Karen Mulleners
Specialist in fluid-solid interactions in hydrodynamics at EPFL Lausanne

Rosanna Larciprete
Expert in 2D materials, MXenes at CNR-ISC

Jamal Yagoobi
Full Professor at Worcester Polytechnic Institute

Toshiyuki Kawasaki
Full Professor at Nishinippon Institute of Technology

Anne-Magali Seydoux-Guillaume
Mineralogist specializing in rock-fluid interactions

Banjamin Vest
Expert in plasmonics and quantum nanophotonic

Albano Cavaleiro
Professor at University of Coimbra, specialist in surface engineering

Jose Luis Torero
Professor in fire protection engineering at University College

Steven Van Petegem
Scientist in the Structure and Mechanics of Advanced Materials

EXPLORING INTERFACES

IntREE Graduate School & LABEX Intéractifs Conference on Research Highlights 2020-2024

FROM **31 March** TO **2 April 2025** | **2:00pm**

IFMI H6

We look forward to welcoming you to learn more about LABEX's cutting-edge research on transfer and interactions at fluid-solid interfaces.
Don't miss the opportunity to hear from our guest researchers, joining us from around the globe.

Labex Interactifs · INTREE · France 2030 · Université de Poitiers · IC2MP · Institut Pprime · Isae ENSMA · cnrs

Program

Monday, March 31, 2025

14:00–14:20	**Introduction: Amphitheater**		
	IT	**Noël BRUNETIERE, Philippe CARRE, Jacques BOREE, Karl JOULAIN, Yannick POUILLOUX**	Introduction
14:20–15:20	**Technical session: Amphitheater**		
14:20–15:00	KL	**Anne-Magali SEYDOUX-GUILLAUME** Laboratory of Geology of Lyon, Earth, Planet, Environment	What Minerals Say at the Nanoscale: A Journey Through Time and Space
15:00–15:40	KL	**Albano CAVALEIRO** University of Coïmbra	The importance of self-adaption to optimize the interface in mechanical contacts
15:50–16:10	**Coffee break: Hall**		
16:10–18:10	**Technical session: Amphitheater**		
16:10–16:50	KL	**Toshiyuki KAWASAKI** Nishinippon Institute of Technology, Fukuoka	Visualization and control of flows in liquids directly irradiated by plasma
16:50–17:10	IT	**Lara ALOMARI** EUR PhD	Investigation of the physical and chemical properties of plasma-liquid interactions at atmospheric pressure and their influence on reactive species generation
17:10–17:30	IT	**Marcel KUHMANN** EUR PhD	Modelling iron particle combustion
17:30–17:50	IT	**Jeanne MAUCOURT** EUR PhD	Conservation of Earthen Heritage Collections: Validation of TEOS Treatments on Mesopotamian Tablets
17:50–18:10	IT	**Anna EL KHOURY** EUR PhD	A battle against arsenic toxicity by Earth's earliest complex life forms
18:10–20:00	**Cocktail and posters: First floor**		

