A new method for producing remarkably efficient atom catalysts

In cooperation with Italian colleagues from the University of Trieste, RCPTM researchers have developed a new method that can accelerate diverse chemical reactions used, for example, in food, chemical and pharmaceutical industries. The novel accelerators of the reactions (catalysts) are single atoms of metals firmly anchored to a carbon material based on a graphene platform. These atoms can speed up numerous reactions, with no losses of efficiency even after repeated use. The arrangement increases the catalysts’ efficiency, reducing both amounts needed and production costs. The work has been recently published in the prestigious journal Advanced Materials, one of the world’s top three materials science journals.

“We took a chemically modified form of graphene and attached functional groups that provide convenient chemical links for robustly bonding metal atoms. In this way, we chemically anchored individual copper atoms to the surface of graphene and found they had unprecedented efficiency for catalyzing the chemical reactions used for producing important pharmaceutical substances,” said Radek Zbořil, director of RCPTM and originator of the idea.

Finding a universal technology for anchoring and utilizing individual atoms enables exploitation of the advantages of both soluble and insoluble (solid-state) catalysts, which was previously impossible. In this case, all the atoms are involved in the catalytic process, achieving full atomic-level economy. “Thus, lower amounts of the catalyst are required. Moreover, such single metal atoms strongly bound to graphene exhibit extraordinary efficiency, which remains after recycling the catalyst,” added Zbořil.

Strongly anchoring individual atoms for catalytic purposes has been an attractive, but unfeasible ‘pipedream’, until recently. “The technology developed in Olomouc has a unique ability to firmly anchor a wide range of individual atoms in sufficient quantities and even control their oxidation state. Thus, the new catalysts offer a wide spectrum of applications,” said Paolo Fornasiero from the University of Trieste.

Preparation of the catalytic material does not require demanding synthetic conditions. “Chemical bonding of atoms takes place at room temperature. The starting material for producing the graphene substrate is graphite fluoride, an industrial lubricant available in tons, so upscaling the technology should be relatively straightforward. Importantly, we can firmly anchor other single metal atoms, such as gold, platinum, iron, cobalt or nickel, to graphene. We already have promising results, for example, in electrocatalytic reactions enabling production of alternative energy sources. Here, we exploit a combination of excellent graphene conductivity and high efficiency of the anchored single metal catalysts,” said Aristides Bakandritsos from RCPTM.

Recent advances in graphene chemistry in RCPTM laboratories have led to the development of a number of new materials and techniques, including preparation of carbon-based magnets, two-dimensional carboxylic acid, highly efficient oil sorbents and the smallest metallic magnets.

New graphene derivatives meet high criteria for use in supercapacitors

For several reasons, some of the most intensive research efforts in materials chemistry are focused on development of new electrode materials for supercapacitors. In addition to demanding physico-chemical properties, including high specific capacitance, stability, and energy storage density, they must meet environmental requirements, such as no heavy metal content and the ability to work in environmentally friendly electrolytes. Graphene derivatives developed in RCPTM laboratories by chemically modifying fluoro graphene are suitable candidates as they meet the strict requirements. These novel derivatives are conductive, miscible with water, and carry easily ionizable groups on their surfaces. Hence, they can work in aqueous and environmentally friendly electrolytes, providing high specific capacity and remarkable stability. A prototype supercapacitor has been charged and discharged more than 10,000 times, retaining its capacitance. The method employed for preparing the material enables easy optimization of its properties by controlling the reaction conditions. This work follows substantial research into the preparation, properties, and applications of carbon-based supercapacitors carried out in RCPTM laboratories [e.g. Jayaramulu K. et al. Adv. Mater. 30, 1705789, 2018; Bakandritsos A. et al. Adv. Funct. Mater. 28, 1801111, 2018].

Carbon quantum dots, which are highly photostable and fluorescent, were discovered 15 years ago. Since then, they have been widely used as fluorescent labels for in vitro bioimaging, i.e. fluorescently marking various cells, substances and/or structures in cells. They are also being increasingly used as intravenously administered fluorescent contrast agents for in vivo imaging of healthy and diseased tissues. This application exploits their biocompatibility, derived from their simple element composition (predominately carbon, oxygen, and nitrogen). RCPTM scientists have recently attempted to combine the labelling and contrast uses for fluorescently monitoring stem cells in a living organism after their subcutaneous transplantation and intravenous application. They proved to be efficient contrast agents for in vitro imaging of human stem cells, and for the first time intravenously applied mesenchymal stem cells labelled with carbon dots were detected in a mouse tumour. Carbon quantum dots were also used as fluorescent labels for semi-quantitative detection of the transplanted cells and confirmation of the stem cells’ migration to the afflicted inflammatory/tumour site, so-called stem cell homing. Thus, carbon dots may play important roles in the major uses of stem cells: targeted therapy and regenerative medicine. This work follows several recent studies by scientists from Olomouc on uses of carbon dots in biomedicine [e.g. Bao X. et al. Light-Sci. Appl. 7, 91, 2018; Holá K. et al. ACS Nano 11, 12402–12410, 2017; Kalytchuk S. et al. ACS Nano 11, 1432-1442, 2017].

