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Pillared graphene to improve the performance of supercapacitors

A ***supercapacitor*** (SC) is used to store electricity within a cell made up of two porous electrodes impregnated with electrolyte. These electrodes are separated by an insulating membrane and permeable to electrolyte species, which ad/desorb on the surface of the electrodes according to the potential applied across the device. To achieve optimal performance, the electrode material must have a large developed surface area. Additionally there must be a matching between the size of the micropores (where adsorbed takes place) and the diameter of the electrolytic ions. Can graphene present these two prerequisites?

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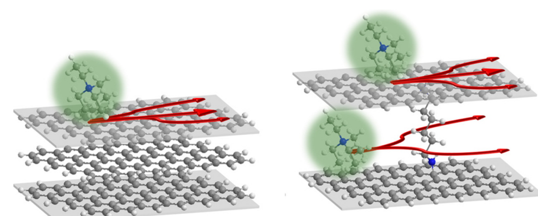
Molecular Systems and nanoMaterials for Energy and Health Laboratory

Researchers at IRIG's Molecular Systems and nanoMaterials for Energy and Health Laboratory use graphene because of its large specific surface area, electrical conductivity and mechanical flexibility. Reduced graphene oxide (RGO), a material close to graphene and tested for SCs, however, offers limited gravimetric capabilities. Indeed, graphene sheets tend to re-aggregate, thus reducing the surface area available for ion adsorption (*Figure*, left). These researchers had the idea to space the graphene sheets using a pillar molecule thus forming galleries of pillared graphene (*Figure*, right). They showed that the number of pillars in the galleries had a significant influence on the density of adsorbed electrolytic species and their transport kinetics: a median filling favours the access of ions to the galleries, increases the surface area available for adsorption and improves ion transport within this 2D porosity. The density of these samples was then modified to achieve higher volumetric capacitances

All the results obtained provide evidence that the use of covalently grafted pillars, combined with density control, will contribute to important research perspectives on carbonaceous materials for the development of high performance SCs.



Schematic diagram between aggregated RGO graphene (left) and expanded pillared graphene (right).

The operating principle of a ***supercapacitor*** (SC) is based on the adsorption of ions on the surface of charged electrodes, as well as on the migration kinetics of these ions within the cell. The parameters that describe the performance of SCs are energy and power densities. The energy density is directly proportional to the developed surface of the electrode and thus to the density of electrolyte species adsorbed at its surface.

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Banda H, Périé S, Daffos B, Taberna PL, Dubois L, Crosnier O, Simon P, Lee D, De Paëpe G and Duclairoir F. Sparsely pillared graphene materials for high-performance supercapacitors: Improving ion transport and storage capacity. *ACS Nano*, 2019

A multi-target strategy to inhibit tumour progression

Despite significant progress in conventional or targeted cancer therapies, therapeutic resistance remains a significant clinical challenge in the treatment of human malignancies. Multiple mechanisms are involved including selection of resistant cells during cancer progression and establishment of compensatory cellular signaling pathways that promote tumor growth. Could we overcome cancer resistance?

Contact: Nadia Cherradi
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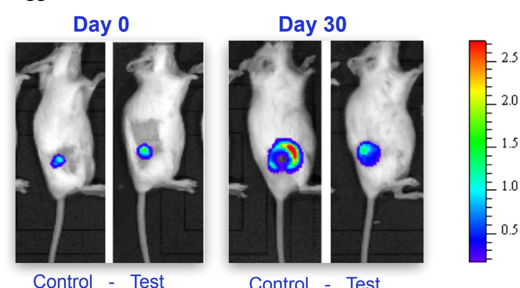
The control of messenger RNA (mRNA) stability/ degradation is a major mechanism for the regulation of gene expression, which is carried out by specific mRNA-binding proteins (RBP) and/or microRNAs. Through their binding to regulatory sequences in the mRNA, RBP induce the recruitment of molecular complexes promoting mRNA stabilization or degradation. Deregulation of these mechanisms is a hallmark of cancer cells. Notably, a prolonged stabilization of some mRNAs leads to an overexpression of proteins promoting tumor progression and aggressiveness.

Researchers from IRIG's Cancer Biology and Infection Laboratory had shown in a previous study that intra-tumoral injection of the mRNA-binding protein called TIS11b/BRF1 in mouse lung cancer inhibits the formation of blood vessels that cause tumor growth and metastatic spread. Using genetic engineering, these researchers recently developed a second-generation protein of which the mRNA-destabilizing activity has been greatly improved. Injection of this modified protein into breast tumours in mice resulted in significant inhibition of tumour growth (*Figure*) and a dramatic reduction in the expression of markers of tumour invasion, inflammation and metastatic spread

This innovative multi-targeted anti-cancer strategy demonstrates that the simultaneous degradation of a set of mRNAs is a relevant approach to halt the expression of several genes that promote tumor progression and aggressiveness.



