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IPCMS NEWS

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Editorial

Research must go on! For some time now, our country has been facing political and budgetary instability, which has not left research funding unscathed. On an international scale, science is sometimes called into question and academic freedom challenged. Nevertheless, we remain motivated and proactive in our efforts to continue achieving significant results, developing new themes and equipping ourselves with high-performing instruments to help us do so.

In the previous issue of IPCMS News, we reported on the inauguration of a brand new low-temperature STM microscopy platform for exploring unique photo- or magneto-stimulable objects. This platform continues to grow thanks to the recent ERC Advanced Grant AETHER awarded to our colleague Guillaume Schull, who is developing an original approach based on spectral and temporal analysis of photons emitted in the tunnel junction.

Always striving to acquire state-of-the-art equipment that will enable us to explore new frontiers in the characterisation of matter and materials, we inaugurated a new Operando transmission electron microscopy system at the beginning of October (see photos). The new JEOL Grand ARM300F2 and its ancillary equipment, unique in France, offers sub-angstrom resolution, enhanced analytical capabilities, and is central to the platform's methodological developments in environmental and 3D microscopy. This microscope is funded by the French government, the Grand Est Region, the Eurométropole de Strasbourg as part of the three-year Strasbourg European Capital contract, the European Union - ERDF Fund operated by the Grand Est Region, the CNRS, the University of Strasbourg and the Jean-Marie Lehn Foundation, whose commitment to this research project in a tight budgetary context we greatly appreciate.

We would also like to acknowledge the support of CNRS Physics in helping our young and new colleagues Alexie Boyer and Paul Noël get their project off the ground through the TREMPLIN programme.

Members of the laboratory are also embarking on industrial ventures. Two new start-ups have recently emerged and are based in our premises: RemeDy, which offers a new process for extracting rare earths, and Lumensium, which has developed a device for the discriminating detection of neutrons. We hope that they will flourish and that our buildings will soon become too small for their activities.

As usual, IPCMS News provides an opportunity to highlight a selection of recent results that illustrate our laboratory's multidisciplinary research. You will discover a new family of luminescent molecules for organic electronics, how to stabilise superconductivity in thin oxide films, and how polypyrrole nanoparticles can be optimised for water splitting reactions. You will also see a nice example of controlling the magnetism of nanodevices using light pulses, as well as the creation of next-generation electronic circuits for artificial intelligence based on 2D nanostructures.

Enjoy reading !

Pierre Rabu, Director

The new JEOL Grand ARM300F2

Left to right : **Christelle Wieder**, Maire adjointe de Strasbourg ; **Sandra Regol**, députée du Bas-Rhin ; **Françoise Bey**, Conseillère d'Alsace ; **Claudio Galderisi**, Recteur délégué à l'Enseignement supérieur, à la recherche et l'innovation pour la Région académique Grand Est ; **Pia Imbs**, Présidente de l'Eurométropole de Strasbourg; **Jacques Witowski**, Préfet de la Région Grand Est et du Bas-Rhin ; **Frédérique Berrod**, Présidente de l'Université de Strasbourg ; **Pierre Rabu**, directeur de l'IPCMS ; **Frédéric Petroff**, Directeur adjoint scientifique de CNRS Physique ; **Irène Weiss**, Conseillère régionale de la Région Grand Est ; **Thomas Ebbesen**, directeur de la Fondation Jean-Marie Lehn.
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Towards predictive approaches for high-temperature superconductivity

Superconductivity is a fascinating state of matter in which pairs of electrons form a quantum state at theacroscopic scale. Materials that become superconductive at temperatures close to room temperature would enable numerous technological applications, such as lossless electricity transmission.

There exist a comprehensive theory able to explain and predict how and at what temperature superconductivity emerge in metals such as aluminum and niobium, unfortunately always at very low temperatures, or extreme pressures. The so-called high-temperature superconductors, such as copper oxide derivatives called cuprates, become superconducting at much higher temperatures, which traditional theory is unable to explain. In collaboration with researchers from the Institut Quantique (University of Sherbrooke, Canada) and Rutgers University, we have developed a theoretical approach that will ultimately make it possible to predict the high-temperature superconducting properties of materials from the sole knowledge of their chemical composition, and the basic principles of quantum mechanics. This work is published in Physical Review X.