Carbon dots assist in human stem cell imaging


Tremendous progress has been made in development of metal-organic frameworks (MOFs) during the past decade due to their substantial potential utility in diverse applications, including catalysis, gas storage, environmental technologies, and targeted drug delivery. Their main advantages are their nanoparticle periodicity, controllable porosity, possibility of channel functionality, and extensive structural diversity. However, even the most active MOF structures are often fairly sensitive to moisture and unstable in aqueous environments, which significantly hinders their practical application. This problem can be overcome by developing stable hydrophobic MOF nanostructures. Despite undisputed progress in this area, their design and preparation still pose enormous challenges. In collaboration with colleagues from the Technical University of Munich and Max Planck Institute in Germany, the RCPTM Photoelectrochemistry group has recently reviewed and critically evaluated progress in this area. The review, published in the journal Advanced Materials, offers a critical summary of hydrophobic MOF structures, particularly control of their structure, synthetic processes, characterization, and practical uses. Physical aspects of wetting hydrophobic materials are summarized in the introduction, along with a discussion of four key strategies for synthesizing hydrophobic MOFs and major challenges in quantifying their wettability. Attention is also paid to practical applications of hydrophobic MOFs, such as hydrocarbon storage and separation, and their use for separating spilt oil and organic fractions from water. This work exploits the experience of RCPTM scientists in the preparation and applications of MOF-based superhydrophobic hybrid nanostructures (e.g. Jayaramulu K. et al. *Adv. Mater.* 29, 1605307, 2017; Jayaramulu K. et al. Angew. Chem. Int. Ed. 55, 1178-1182, 2016).
We extend our warmest congratulations to Josef Michl on his 80th birthday

Prof. Michl recently celebrated his 80th birthday, and to mark the event the Institute of Organic Chemistry and Biochemistry of the Czech Academy of Sciences (where Professor Michl is jointly based, together with the University of Colorado in Boulder) arranged a conference entitled Josef Michl 80. RCPTM General Director Radek Zbořil couldn't miss such an event, congratulated Mr. Michl on his birthday, and contributed with a presentation called Chemistry of Graphene and Carbon Dots Towards Advanced Magnetic, Biomedical and Environmental Technologies.

Professor Michl's research interests lie in macromolecular chemistry, photochemistry, molecular electronics, research towards designing efficient solar cells, and molecular building blocks of nanorotors and nanomotors. In October 2013, he gave a talk as part of the Rudolf Zahradník Lecture Series, which Radek Zbořil presides over. In spring 2014, three superstars of Czech chemistry—Josef Michl, Pavel Hobza, and Rudolf Zahradník—met in Olomouc.

Michal Otyepka delivered a talk on fluorographene chemistry

The chemistry of fluorographene was a major focus of a talk given by Michal Otyepka (physical chemist and vice director of RCPTM) at the 18th international Density-Functional Theory and its Application conference, held in the Spanish town Alicante at the end of July. He was the only invited speaker from the Czech Republic at this prestigious gathering of theoretical and computational chemists. He spoke about the contribution of theoretical methods in researching and developing graphene derivatives to an audience of around 190 people from 30 countries. The conference was one of a biennial series that provides a unique platform for expert discussion on DFT methods and their employment in computational chemistry. The previous conference, in 2017, was held in the Swedish town Tällberg.

Plant Biotechnology: The Green for Good V conference has stimulated collaborative research on nano- and biotechnologies

RCPTM participated in a conference called Plant Biotechnology: Green for Good, organized by the Centre of the Region Haná for Biotechnological and Agricultural Research (CRH) on behalf of the European Federation of Biotechnology (EFB) in June. The meeting provided fresh inspiration for collaboration between researchers engaged in the two fields. Chemists Rajender Varma and Jan Filip delivered talks in a new section called Sustainable Environmental Technologies, supervised by Michal Otyepka, RCPTM's vice director. Michal Otyepka also shared his experience in applying for, evaluating, and meeting objectives of ERC grants.