Tuesday, April 1, 2025

8:50–10:00	**Technical session: Amphitheater**

8:40–9:20	KL	**Benjamin VEST** Institut d'Optique, Palaiseau	Controlling Far-Field Radiation with Photoluminescent and Incandescent Metasurfaces
9:20–9:40	IT	**Arthur TAUSCH** Labex PhD	Elaboration and characterization of thermochromic mixed valence manganites: towards a new generation of stealth surface
9:40–10:00	IT	**Fatih ZIGHEM** PhD of Hatem BEN MAMOUD	Investigating the interplay between biaxial multicracking of nanometric thin films and their magnetic properties: a nuanced separation of magnetoelastic and magnetostatic effects
10:00–10:30	**Coffee break: Hall**		
10:30–12:10	**Technical session: Amphitheater**		
10:30–11:10	KL	**Steven VAN PETEGEM** Laboratory Condensed Matter, Paul Scherrer Institute, Switzerland	Beyond the Melt: How Solidification Shapes Material Properties
11:10–11:30	IT	**Olga SMERDOVA** PhD of Florian FEYNE	Thermal Ageing of a Room-Temperature Vulcanised Silicone Seal : Role of Confinement
11:30–11:50	IT	**Nicolas SENICOURT** Labex PhD	Microstructural modifications induced by He implantation in nitride-based multilayer coatings
11:50–12:10	IT	**Mhadji ABDOUSSALAM** Labex PhD	Modeling and simulation of thermo-mechanical Coupling using a gradient-based Damage and Thermal degradation approach
12:10–14:00	**Lunch: Plazza**		
14:00–15:20	**Technical session: Amphitheater**		
14:00–14:40	KL	**Jamal YAGOOBI** Worcester Polytechnic Institute, USA	Electrohydrodynamically Driven Two-Phase Heat Transport Devices for Space and Terrestrial Applications
14:40–15:00	IT	**Valentin BERRY** Labex PhD	Study of electric charge distribution at solid/liquid interfaces using an acousto-electric method
15:00–15:20	IT	**Ihssan MATAR** Labex PhD	Electro-Convective Flow Study of Hydro-fluoro-ether (HFE-7100) in Electro-Hydro-Dynamic (EHD) Systems
15:20–15:50	**Coffee break: Hall**		
15:50–17:10	**Technical session: Amphitheater**		
15:50–16:30	KL	**Karen MULLENERS** EPFL, Lausanne	Shaping up to explore and exploit fluid-structure interactions of flags
16:30–16:50	IT	**Vincent ROBIN** PhD of Mohamed SAADANA	One-dimensional statistical modeling of a DBD reactor

16:50–17:10	IT	**Eric GONCALVES** PhD of Lucas MENEZ	Simulation of wall damage induced by a bubble collapse using a strong coupling partitioned method.
20:00–22:00	**Gala dinner: Clos de la Ribaudière**		

Wednesday, April 2, 2025

8:50–10:00	**Technical session: Amphitheater**		
8:40–9:20	KL	**Rosanna LARCIPRETE** Institute for Complex Systems, Italian National Research Council	Hydrogen adsorption, surface chemistry and storage in 2D materials.
9:20–9:40	IT	**Sophie CAMELIO** PhD of E. DE LOS SANTOS VAZQUES	Self-organized chains of plasmonic nanoparticles in dielectric films : a reusable platform for SERS applications
9:40–10:00	IT	**Antoine GUITTON** PhD of Renaud GENIN	Surface tailoring and characterization techniques for enhanced understanding and control of properties
10:00–10:30	**Coffee break: Hall**		
10:30–12:10	**Technical session: Amphitheater**		
10:30–11:10	KL	**Jose TORERO** University College London	Fire Science and Fire Engineering, the Difference between Knowledge and Professional Competency
11:10–11:30	IT	**Christophe COUPEAU** PhD of Kimheng MENG	Damage mechanism by buckling: Influence of plasticity and interfacial delamination
11:30–11:50	IT	**Vincent MAUCHAMP** PhD of Ayoub BENMOUMEN	Structural and property engineering of 2D titanium carbides (MXene) thin films using ion irradiation
11:50–12:10	IT	**Hanane IDRIR** Labex PhD	New nanostructured Cu-Ag for application in severe environment (high stress and high strain rate)
12:10–12:30	**Closure: Amphitheater**		
12:10–12:30	IT	**Noël BRUNETIERE, Pierre-Olivier RENAULT**	Closure

Registration

This event will be held in IFMI amphitheater. A registration is needed to participate to this event, more particularly for the lunch.

Registration here

List of Abstracts – Keynote lectures

What Minerals Say at the Nanoscale: A Journey Through Time and Space

A.-M. Seydoux-Guillaume KL

Laboratory of Geology of Lyon, Earth, Planet, Environment

The interpretation of planetary dynamics requires the integration of geological processes (e.g. tectonics, weathering, erosion, sedimentation, impacts) in a temporal framework. In the course of various geological processes, rocks are affected by physical and chemical mechanisms that leave traces, more or less visible and lasting, but often detectable only at the nanoscale. Through selected examples, I will show how the combination of cutting-edge tools, such as the Transmission Electron Microscope (TEM) and Atom Probe Tomography (APT), provides access, at the nanoscale, to (i) mineral structures and their transformations, (ii) elemental and isotopic mobilities, and thus contributes to improving our understanding of mechanisms active at the nanoscale.