The efficiency of the method is demonstrated via the study of two families of multilayer cuprates : $HgBa_2Ca_{(n-1)}CunO_{(2n+2)}$ et $Ca_{(1+n}Cu_nO_{2n}Cl_2$ (n=1,...,5). Based on the crystal structure and a single fixed parameter, we reproduced and explained numerous experimental results. In particular, the fact that tri-layer compounds (n=3) are more favorable for superconductivity. Two opposing factors explain this result: the presence of internal copper dioxide planes with properties advantageous for superconductivity, but an inhomogeneous distribution of electrons that disadvantages these internal planes.

Going beyond previous models, which struggled to link predictions to the specific characteristics of each material, this work represents a first step toward a fascinating research program, particularly for the design of new, more efficient superconducting compounds, as well as for a fundamental understanding of the link between superconductivity and the atomic composition of materials.

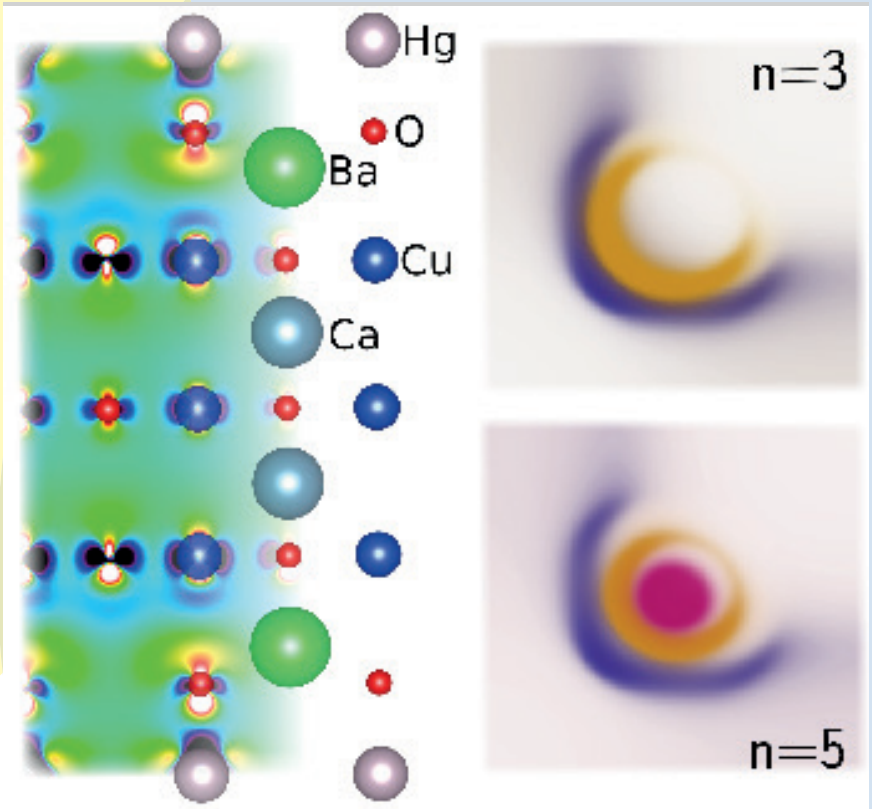

Illustration of the crystal structure of the three-layer compound $HgBa_2Ca_2Cu_3O_8$(n=3) and the inhomogeneous distribution of electrons, typical distributions of the last occupied electronic states (Fermi surface) in arcs and pockets, which reflects the higher electron density in the outer planes.