Rajender Varma addressed the exploitation of carbonaceous waste in environmental technologies, and Jan Filip spoke about uses of iron-based nanomaterials for water remediation, in contributions respectively entitled Carbonaceous waste: sustainable applications in chemical transformations and environmental remediation and Iron-based (nano)materials: an advanced tool for water.

“The G4G conference was a very stimulating forum, which brought new insights into the fields of plant biotechnologies and sustainable environmental nanotechnologies, and the potential overlaps between them. Although I originally expected environmental nanotechnologies to arouse marginal interest, I successfully made two valuable contacts for collaboration between nanotechnologies and biotechnologies. One was from Olomouc and the other from Switzerland. On the whole, I was pleasantly surprised by the high level of the talks, posters, and nice atmosphere throughout the whole event,” said Jan Filip.

According to Michal Otyepka, potential overlaps between the two fields have always been exciting. RCPTM and CRH have been addressing distinct aspects of technologies for sustainable development and collaborative research may bring beneficial results. “RCPTM can contribute through expertise in advanced approaches for monitoring pollution in wastewater, groundwater and surface water remediation, the development and application of new materials for environmentally friendly chemical processes, and uses of waste materials for generating new materials,” explained Otyepka.

The conference was held at the Faculty of Science, Palacký University, Olomouc, on June 10-13. About 150 researchers and students from 20 countries participated, attending 35 lectures and presenting about 80 posters. The conference has been organized every two years since 2011.
The story of water and its essential role in our lives was depicted in a photographic exhibition Water and Civilization, presented in June on Kampa Island, Prague. RCPTM was one of 16 institutions, both domestic and foreign, that contributed to the exhibition. The major goal of the event was to raise awareness of the importance of water as a strategic material that we, and coming generations, must protect and cherish. Jan Filip, Michal Otyepka and Radek Zbořil from RCPTM participated in putting it together. The curator of the exhibition, and co-author of texts accompanying the exhibits, was the Egyptologist Miroslav Bárta, who expressed his appreciation for RCPTM’s participation in the project. “RCPTM ranks among the most prominent research centres in the country. Its broad significance is reflected in the centre’s long-term scientific results, publications, and education of new generations of scientists. Therefore, its contribution to the exhibition was crucial. RCPTM’s displays clearly and effectively explained the properties of water and its importance for life on earth,” said Bárta. Scientists from RCPTM also drew attention to other issues, such as threats posed by new types of contaminants, water remediation by nanoparticles, and uses of nanomaterials in renewable energy production, e.g. by water splitting.

The exhibition tells the story of water on 22 double-sided boards through images captured in diverse parts of the planet by various photographers. Accompanying texts were written (with inputs from Miroslav Bárta) by representatives of major institutions such as, besides RCPTM, the Scripps Institution of Oceanography, University of New England, UC Cyber-Archaeology, Czech Institute of Egyptology, and Global Change Research Institute, CAS.

In May, Mathias Beller (an expert on chemical catalysis and organic/organometallic chemistry from Leibniz Institute for Catalysis, University of Rostock, and a highly cited scientist) made an illuminating contribution to the Rudolf Zahradník Lecture Series entitled Catalysis for a Sustainable World.

Professor Beller ranks among the leading experts in chemical catalysis and development of new technologies employing nanomaterials. He focuses on catalytic processes, high pressure chemistry, and synthesis of biologically active agents. “In his lecture, he explained the pros and cons of catalytic processes in various fields, such as drug development, food production, and synthesis of materials,” said RCPTM’s General Director Radek Zbořil, who presides over this lecture series. Generally, it aims to introduce the academics and general public in Olomouc to world-renowned researchers in chemistry, materials science, and optics.

It was the first time this highly acclaimed scientist had visited Olomouc. His stay may result in further collaboration. “You can develop new materials and we have extensive experience with catalytic applications, which seems to be a very good platform for collaboration,” said Beller.

Prof. Beller regularly appears in the Highly Cited Researchers list. He has obtained an advanced ERC grant and been awarded various honorary doctorates and other prizes, including a Dr. Karl Wamsler Innovation Award. His h-index is 124 and he has published more than 1000 papers in the most prestigious journals such as Science, Nature, Nature Chemistry, and Nature Catalysis.

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Catalysis can aid sustainable development according to a recent speaker
Currenty, you are based at two institutes—RCPTM and Matej Bel University. What lies behind this decision?

