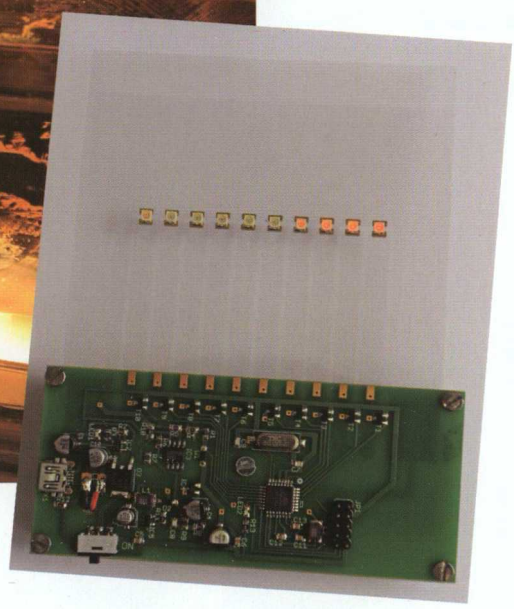

Photo p. 4: an industrial prototype for the isolation of graphene on metallic structures made by the Polish company SECO-WARWICK in Świebodzin. Above: a test reactor for developing technologies of producing graphene and modifying its properties. Above right: a demonstration of graphene's application in "flexible electronics"

project. As a result, last June we opened Europe's largest center for isolating graphene on copper foil, which is also one of the largest in the world.

A bit of a blunt question, perhaps, but... is there money in it?

It's a very sensible question. I'd go as far as saying we should be asking it more frequently in Poland. In our society, we have developed a habit of treating it as something shameful, not becoming of scientists. Meanwhile, everywhere else it's the case that whether you're a scientist or not, you need to find ways of commercializing your work. At my institute, we have been working for many years on making semiconductor structures which we sell to the best and most demanding research and commercial centers around the globe. For me, graphene is simply the next product. Of course there's money in it. The next aim is to maximize added value. It's far more profitable to sell hotcakes than flour. We want to offer more than just graphene – we want to make it into a product. I'm trying to convince everyone I can in Poland to really focus on specific applications using Poland's experience and specialization.

Has working closely with business changed your role as a scientist?

Oh, very much so. Previously, my attitude was typical of most scientists working in Poland. Lately I've been trying to be more effective. All the projects I'd been working on live on as existing technologies. None have been developed purely in order to use up funds. If we didn't work alongside industry, we would live in a very insular world. We think that everything we do is fantastic, but what if that's not the case? Industry gives quick, frequently harsh answers to whether something is useful or not. This is excellent motivation for improving the quality of our work.

So are you suggesting a shift in the way of thinking?

I'm beginning to see it, yes. Not necessarily among entrepreneurs, but certainly among people like those working at the Industrial Development Agency. They used to regard scientists as mostly harmless cranks who do some weird tinkering, but nothing much ever comes of it. Meanwhile it turns out that it's possible to achieve something with them. Not only that, but it can then be shown off to the rest of the world. And the mentality of scientists is changing, too. We no longer work from project to project – we do need to be doing something, but it needs to be valuable. Maybe a company will be spun out; perhaps there will be profit or another tangible result? We still don't have a system or procedures – it's all very new. Perhaps I'll run out of time, but I hope my younger colleagues will benefit. And, more than anything, if we create the right scientific, technological and intellectual foundations, perhaps any future bumps in the road won't be as painful. ■

Interviewed by Agnieszka Pollo and Anna Zawadzka