Measurement of tumor growth by bioluminescence imaging (IVIS system, Calipers) in mice showing breast tumors treated or not (Control) with the modified TIS11b protein (Test). Blue-red scale: increasing number of living tumour cells.

REFERENCE

Rataj F, Planel S, Denis J, Roelants C, Filhol O, Guyon L, Feige JJ and Cherradi N. Targeting AU-rich element-mediated mRNA decay with a truncated active form of the zinc-finger protein TIS11b/BRF1 impairs major hallmarks of mammary tumorigenesis. *Oncogene*, 2019

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New generation of artificial magnetic membranes

Artificial membranes are increasingly being studied, particularly in biology and health, to understand life and for therapeutic purposes, or in fields related to optics to be used as flexible photonic devices. These membranes are often made of polydimethylsiloxane (PDMS) films, a polymer used for decades for its tunable elastic modulus, biocompatibility and transparency.

Researchers at the Spintronics and Component Technology laboratory (Spintec) have developed a new type of membrane partly derived from studies on magnetic particles for biology (such as those used for the destruction of cancer cells induced by magnetomechanical vibrations). ***These innovative membranes***, which incorporate periodic 2D networks of magnetic particles (*Figure*), are biocompatible and magnetically actuated. Their great potential lies in their ability to be remotely activated by an external magnetic field; from a planar state in a null field, they become concave under the action of an applied magnetic field, and thus constitute diffraction gratings for the visible, whose deformations are finely regulated magnetically. Experimental optical responses controlled magnetically show interference spots (*Figure*) that gradually stretch into a series of fringes when the magnetic field is applied. These diffraction patterns are in excellent agreement with the magnetomechanical and optical analytical models that are developed at Spintec. Deformations of a few microns can be controlled on membranes of centimetric diameters.

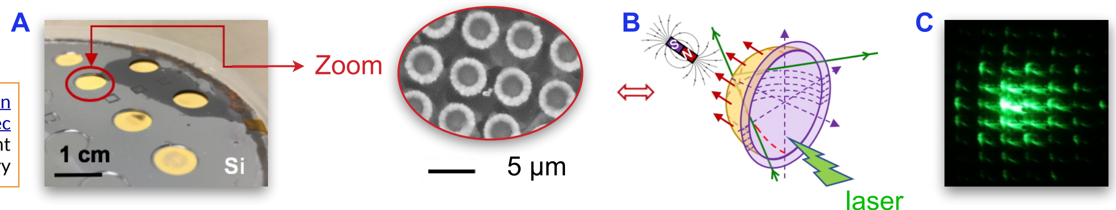
More generally, these results suggest that this type of biocompatible and operable magneto-elastic membranes has potential applications in adaptive optics, photonic devices, but also in biophysics, biology and biomedical fields.

These ***innovative membranes*** are made up of PDMS/Au bilayers of thickness 5µm/100nm, diameter ~1cm, integrating networks of magnetic permalloy pillars (Ni and Fe alloys) prepared by lithographic techniques at the CEA-Grenoble PTA platform.

REFERENCE

Joisten H, Truong A, Ponomareva S, Naud C, Morel R, Hou Y, Joumard I, Auffret S, Sabon P and Dieny B. Optical response of magnetically actuated biocompatible membranes. *Nanoscale*, 2019

A - Photograph of membranes suspended on the holes engraved on the back of the silicon plate.
Zoom: Scanning electron microscope photography of the magnetic lattice (Ni80Fe20) integrated into the membrane, constituting the deformable 2D diffraction lattice.
B - Diagram of the magnetic actuation of a membrane illuminated by a laser beam, initially flat, deformed approaching a magnet.
C - Diffraction pattern strongly impacted by low membrane deflections.



Contact: Hélène Joisten
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Structural defects to renew microtubules

Microtubules play a decisive role in the management of the internal organization of living cells. They serve as rails for intracellular transport and as cables to separate chromosomes during cell division. They are very dynamic polymers that are permanently assembled and disassembled at their ends. This process, called dynamic instability, allows the network of microtubules to produce forces and adapt its architecture to that of the cell.

Microtubules are composed of 13 proto-filaments that combine to form a rigid and hollow tube. But this arrangement is not as perfect as it seems. Recently, several laboratories have observed that the dynamics of microtubules are not limited to their ends. Indeed, tubulin molecules (the basic brick used for their polymerization) could also be added along a microtubule of constant length. But the underlying mechanism was still unknown.

To solve this question, a consortium of researchers from the IRIG's Cell & Plant Physiology Laboratory, the Institute of Genetics & Development of Rennes, the Cell Biology Research Centre of Montpellier and the Interdisciplinary Laboratory of Physics of Grenoble explored the possible links between the structure, biochemistry and incorporation of tubulin along microtubules. Their observations of microtubules in electron microscopy revealed the existence of many defects (holes, dislocations) along the few millimeters of microtubule present in each cell. Fluorescence microscopy analysis of the renewal dynamics of the molecules that make up the microtubules revealed that these nanoscopic defects in the wall of the microtubule are at the origin of the incorporation of new tubulin molecules.