The importance of self-adaption to optimize the interface in mechanical contacts

A. Cavaleiro KL

University of Coïmbra, Portugal

Friction is strongly dependent of the type of interface occurring in the mechanical contact. In both unlubricated and lubricated sliding, solid-solid contact is unavoidable determining the friction performance. Therefore, it is imperious to understand how the interface in the solid contact can be tackled in order to form a material able to provide the desirable low friction. Self adaption is known for a long time as a concept being developed to take advantage of the synergy between the physical / chemical conditions and the materials/elements existing in the contact during sliding, allowing the transformation of the interface and giving rise to low friction.

In this talk, several examples will be presented showing how self adaption is explored to modify the top surface of transition metal dichalcogenides – based coatings for achieving super-low friction as well as how the interaction of polymer containing oils can interact with C-based sputtered coatings for improving the friction performance. In all the shown examples, the interface between both elements of the sliding pair is thoroughly studied to understand which are the sliding mechanisms supporting the final tribological behaviour.

Visualization and control of flows in liquids directly irradiated by plasma

T. Kawasaki KL

Nishinippon Institute of Technology, Fukuoka

Understanding the interactions at the interface between plasma and liquid is essential for developing plasma life science involving liquids, such as plasma medicine and plasma agriculture. Most of the research in this field has focused on chemical reactions due to plasma–liquid interactions. This study is focusing on liquid flows caused by plasma–liquid interactions (plasma-driven liquid flows). Plasma-driven liquid flows that can be generated even without any external devices in plasma-irradiated bulk liquid have recently attracted attention as one of the important phenomena caused by physical and chemical interactions at the gas–liquid interface. Therefore, elucidating the mechanism of plasma-driven liquid flows is crucial to explain their interactions. Two types of plasma-driven liquid flows with different directions in bulk liquid have already been reported and comprehensively investigated [1, 2]. However, the relationship between the properties of the plasma jet and the two types of liquid flows still needs to be determined. Under such circumstances, this study succeeded in instant switching control between the two types of plasma-driven liquid flows by changing plasma conditions [3, 4]. No other similar studies have been found. In the presentation, detailed results will be reported.

[1] T. Kawasaki et al., Jpn. J. Appl. Phys., 59, SHHF02 (2020).

[2] T. Kawasaki et al., J. Appl. Phys., 130, 243303 (2021).

[3] T. Kawasaki et a., Jpn. J. Appl. Phys., 62, 060904 (2023).

[4] K. Shen et al., IEEE Trans. Plasma Sci., 52, 2130-2136 (2024).

Controlling Far-Field Radiation with Photoluminescent and Incandescent Metasurfaces

B. Vest KL

Laboratoire Charles Fabry, Institut d’Optique, Palaiseau

Intrinsically incoherent thermal or luminescent emitters can be coupled to metasurfaces to establish some coherence in emission and therefore to enable structuration of the emitted field. In this presentation, I will introduce the design, fabrication and experimental characterization of several light-emitting metasurfaces designed using a Kirchhoff’s law approach and demonstrating control of the polarization state and of the angular radiation pattern.

Electrohydrodynamically Driven Two-Phase Heat Transport Devices for Space and Terrestrial Applications

J. Yagoobi

KL

Worcester Polytechnic Institute, MA, USA

Electrohydrodynamic (EHD) conduction pumping of a dielectric liquid arises from the interaction of the induced electric fields and flow fields via the Coulomb force. The required free charges come from the dissociation and recombination of neutral electrolytes present in the fluid. When the external electric field exceeds a threshold, the rate of dissociation exceeds that of recombination. There is a non-equilibrium heterocharge layer that forms in the vicinity of each electrode due to ion motion caused by the Coulomb force. The attraction of the ions present within the heterocharge layers to the adjacent asymmetric electrodes of a given pair causes bulk fluid motion in the desired direction.