B. Bacq-Labreuil, B. Lacasse, A-MS Tremblay, D. Sénéchal, and K. Haule, Physical Review X 15, n°. 2, 021071 (2025)
DOI : 10.1103/PhysRevX.15.021071

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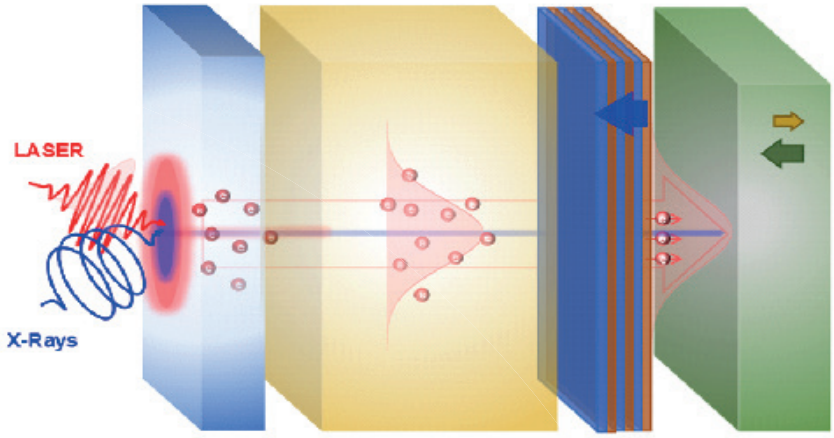
cnrs Université de Strasbourg

Tuning ultrafast demagnetization with ultrashort spin polarized currents in multi-sublattice ferrimagnets



Left to right: Hot electrons generated by a laser in platinum (light blue), the copper (yellow) is used to block the laser pulse so that only the hot electrons propagate and transport a spin current through the magnetic spin valve structure of cobalt platinum (blue-brown) and iron gadolinium (green).

Spintronic components are based on changes in the orientation of magnetic moments, such as electron spins. Spin-current-based devices can therefore operate extremely quickly, currently on time scales of up to one hundred picoseconds (one picosecond is 10^{-12} s). However, the microscopic processes themselves run much faster, in the range of a few hundred femtoseconds (1 fs = 10^{-15} s). The international team, involving the University of Strasbourg, femtoslicing team HZB-BESSY II Berlin, Uppsala University and several other universities, has succeeded for the first time to elucidate how ultrafast spin-polarised current pulses can be characterized by measuring the ultrafast demagnetisation in a magnetic spin-valve within the first hundreds of femtoseconds. With a femtosecond infrared laser, they generated ultrashort hot electrons in a platinum (Pt) top layer. A thin Co/Pt layer, acting as a spin polariser, generated the spin-polarised HE pulses (SPHE) (see Figure). The team was able to characterise these SPHE pulses by analysing the ultrafast demagnetisation dynamics within the $Fe_{74}Gd_{26}$ ferrimagnetic layer, separately probing the ultrafast spin dynamics for each component of the complex sample system: the Fe and the Gd sublattices (see Figure). With the help of the theoretical models developed by a team led by O. Eriksson at Uppsala University, it was possible to determine the crucial parameters of the SPHE current pulses. For the first time, the team has been able to really shed light on the ultrafast dynamic behaviour of spin currents in rare earth based complex magnetic materials. The findings are useful for the development of spintronic devices that enable faster and more energy-efficient information processing and storage.

Gupta, D., Pankratova, M., Riepp, M. et al. , Nature Commununications 16, 3097 (2025).
DOI : 10.1038/s41467-025-58411-3

