Current-Induced Spin-Wave Doppler Shift

The first observation of a current-induced Doppler shift for spin waves has recently been reported by two researchers of the IPCMS. This phenomenon - predicted forty years ago – allows one to determine precisely the magnitude of the spin current, which is an important quantity in the field of spintronics.

The use of the Doppler effect to observe moving objects has been widely adopted in astronomy, navigation, weather observations or medical imaging. This effect manifests itself as a change of the frequency of a wave when it is emitted or detected by a moving object.

In a metal ferromagnet, the electrons responsible for the magnetism also contribute to the electrical conduction (so-called "itinerant magnetism"). Under the influence of an electrical current, these electrons are put in motion, so that one expects the waves of precession of the magnetization (the so-called "spin waves") to be Doppler shifted [P. Lederer and D. Mills, Phys. Rev. 148, 542 (1966)]. This idea has been revisited in the context of spin transfer, i.e. the manipulation of the magnetization using spin-polarized currents. Indeed, the current–induced spin-wave Doppler shift can be seen as an elementary spectroscopic signature of spin transfer .

To observe this effect, we use the technique of propagating spin-wave spectroscopy which has been down-scaled to a sub-micrometer size. A typical microfabricated sample is shown in the left figure. It comprises a micrometer-wide strip of permalloy (nickel-iron alloy) and a pair of sub-micrometer meander-shape patterns which are used as antennae for exciting and detecting spin waves propagating along the strip. The microwave response of these antennae is measured with the help of a network analyzer, which allows one to characterize the propagation of spin waves between the two antennae. When a high enough electrical current is sourced through the strip, the signal corresponding to spin waves propagating along the electron flow (red curve on the right figure) is systematically shifted to a higher frequency than the signal corresponding to spin waves propagating against the electron flow (blue curve). From the magnitude of the frequency shift, the degree of the spin polarization of the diffusive electrical current is estimated to be of the order of 50%. ■

V. Vlaminck and M. Bailleul, Science **322**, 410 (2008).

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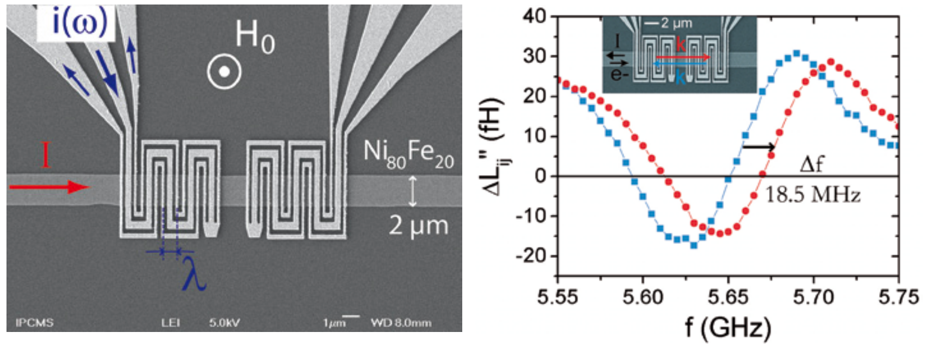

Figure : (Left) Scanning electron micrograph of a device with a permalloy strip and two spin-wave antennae. (Right) Propagating spin wave signals in the presence of a I=-6mA current flowing along the strip (the propagation directions are indicted in the inset).

Inauguration of a new TEM JEOL 2100 F at IPCMS

One of the major challenges in the forthcoming years concerns the control of nanomaterials properties, in order to build up the next generation devices which could reduce to some dozens or even a few atoms. In that respect, a new generation transmission electronic microscope has been installed at IPCMS to strengthen the platform of electronic microscopy in Strasbourg, including an environmental microscope for the study of soft matter and another one dedicated to biological materials. This new equipment will be dedicated to the study of nanostructures for spintronics, hybrid materials, carbon materials and nanoparticules for catalysis. Further, it will allow to develop new fields at the forefront in electronic microscopy, such as structural and analytical tomography, as well as in-situ experiments under electron beam.