This presentation will fundamentally illustrate the EHD conduction pumping mechanism and its resultant transport characteristic Specifically, the heat and mass transport resulting from EHD conduction pumping of a dielectric fluid in macro-, meso-, and micro-scales in the presence and absence of phase change (liquid/vapor) will be described. The results of two-phase heat transport experiments that were conducted on board variable-gravity parabolic flights will be presented.

In addition to its potential terrestrial applications, the EHD conduction pumping technology is expected to provide technological advances that will support NASA's various missions. EHD pumps are simple in design, light weight, non-mechanical, free of vibrations and noise, and they allow for effective active control of heat transfer and mass transport. EHD pumps require minimal electric power to operate.

Shaping up to explore and exploit fluid-structure interactions of flags

K. Mulleners

KL

EPFL, Lausanne, Switzerkland

Leaves, insect wings, and fish fins are only a few examples of flexible structures found in nature that come in a myriad of different shapes and sizes, which might affect the way they interact with the surrounding flow. This idea inspired us to study how the planform shape of cantilevered flexible sheets or flags affect their flapping dynamics, critical flutter velocity, and the aerodynamic forces they experience. The shape design space of such flags is vast, and only a selected number of shapes could be tested using conventional supervised experiments. In this talk, I will first discuss results on the effect of aspect ratio and taper of flags on their flapping dynamics using conventional experiments. Then, I will present the self-exploring automated experiment using (industrial) robots that we are developing to cover and explore a larger portion of the input parameter space. Our self-exploring automated experiment can continuously and in loop fabricate flags with different planform shapes, measure their structural and aerodynamic response, analyse the fluid-structure interactions, and select new flag shapes to test. To optimise and guide the selection of the new flag shapes, we use a combination of data-science tools to maximise the information gain with every new experiment and drive exploration to uncover new flapping regimes.

Hydrogen adsorption, surface chemistry and storage in 2D materials

R. Larciprete

KL

CNR-ISC, Rome, Italy

The functionalization of 2D materials with H atoms represents an efficient means for tuning their fundamental properties: in fact, hydrogen chemisorption, besides changing their chemical composition, can be an effective way to modify their electronic and structural properties. Furthermore, the characteristic properties of 2D materials, such as wide surface area, layered morphology, excellent electrical properties and high thermal stability, make them an attractive alternative to other solid-state materials for hydrogen storage. In this study we used x-ray photoelectron spectroscopy (XPS) and absorption spectroscopy (XAS), thermal programmed desorption (TPD) and scanning tunneling microscopy (STM) combined with density functional theory (DFT) calculations to investigate the interaction of H atoms with different classes of 2D materials (graphene, MoS2, MXenes,. . .). For these systems we could determine the configuration of the hydrogenated interface, calculate the energetics for hydrogen chemisorption and diffusion, establish adsorption and storage efficiency, and follow surface reactions and H2 desorption as a function of the temperature. The results obtained, in addition to deepening the knowledge of the fundamental processes governing material hydrogenation, represent a valuable contribution to the development of innovative hydrogen technologies based on 2D materials.

Fire Science and Fire Engineering, the Difference between Knowledge and Professional Competency

J. Torero

KL

University College London, United Kingdom

There are very few programmes in Fire Engineering globally and most people practising Fire Engineering are self-educated. Furthermore, there are no accreditation processes that define what Fire Engineering is. Many scientists have developed expertise in fire science and many have developed educational programmes in Fire Engineering. Nevertheless, the question remains, are we educating competent fire engineers? This presentation will address the issue of Fire Engineering competency in the context of fire science knowledge.