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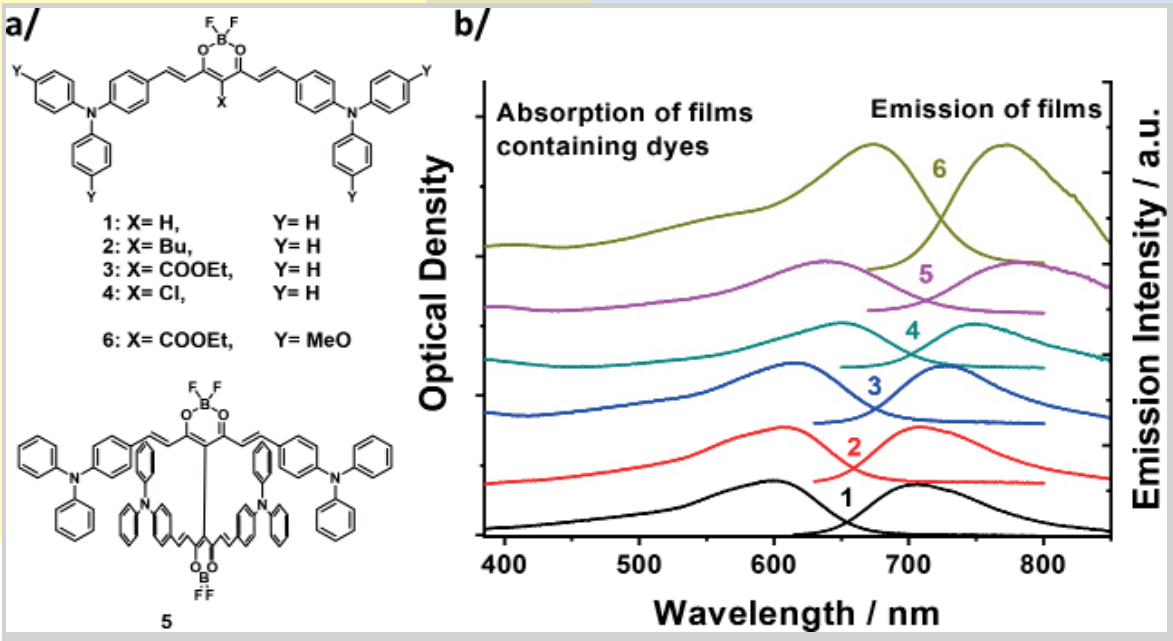
Curcuminoid platform for luminescent organic electronics

This paper describes the synthesis, theoretical study, photophysical characterization and the preparation of devices such as light-emitting diodes (OLEDs) and solid-state organic laser material using curcuminoid derivatives complexed with boron difluoride. While it was demonstrated in 2018 that two compounds of this family could be incorporated into near-infrared-emitting organic light-emitting diodes (OLEDs), this paper conclusively proves that all derivatives containing terminal triphenylamine groups are effective in OLEDs and demonstrate amplified spontaneous emission (ASE). For high-efficiency OLEDs, it is necessary to involve the energy of the triplet excited state of the dyes in the luminescence process, which is clearly not easy. For this purpose, one can take advantage of delayed fluorescence properties. Known for more than one hundred years, this process was exploited by Pr. Adachi 10 years ago to improve OLEDs' efficiency. This mechanism well known as Thermally Activated Delayed Fluorescence (TADF) lies on the disconnection of HOMO and LUMO orbitals of the luminescent dye via the twisted structure of the molecule. As a result, the molecule exhibits a small singlet-to-triplet gap that permits the repopulation of the singlet state via thermal excitation. In this paper, we demonstrate that despite the absence of twist in the molecules (and therefore of a large singlet-to-triplet gap), the TADF process is still possible and can result in efficient devices with emission up to 800 nm. Conversely, twisted molecules do not have the ability to show ASE. In the present case, a low ASE threshold was observed in the NIR, allowing dyes to show ASE up to 900 nm. In a nutshell, there is evidence that the curcuminoid boron difluoride platform can be used for OLED and organic laser applications, as this family of dyes is within the few molecules that efficiently exhibit both properties.



a/ Chemical structures of the investigated dyes; b/ UV/visible absorption and emission spectra of the thin films of those dyes in a host matrix (4,4'-Bis(N-carbazolyl)-1,1'-biphenyl) at 3wt.%

A. D'Aléo, X. Tang, D.-H. Kim, D. Valverde, E. Zaborova, G. Canard, A. Brosseau, L. Mager, G. Clavier, C. Adachi, Y. Olivier, J.-C. Ribierre, Advanced Optical Materials, 2025, 2500338.
DOI : 10.1002/adom.202500338