These results show that, in microtubules as well as in metal alloys, structural defects can also be at the origin of original properties and thus offer a new lever to regulate their stability.

The structure of microtubules is dynamic in the vicinity of a defect. The incorporation of new tubulin molecules(yellow) into the network spreads the defect along the microtubule and effectively renews its composition. Illustration of Illuscientia

Microtubules are rigid filaments that are part of the skeleton of cells. They are in permanent renewal and their average life time does not exceed a few minutes. Indeed, microtubules grow regularly, from the center of the cell to the periphery, but can at any time disassemble completely and randomly. The permanent reconstruction process allows the network of microtubules to adapt its architecture and to accompany morphological changes in the cells.

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Schaedel L, Triclin S, Chrétien D, Aubrieu A, Aumeier C, Gaillard J,Blanchoin L, Théry M and John K. Lattice defects induce microtubule self-renewal. *Nature Physics*, 2019

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A strategy to reduce fluorescence intermittencies in super resolution microscopy

Super-resolution fluorescence microscopy makes it possible to observe living matter at the nanoscopic scale from both structural and dynamic point of views. In the latter case, individual target molecules are tracked when they diffuse into a cell, using a technique called ***sptPALM*** (single-particle-tracking Photo-Activated Localization Microscopy). However, a major obstacle to this technique is the imperfection of the fluorescent proteins used as markers, which tend to "blink", *i.e.* to fade transiently, easily causing the loss of the individual molecule's tracks. Is there a strategy to reduce or eliminate this problem?

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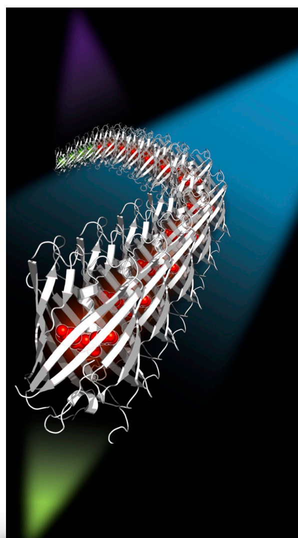
IBS
Institut de Biologie Structurale

Researchers at IBS, in collaboration with the Catholic University of Leuven in Belgium, have undertaken to study the nature of blinking in mEos4b, the latest variant of a series of green to red photoconvertible fluorescent proteins widely used in super-resolution microscopy.

Using a mechanistic approach combining X-ray crystallography, optical spectroscopy and analysis of the fluorescence traces of single molecules, the work revealed a major source of blinking, linked to a photochromism phenomenon. Following excitation by the 561 nm laser of the sptPALM microscope, fluorescent proteins can change conformation and transiently convert into a non-fluorescent state. The study of this non-fluorescent state then revealed its high sensitivity to cyan-coloured light. Thus, a low illumination of the sample with a cyan laser at 488 nm forces a rapid return to the fluorescent state, considerably reducing the lifetime of the non-fluorescent state, and consequently the intensity of blinking.

Since most sptPALM instruments have a 488 nm laser, additional illumination at this wavelength is very easy to achieve, providing a significant improvement in data quality with minimal effort. In their paper, the researchers were able to study the diffusion of the MAP4 protein (microtubule associated protein 4), which interacts with microtubules, in a much more precise way than before. They are now trying to apply their flicker suppression strategy to the issue of molecular counting by qPALM (quantitative Photo-Activated Localization Microscopy) imaging.

In this work, the mechanistic understanding of the origin of the phenomenon of mEos4b blinking, using advanced structural biology techniques, has provided a simple solution to a microscopy problem in cell biology. This is therefore a case study demonstrating the full methodological potential of an integrative approach between structural and cell biology.



Artist's view of the mEos4b protein diffusing in a sample, and illuminated by three lasers at 405 nm, 488 nm and 561 nm. The 488 nm laser suppresses the blinking of mEos4b.

REFERENCE

De Zitter E, Thédié D, Mönkemöller V, Hugelier S, Beaudouin J, Adam V, Byrdin M, Van Meervelt L, Dedecker P and Bourgeois D. Mechanistic investigation of mEos4b reveals a strategy to reduce track interruptions in sptPALM. *Nature Methods*, 2019

sptPALM: in this technique, the target molecules are most often labelled with a "green-to-red photoconvertible" fluorescent protein. The individual fluorescent proteins, initially in the green state, are gradually photoconverted to the red state using a 405 nm laser, and the red fluorescence emission is visualized over time using a high sensitivity wide field microscope equipped with a 561 nm excitation laser, allowing the trace of each target molecule to be followed.

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