In Banska Bystrica I held positions ranging from head of department to chairman of the faculty academic senate, while also lecturing. However, I reached a stage where I wanted to devote more time to science, my most intense interest, but scientific teams in Slovakia, apart from Bratislava and Kosice, are too small to break through. They can only benefit from joining bigger research centres. In the beginning I was looking for a possibility in Slovakia but the situation there wasn’t as good as in the Czech Republic. In Olomouc I had a PhD student and was familiar with RCPTM's research activities, so when I learnt they were hiring a computational chemist, I seized the chance.

What's your primary focus?

My work covers three research areas. Since my PhD studies I have been focusing on calculations of electrical and optical molecular properties in basic and excited states. This experience led to an invitation for me (and colleagues from the University of Nantes) to collaborate with Professor Bernard Feringa's group at the University of Groningen in research on photoswitches. We started to investigate the mechanism behind their functionality. The third area is the chemistry of fluorographene, predominantly understanding the principles of its reactivity, chemical transformation, and why some of its derivatives are efficient catalysts for technologically interesting reactions. During the past year we've been trying at RCPTM to connect the two research areas—the chemistry of photoswitches and fluorographene. We are at the beginning of the process, however.

This year you have successfully made it to Nature Communications with a paper on photoswitches. Can you give us more detail?

A photoswitch is a molecule that can be switched between two molecular states by electromagnetic radiation. Scientists are making intense efforts to develop switches that work in the visible light spectrum. Most of those designed to date only work in the ultraviolet spectrum, which is not suitable for applications in biological systems, or their absorption maxima are close to each other, so selectively affecting just one of them is impossible. In Nature Communications we reported the successful design of a switch that works in the visible spectrum with absorption maxima spaced ca. 100 nanometres apart; which is superb. Moreover, such switching occurs in an aqueous environment, which is vital for biological and pharmacological applications. In our study, involving experimental and computational methods, we managed to describe basic parameters of the mechanism behind the switch, which allows its optimization. The idea of such a novel switch was proposed by our colleagues from the Netherlands, who invited us to join their research following previous collaboration that yielded other notable publications.

You work in Slovakia, have had fellowships in France, Belgium and Greece, and now you've gained experience with Czech science. Can you compare these different environments?

The Czech Republic has invested a lot more in science than Slovakia, which has been reflected in progress. Czech science has managed to make use of the European Structural Funds through different operational programmes, unlike Slovakia, which failed to follow it through. In Banska Bystrica, I was and still am pursuing the goal of improving the infrastructure, linking the research to the international environment, and maintaining enthusiasm of the people. I am succeeding only partially, but RCPTM provides inspiration. I recognise a number of crucial factors, including employing foreign researchers, securing major grants, and having brilliant students who participate in research activities even during their studies, which boosts their motivation.
Introducing scientific infrastructure

Scanning electron microscopy system with a focused ion beam (SEM/FIB)

A new addition to the RCPTM infrastructure, a Scios 2HiVac SEM/FIB system, combines a raster electron microscope, ion optics, and modern sample manipulation capabilities. Besides imaging nanoscale structures the equipment enables nanoscale work with samples, providing information not only about surfaces of materials (2D imaging) but also particular depth (3D) profiles. SEM/FIB can be used to create so-called lamellas for TEM imaging and analysis of samples that are too thick for primary analysis by transmission electron microscopy (TEM, HRTEM). Moreover, it does not change important properties of samples. The goal of preparing these lamellas is to look inside the studied materials and image their inner structure. The new microscope will allow high-level investigation of phenomena that could not be studied previously, despite the centre having state-of-the-art TEM and HRTEM microscopes. From an instrumental perspective, the combination of the mentioned technologies (SEM/FIB, TEM, and HRTEM) will allow RCPTM to join the top ranks of European scientific centres in capacity to characterize structurally and chemically complex nanomaterials, thereby increasing its global competitiveness.

Coming soon

Chemistry Meets Industry and Society

RCPTM Director, Professor Zbořil, will be presenting a plenary lecture at the Chemistry Meets Industry and Society conference (CIS 2019), which will take place on August 28-30 in Salerno, Italy. In the Smart Materials section, he will deliver a talk on low-dimensional carbon nanostructures for biomedical, magnetic, and environmental technologies.

This conference, organized by the Italian Chemical Society in collaboration with the European Chemical Society, the Italian Pharmaceutical Association, the Italian Chemical Industry Federation, and other partners, aims to enhance interaction between chemistry-related research and industry. The CIS 2019 conference thus want to respond to the growing need of industrial practice and socially relevant topics in the field of chemistry in an effort to streamline technology transfer from scientific laboratories to the business sector.