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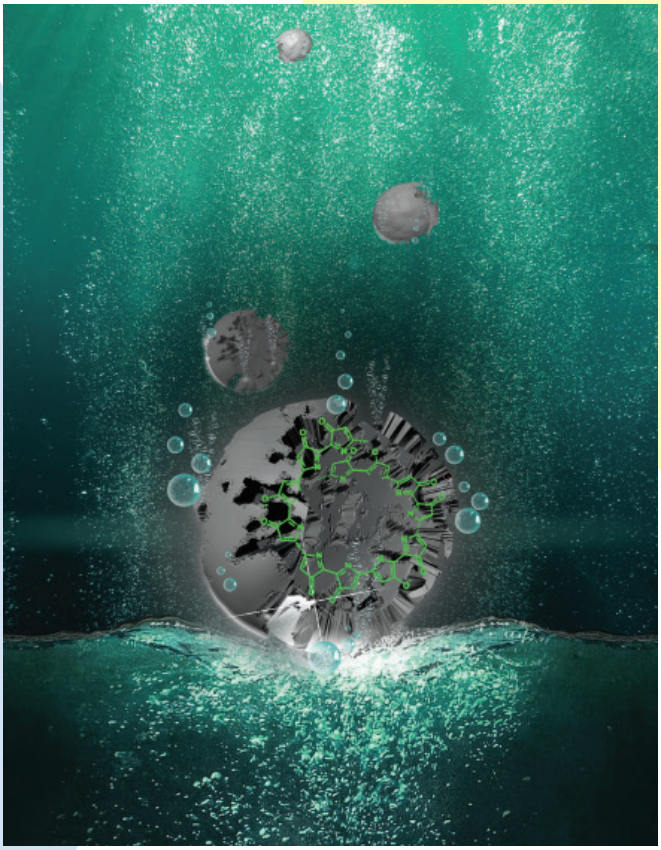
Semiconducting Overoxidized Polypyrrole Nano-Particles for Photocatalytic Water Splitting

A fruitful collaboration among several CNRS teams has revealed that polypyrrole particles—an organic polymer obtained via high-energy irradiation of an aqueous pyrrole solution—can absorb visible light to oxidize water and generate oxygen. Under specific conditions, these particles may also produce hydrogen peroxide, a compound of considerable industrial interest. Until now, most materials capable of this transformation have been inorganic semiconductors, such as titanium dioxide. Beyond their promising catalytic performance, these nanostructures are notable for their straightforward synthesis, which does not require scarce or costly metals. This discovery opens new avenues for the development of sustainable materials for clean and renewable energy applications.

To enhance electrocatalytic properties and facilitate device integration, a key research focus is understanding the relationship between structure and performance. In this context, characterizing these novel nanomaterials—particularly their surface features—remains a major challenge. Parameters such as particle size, porosity, and the presence and distribution of nanometric heterogeneities are critical, making precise electron microscopy analysis at the single-particle level essential.

It was observed that these particles form a matrix encapsulating agglomerates of small black nanoparticles, a few nanometers in diameter. These nanometric particles are distributed both on the surface and within the particle interior, while a network of tunnels permeates the spheres. The study also clearly demonstrated that particle size and dispersion strongly depend on the absorbed irradiation dose and pyrrole concentration. Furthermore, catalytic performance is dictated by internal structure, surface area, and the heterogeneous nature of the larger nanoparticles' interiors.

Overall, this work underscores the iterative nature of scientific research, in which synthesis, characterization, and property measurements inform one another. Ongoing studies aim to further elucidate the behavior of these organic semiconducting materials using operando techniques and theoretical analyses.



X. Yuan, G. E. Lopez, V.-D. Duong, S. Remita, D. Dragoe, D. Ihiawakrim, O. Ersen, Y. Dappe, W. Leibl, H. Remita & A. Aukauloo, Small 2025, DOI : 10.1002/smll.202407364