IPCMS *News*

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Summary

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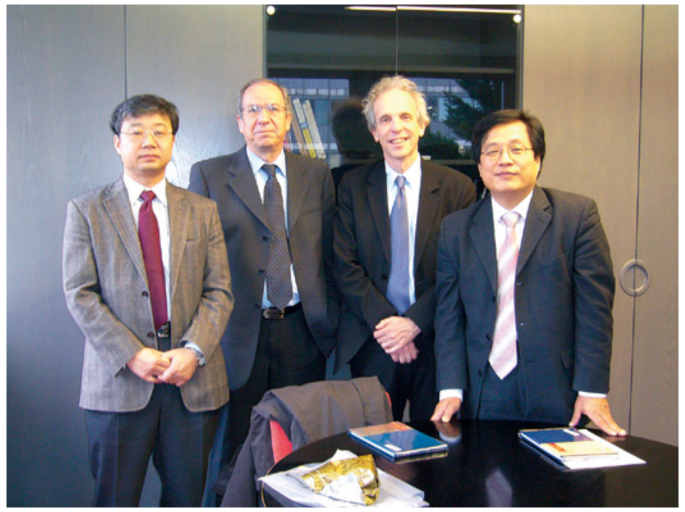
Korean-French Collaboration

A cooperation agreement between Ewha Women University (South Korea) and Louis Pasteur University (France) was signed on December 16th, 2008. Both universities aim to reinforce their relationships by developing cultural and academic interchanges in education and research.

They agree to cooperate and work together toward the internationalization of higher education. The cooperation includes exchange of students, visits of faculty members, joint research projects and cultural programs. The IPCMS is already strongly involved in several scientific projects on spintronics and nanophotonics, and in this frame welcomes PhD students and postdocs coming from South Korea.

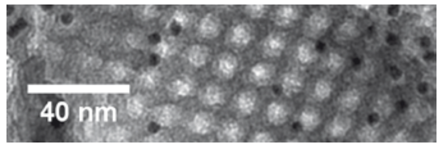


From left to right :
Prof. W. Kang, Dr. M. Drillon, Prof. A. Beretz, Prof. J.W. Wu

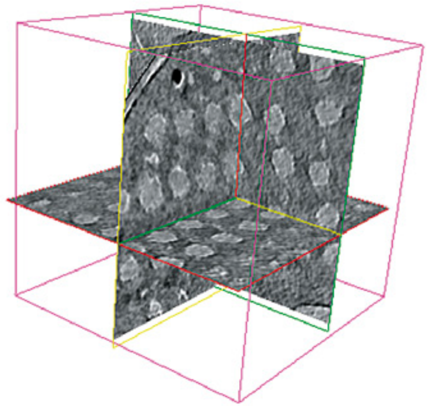
Institut de Physique et Chimie des Matériaux de Strasbourg

Stacking faults and pore connections in ordered mesoporous silica FDU-12

Ordered mesoporous materials with large, self-organized and interconnected pores have attracted considerable attention in the past few years due to the wide range of potential applications, especially in areas involving selective tunnel diffusion, immobilization and separation of large molecules or biomolecules. In the particular case of mesoporous materials with cage-like structures, the design of the structure by appropriate synthesis is a key issue for applications where the final topology is important. A comprehensive characterization of these materials requires the use of different analytical techniques, but most of them average the objects present in the volume of observation and washes out the detailed shape of the cavities and the small connections between them. To recover the detailed morphology and structure, we used the ability of electron tomography- a technique which consists in the volume reconstruction of an object from a series of 2D images recorded by electron microscopy- to provide three-dimensional information at a nanometer scale.

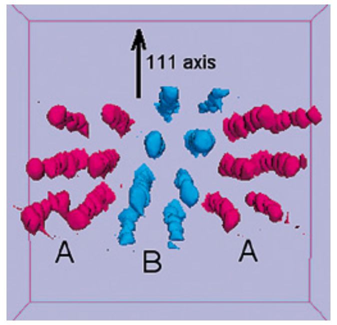


Typical 2D-TEM image of the FDU-12 silica. Dark dots are 5 nm gold nanoparticles used for the 3D reconstruction of the object.



Three orthogonal sections through the reconstructed volume of the FDU12 material.

Herein we report on an accurate and complete analysis of the large-cage mesoporous FDU-12 silica by combining small-angle X-ray diffraction (SAXRD), nitrogen sorption, and electron tomography (3D-TEM) techniques. We show that the 3D-TEM technique is an essential tool for multi-scale characterization of nanomaterials, providing direct information on the morphology of individual objects and their organization at the nanoscale. We evidenced thus that the *fcc* structure usually assigned to the FDU-12 materials is in fact an intergrowth of cubic and hexagonal close-packing structures with very limited domains without any defect (in the order of 2-3 close-packed cavities stacking). For the first time, we also provided direct evidence for the presence of peculiar stacking defects between rows of cavities, referred to as "z-shifted [111] zones". Beside these defects, interstitial cavities and well-located cavities but with a smaller size were also revealed by this technique, in agreement with the bimodal pore size distribution deduced from physisorption. Moreover, 3D-TEM analysis allowed obtaining reliable estimate for the cage diameter and interconnectivity that are crucial for understanding the physical and chemical properties and their use in future applications. ■



Modelling of a stacking defect between rows of cavities.