List of Abstracts – PhD presentations

Investigation of the physical and chemical properties of plasma-liquid interactions at atmospheric pressure and their influence on reactive species generation

L. Alomari[1,2] , *T. Orrière*[1] , *B. Teychene*[2] , *E. Moreau*[1]

IT

[1] Institut Pprime, Poitiers
[2] IC2MP, Poitiers

Over the past decade, the interaction between non-equilibrium plasmas and liquids has gained increasing significance particularly in applications such as water treatment, the main focus of our project. Plasma is a rich source of Reactive Nitrogen and Oxygen Species (RONS) that can oxidize and eliminate a large group of micropollutants in water. However, ensuring optimal plasma water treatment efficiency relies on two key factors: 1) the production of RONS and 2) their transport through the plasma/liquid interface and within the liquid itself. The production of RONS depends significantly on the discharge type and regime, whereas their motion is primarily governed by the plasma-induced liquid flow (in the absence of external forces). Therefore, our project consists to study the electrical, chemical and flow characteristics of different discharge types, to gain deeper insights into the mechanisms enhancing RONS production, and to identify the main driving forces of the liquid flow.

Three types of discharge were investigated: direct current discharge (DC), alternating current dielectric barrier discharge (AC-DBD), and nanosecond pulsed DBD (NP-DBD). All three discharge are tested on the same needle-to-liquid configuration. Among the three discharge types studied, the AC-DBD showed the better compromise between stability, energy consumption and reactive species generation. Flow measurements inside the liquid were thus performed on the AC-DBD using Particle Image Velocimetry (PIV). The formation of two vortices is observed on either side of the discharge axis and a significant velocity gradient between the plasma/liquid interface and the bulk liquid. A notable similarity exists between the higher velocity zones and the regions with elevated reactive species concentration, highlighting the potential to optimize the generation of reactive species and, consequently, the efficiency of plasma discharge, simply by controlling the transport phenomena. To achieve such control, several parameters including frequency, voltage, surface tension, conductivity and discharge duration were examined independently. This will help select input parameters optimizing the efficiency of plasma water treatment.

Conservation of Earthen Heritage Collections: Validation of TEOS Treatments on Mesopotamian Tablets

Jeanne Maucourt[1,2] , ***Fabien Hubert***[1] , ***Baptiste Dazas***[1] , ***Ann Bourgès***[2]

IT

[1] IC2MP, Poitiers
[2] C2RMF, Paris

Mesopotamian cuneiform tablets, a raw earth objects embedding humanity's earliest writings, are vulnerable to degradation due to salts inherently present in the original soil used for their fabrication. These salts and their efflorescence cause structural damage, leading to text loss. Since 1996, the Louvre has used tetraethyl orthosilicate (TEOS) as a consolidant, adapting a method from stone conservation. While this irreversible treatment has shown promising results, the long-term effectiveness and potential side effects of this treatment remain uncertain. Recent studies indicate that TEOS efficacy depends on the tablets' porosity and mineral composition. Characterizing the mineral/TEOS interface, as well as identifying critical factors influencing conservation outcomes, is at the heart of this project. Based on a detailed structural and mineralogical analysis of the parent material, this study will revolve around experimentally lab-made tablets, enabling an unprecedented set of experiments to ultimately ensure the long- term preservation of these invaluable artifacts.

Modelling iron particle combustion

Marcel Kuhmann[1] , ***Zakaria Bouali***[1], ***Ashwin Chinnayya***[1], ***Vincent Robin***[1]

IT

[1] Institut Pprime, Poitiers

The combustion of metal powder - and iron in particular - has desirable characteristics making it a promising contributor to a carbon-free energy mix: the potential of an energy cycle without greenhouse gas emissions, a high energy density and a more favourable risk profile than other eminent energy carriers such as hydrogen or ammonia.

Our numerical modelling work targets two different length scales: the microscale concerning single particles, and the mesoscale of a iron particle-laden reactive flow. The microscale will be the focus of the first part of the presentation. A model of the combustion process of a single particle will be presented, takeing into account the major physicochemical processes, that is the oxidation of the iron particle via O2 absorption, intra-particle phase changes, and heat exchange with the environment across the particle-gas interface. The second part of the presentation will treat the mesoscale, specifically validation analyses concerning the integration (two-way coupling) of the single particle model into a CFD solver for particle-laden reactive flows.

The numerical simulations based on the models are expected to provide important insights into the characteristics of reactive front propagation in iron particle-laden flows.