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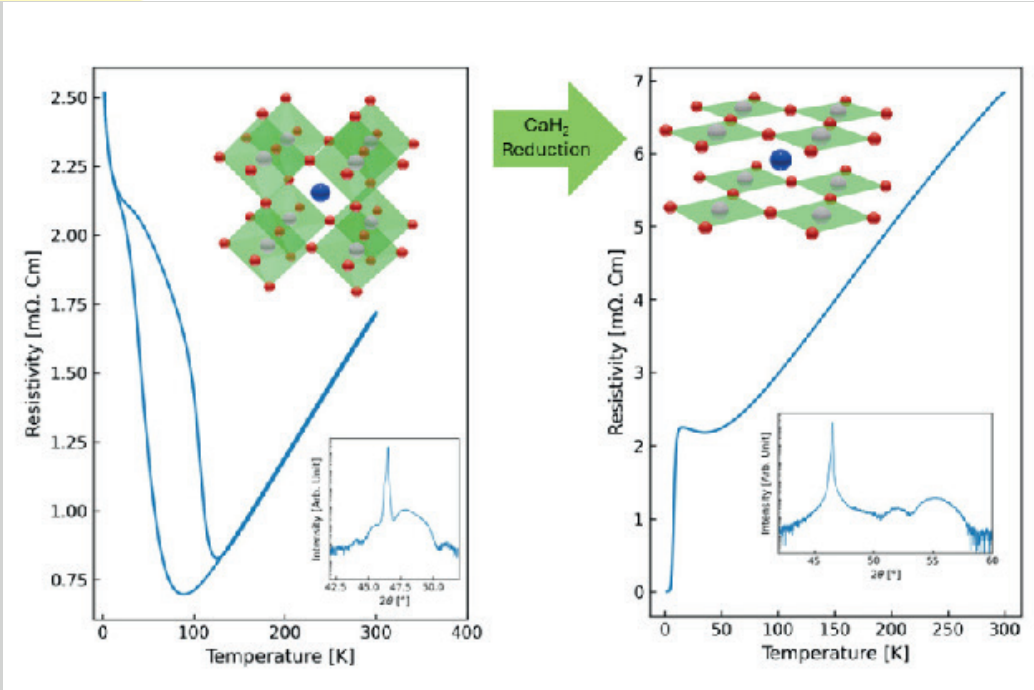
Researchers demonstrate superconductivity in undoped infinite-layer nickelate thin films, prompting a rethink of the nickelate phase diagram



(Left) Temperature dependence of the resistivity for a $PrNiO3$ thin film grown onto a $SrTiO_3$ (STO) substrate. The top inset shows the perovskite unit cell, while the bottom inset presents the X-ray diffraction pattern around the STO (002) peak.
(Right) Temperature-dependent resistivity after topotactic reduction using CaH2, revealing a superconducting transition below 11 K. The top inset illustrates the infinite-layer structure, and the bottom inset shows the expected shift of the (002) diffraction peak.

A team of French and Italian researchers has demonstrated that superconductivity can emerge in infinite-layer PrNiO2 thin films without chemical doping. This discovery challenges the current understanding of the nickelate phase diagram. Since the initial observation of superconductivity in these materials, a dome-like dependence of the critical temperature on doping (x), similar to that in cuprates, has emerged. This analogy sparked intense research efforts aimed at drawing direct comparisons between the two systems. However, notable differences have emerged, such as the higher charge-transfer energy and a significant hybridization between rare-earth and Ni ions in nickelates. This hybridization creates an electron pocket at the Fermi level, effectively leading to self-hole doping of the Ni $3dx^2-y^2$ bands, sufficient to induce superconductivity even at $x = 0$. In this study, the authors report a reproducible superconducting state below 11 K in undoped $PrNiO_2$ thin films, obtained via topotactic reduction of epitaxial $PrNiO_3$ grown onto $SrTiO_3$. Advanced microscopy and spectroscopy confirm that this superconductivity does not result from unintentional doping. In particular, 4D-STEM with differential center-of-mass (dCOM) analysis revealed no excess oxygen, while X-ray absorption (XAS) and resonant inelastic X-ray scattering (RIXS) at the ESRF synchrotron confirmed a Ni^{1+} valence state. Interestingly, similar XAS/RIXS features have been observed in non-superconducting samples, indicating that these spectra alone cannot determine the presence of a superconducting ground state. The high crystalline quality of the present samples is likely crucial to enabling superconductivity in this undoped regime.