O. Ersen, J. Parmentier, L.A. Solovyov, M. Drillon, C. Pham-Huu, J. Werckmann, P. Schultz, JACS **130**, 16800-16806 (2008).

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Semiclassical theory of time-reversal focusing

The concept of time reversal has captured the imagination of physicists for more than a century, leading to a vast theoretical oeuvre, sempiternal discussions, and a few concrete experimental realizations.
Among them, the works on spin echoes of E. Hans in the fifties and R. Ernst in the eighties have been of paramount importance concerning the limits in the reconstruction of an initially prepared quantum state. The time reversal of acoustic waves in a nonhomogeneous medium was another experimental deed showing that an initially localized pulse can be accurately reconstructed by an array of receiver-emitter transducers that reinject the recorded signal (A. Derode, P. Roux, and M. Fink, Phys. Rev. Lett. **75**, 23(1995)).
The playback signal was shown to build up in the region of the original excitation, in the form of a reversed wave amplitude. Refocusing of elastic, as well as electromagnetic, waves has been later achieved by the group of M. Fink at the Ecole Supérieure de Physique et de Chimie Industrielle de la Ville de Paris.
Various technological applications of time-reversal mirrors (TRM) have been proposed, and their implementation in medicine is on the way.
In a typical time-reversal setup a high-frequency signal emitted at t=0 at a position $\mathbf{r}_0$ inside a cavity is recorded by a receiver (or an array of receivers) at position(s) $\mathbf{r}_i$ for times in the interval (t_1,t_2). After a waiting time $t_W > t_2$, the reemission of the time-reversed signal is performed in the interval $(t'_2 = 2t_W - t_2, t'_1 = 2t_W - t_1)$. The refocusing around $\mathbf{r}_0$ is expected at $2t_W$ (that is redefined as the time origin for refocusing in the TRM sequence of the figure). The achievement of a good reconstruction even in the case of a single receiver, the robustness against external perturbations during the sequence, and the fact that the relevant information is encoded on the coda of the multiple-scattered original wave, have remained as puzzling features of time-reversal focusing in its various experimental realizations.
A collaboration between the IPCMS and the Universidad Nacional de Córdoba (Argentina) recently proposed a semiclassical theory of time reversal mirrors that correctly describes the observed phenomenology. This semiclassical approach builds in the related theory of spin echoes in complex systems (Loschmidt echo) previously developed by the French-Argentinian collaboration. The reconstructed signal $F(\mathbf{r},t)$ at time t and for $\mathbf{r}$ close to $\mathbf{r}_0$ can be expressed in terms of classical trajectories linking the emission and receiver points (left inset). The semiclassical expansion brings about the importance of the underlying classical dynamics and yields a reconstructed signal proportional to the recording time $\Delta T = t_2 - t_1$ and inversely proportional to the area $\boldsymbol{A}$ of the cavity. The semiclassical theory (black solid line in the figure and in the right inset) is in good agreement with the numerical results for various recording times and sizes of the cavity (colour lines) for the temporal and spatial reconstruction (σ and $\mathbf{p}_0$ are, respectively, the extent and momentum of the initial wave-packet). The robustness of the reconstruction against unavoidable perturbations, which is a crucial ingredient for practical applications of the TRM, can also be analysed within the semiclassical framework and will be the object of further studies. ■

H.L. Calvo, R.A. Jalabert, H.M. Pastawski, Phys. Rev. Lett. **101**, 240403 (2008).

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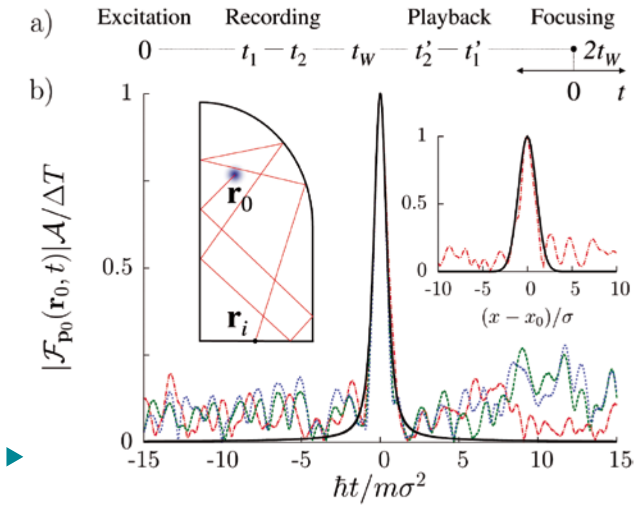
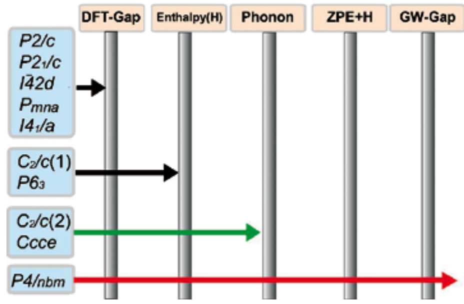