A battle against arsenic toxicity by Earth's earliest complex life forms

Anna El Khoury [1,2] , ***Andrea Somogyi*** [2], ***Abderrazak El Albani*** [1],

IT

[1] C2MP, Poitiers
[2] Synchrotron Soleil, Paris-Saclay

The emergence and evolution of life, a core question in exobiology and Earth's early biosphere can be explored through trace element analysis in ancient marine sedimentary rocks. Arsenic (As), a toxic metalloid, plays a crucial role in this context. Life has historically evolved mechanisms to expel As, linking its geochemical signature to biological activity. In the Paleoproterozoic 2.1 Ga Francevillian biota of Gabon, believed to host Earth's oldest multicellular life, post-mortem pyritization revealed an intriguing redistribution of As. High-resolution geochemical analysis constrained As sources across the Paleoproterozoic, while ICP-MS and laser ablation quantified trace element concentrations in minerals contained with the fossils and in matrix minerals. Synchrotron nano-XRF mapped As distribution within pyrite grains, and XANES determined the different valence states present. By integrating these high-resolution techniques, the study revealed trace elements tied to metabolic activity, offering insights into biogeochemical As cycling and the environmental context in which the Francevillian biota emerged. The data suggest that the Francevillian biota thrived in an ocean characterized by relatively low As concentration in seawater, compared to the period before and after, associated with the hydrothermal As enrichment. However, distinct patterns of As loading in fossil biomass, compared to pyritized concretions, indicate that the fossils countered As toxicity primarily by intracellular accumulation.

Investigating the interplay between biaxial multicracking of nanometric thin films and their magnetic properties: a nuanced separation of magnetoelastic and magnetostatic effects

H. Ben Mahmoud[1,2], ***F. Zighem***[1] , ***D. Faurie***[1], ***P.O. Renault***[2],

IT

[1] LSPM, Sorbonne Paris Nord
[2] Institut Pprime, Poitiers

The magnetoelectronic systems of tomorrow will be deformable to adapt to complex geometries. Flexible electronics have experienced rapid growth, promising numerous applications in various fields such as confined environments and flexible displays. These systems rely on polymers that are lighter and less expensive than silicon. Understanding the interactions between mechanical deformations and magnetic properties is essential : at low strains, magnetic anisotropy is key, while at high strains, it is crucial to examine microscopic damage (fragmentation, decohesion) and its impact. However, the links between thin film fragmentation and their magnetic properties, particularly under biaxial tension, are still underexplored.This thesis aimed to bridge this knowledge gap through specific instrumental developments and studies on model systems. We have investigated model flexible magnetic systems by combining several in situ techniques, enabling the application of significant mechanical deformations (up to 10%) while analyzing their magnetic properties. We designed a tensile device for the air gap of an electromagnet and set up a MOKE magnetometer. In parallel, we installed a magneto-optical Kerr effect (MOKE) magnetometer on the DiffAbs beamline at the Soleil synchrotron. The scientific questions focus on the relationships between stress distribution (before and during multissuration) and the magnetic response of these systems, as well as the underlying mechanisms.

Elaboration and characterization of thermochromic mixed valence manganites: towards a new generation of stealth surface

Arthur Tausch[1,2] , ***Simon Hurand***[1] , ***Fabien Capon***[2] , ***Jérémie Drévillon***[1] , ***Karl Joulain***[1]

IT

[1] Institut Pprime, Poitiers
[2] Institut Jean Lamour, Nancy

While infrared stealth properties of materials were extensively studied in the past years, privileged strategies are often based on active infrared signature reduction (active temperature reduction). A new generation of smart surfaces was studied based on the thermochromic behavior of thin films [1-2]. The objective of this work is to synthetize, characterize and optimize a new material previously proven to be thermochromic around room temperature: mixed valence manganites [3-4]. Deep understanding of thermal radiation in a wide wavelength range, numerical simulation of radiative properties of thin film multilayers and the use of new metaheuristic methods leads to a new description of infrared stealth around room temperature. Based on this new definition, a smart thermochromic surface was optimized to achieve low infrared detection properties by the passive modification with temperature of its radiative properties. This new material based on a Fabry-Perot cavity exhibit very low emissivity on thermal camera's observable range while increasing thermal exchanges with its environment with its temperature. In conclusion, this new generation of surface passively regulates its temperature and remains almost undetectable around room temperature.