Sahib, H., Raji, A., Rosa, F., Merzoni, G., Ghiringhelli, G., Salluzzo, M., Gloter, A., Viart, N. and Preziosi, D.- Superconductivity in PrNiO2 Infinite-Layer Nickelates. Advanced Materials, 37(16), p.2416187, 2025.
DOI : 10.1002/adma.202416187

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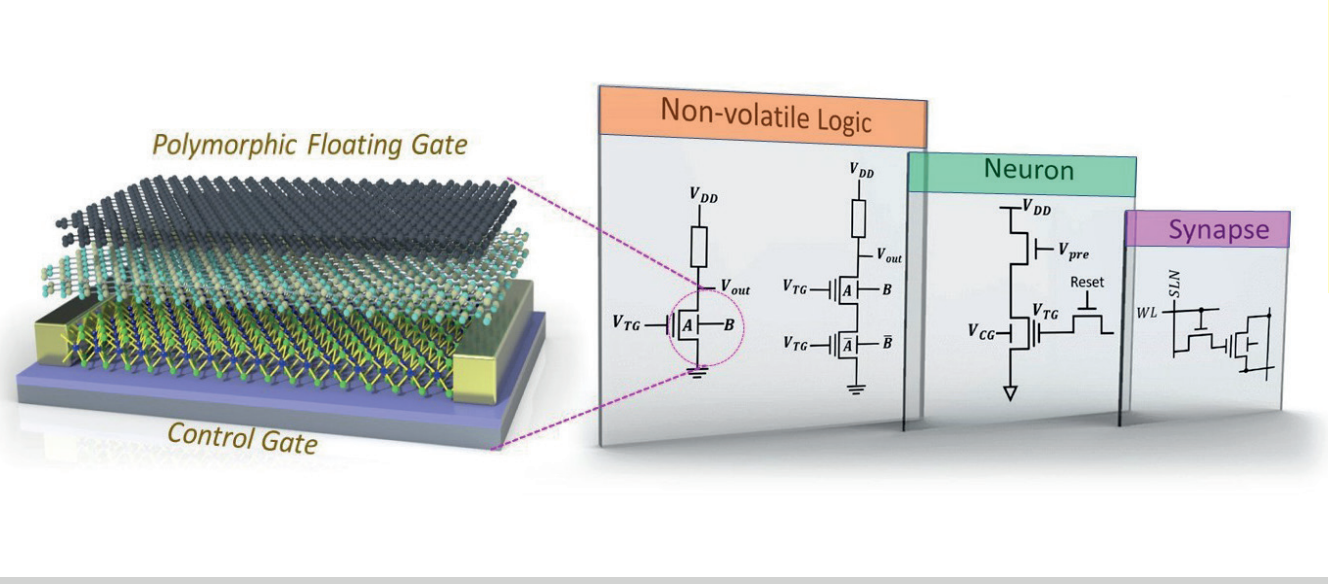
A floating gate topology for agile Artificial Intelligence circuits

This work by Soliman et al. proposes a fundamental rethinking of floating-gate transistors harnessing the van der Waals materials' capabilities. By placing the floating gate on the opposite side of the semiconductor channel (ReS_2), the authors overcome a central electrostatic limitation of conventional designs: the screening of the control gate by the charge reservoir. The inverted layout restores strong gate–channel coupling, while the atomically sharp, trap-free interfaces and the ultrathin screening lengths enhance the memory capability. This topology allows one device to toggle between volatile dual-gate control and nonvolatile floating-gate operation, uniting memory and logic within the same physical element. At the materials–physics level, the mechanism hinges on Fowler–Nordheim tunneling across hBN, capacitive image charges in the graphene gate, and an ultra-thin ReS_2 less than the charge screening length. Furthermore, the device was shown to emulate both synaptic plasticity and neuron firing, showcasing its versatility and relevance for the current AI revolution. Rather than another incremental device metric, the inverted floating gate field effect transistor (IFGFET) introduces a conceptual bridge: by leveraging van der Waals properties, a single transistor can morph between roles—switch, memory cell, synapse, or neuron. This adaptability suggests not only a pathway beyond CMOS scaling, but also a new experimental playground for exploring the physics of charge storage, tunneling, and non-equilibrium dynamics in 2D materials, with profound implications for emergent computing architectures.



M. Soliman, C. Marchand, A. Mahmoudi, N. Kumar Rajak, T. Taniguchi, K. Watanabe, A. Gloppe, B. Doudin, D. Deleruyelle, I. O'Connor, A. Ouerghi, J.-F. Dayen, ACS Nano, 2025, 19, 18757-18768
DOI : 10.1021/acsnano.5c03875

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