(a) Time-reversal mirror sequence. (b) Reconstructed signal at the emission point $\mathbf{r}_0$, for times t close to the refocusing one. The thick solid line is the semiclassical prediction, while the thin coloured ones represent the numerical simulations (see text). Right inset: reconstructed signal at the refocusing time, close to $\mathbf{r}_0$, from the semiclassical prediction (black solid) and the simulation (red dash-dotted). Left inset: billiard used in the numerical simulations showing the emission point $\mathbf{r}_0$, the position $\mathbf{r}_i$ of the receiver-emitter, and a classical trajectory joining them.

Crystal structure of the pressure-induced metallic phase of SiH4 from ab initio theory

Metallization of pure solid hydrogen is of great interest because it could lead to high-temperature superconductivity, and especially because it continues to be an elusive goal due to great experimental challenges. Hydrogen-rich materials, in particular, CH_4, SiH_4, and GeH_4, provide an opportunity to study related phenomena at experimentally achievable pressures, and they too are expected to be high-temperature superconductors. Recently, the emergence of a metallic phase has been observed in silane for pressures just above 60 GPa. However, some uncertainty exists about the crystal structure of the discovered metallic phase. Here, we show by way of elimination, that a single structure that possesses all of the required characteristics of the experimentally observed metallic phase of silane from a pool of plausible candidates can be identified. Our density functional theory and the quasi-particle GW calculations where the self-energy is written as a product of the Green's function (G) and the screened interaction (W) show that a structure with space group P4/nbm is metallic at pressures greater than 60 GPa. Based on phonon calculations, we furthermore demonstrate that the P4/nbm structure is dynamically stable at pressures greater than 43 GPa and becomes the ground state at 97 GPa when zero-point energy (ZPE) contributions are considered. These findings could lead the way for further theoretical analysis of metallic phases of hydrogen-rich materials and stimulate experimental studies. ■



▲ A schematic illustration of the elimination scheme applied in this study. The end points of the arrows indicate for which criteria a certain space group failed to pass the test. Here ZPE is the zero-point motion. The GW calculation showed the P4/nbm structure is metallic at pressures greater than 60 GPa.

D. Y. Kim, R. H. Scheicher, S. Lebègue, J. Prasongkit, B. Arnaud, M. Alouani, R. Ahuja, PNAS **105**, 16454 (2008).
See also a review about this article in Physics Word entitled "*Physicists get closer to metallic hydrogen*" published on October 21, **2008**. (http://physicsword.com/cws/article/news/36323).

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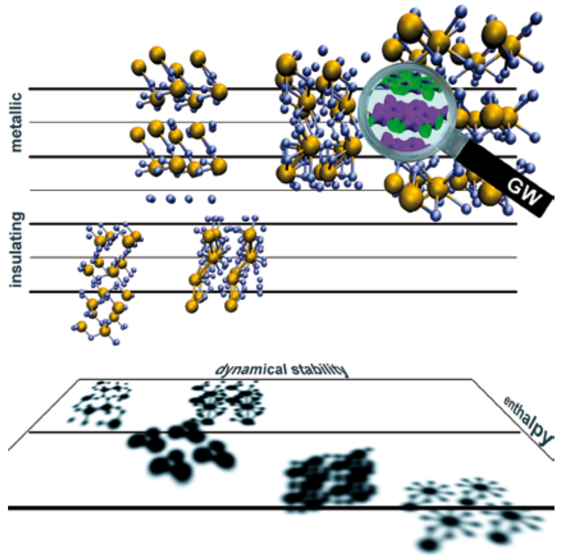

*◀ A series of theoretical analyses led to the identification of the crystal structure of a recently discovered high-pressure metallic phase in silane from a pool of plausible structures. Properties tested involved the band gap, phonon spectrum (dynamical stability), and enthalpy differences, while quasiparticle **GW** calculations allowed for a reliable test of the metallic nature (represented here through the Fermi surface): Image courtesy of D.Y. Kim and R.H. Scheicher.*