[1] C. Napierala, M. Edely, P. Laffez, L. Sauques, Thermo-optical effect of ceramic in the infrared range, Optical Materials 11 (2009).

[2] M. Benkahoul et al., Thermochromic VO2 film deposited on Al with tunable thermal emissivity for space applications, Solar Energy Materials and Solar Cells 95 (2011).

[3] A. Boileau, F. Capon, S. Barrat, P. Laffez, J. F. Pierson; Thermochromic effect at room temperature of Sm0.5Ca0.5MnO3 thin films. J. Appl. Phys. 11 (2012).

[4] P. Laffez, M. Zaghrioui, L. Reversat and P. Ruello. Thermal emittance changes at the charge ordering transition of , Appl. Phys. Lett 93 (2008).

Thermal Ageing of a Room-Temperature Vulcanised Silicone Seal : Role of Confinement

F. Feyne [1], ***O. Smerdova*** [1], ***E. Le Bourhis*** [1], ***F. Lacroix*** [2]

IT

[1] Institut Pprime, Poitiers
[2] LaMé, Tours

Silicone elastomers are frequently used in industry for their low manufacturing cost as seals, with good mechanical properties as well as increased chemical and thermal resistance. However, the thermal ageing of silicone seals is rarely performed at temperatures lower than 100-120 °C. Research work performed during this PhD aims at studying the thermal ageing of RTV (room temperature vulcanized) elastomer seals under moderate ageing temperatures. The industrial application is designed with thin injected silicone seals and vulcanised in confined structures at room-temperature. Targeted lifespans involve developing a methodology based on accelerated ageing in a temperature range between 30°C and 70°C for 10 to 600 days. Industrial representative multi-layered samples, inside which the seal in injected, were designed and manufactured using specifically designed injection moulded for the research works. A total confinement has also been applied to monitor its impact on the ageing mechanism of the seal.The impact of thermal ageing is monitored using several mechanical and physical-chemical characterisations. The thickness of the seal inside the application is smaller than 1mm. The mechanical study performed on the surface of the seal needed a unique development of instrumented indentation method for filled elastomers behaving hyper-elastically. Measurement and analysis method takes into account the surface roughness as well as the low stiffness of the material to better detect the contact point. A good agreement was established between the elastic moduli measured by tensile tests and instrumented indentation. Dissipative cyclic mechanical behaviours reveal similar trends at both scales. The virgin material, a filled PDMS-RTV, has an homogeneous and random distribution of SiO2 and CaCO3 fillers. Moreover, the 3D network is chemically homogeneous and made of short chains without covalent bonds with fillers. A small fraction of chains is however not cross-linked to the network. The hyperelastic and dissipative mechanical behaviour was characterised through monotonic failure tensile tests, multi-steps relaxation tests, cyclic tests and instrumented indentation tests. It was found that the dissipative mechanical behaviour mainly comes from the Mullins effect. The open to air thermal ageing leads to a degradation and stiffening of the surfaces, high mass and volume loss, an embrittlement and a stiffening at the macroscopic scale. The elastic indentation moduli at the core of the samples remain constant. Infrared spectroscopy reveals a higher fraction of fillers on the sample surface. Thus, the proposed ageing mechanism is based on the evaporation of chemical species which are not cross-linked to the network. This mechanism can present several kinetics. All the characterisations were applied to the confined thermally aged samples and the results showed no remarkable evolutions of the mechanical nor physical-chemical properties on the protected surfaces. Thus, the evaporation of the chemical species noticed for the open to air ageing is blocked.

Microstructural modifications induced by He implantation in nitride-based multilayer coatings

N. Sénicourt [1], ***M.-L. David*** [1], ***F. Pailloux*** [1], ***K. Mizohata*** [2], ***K. Sarakinos*** [2], ***P. Djemia*** [3], ***G. Abadias*** [1]

IT

[1] Institut Pprime, Poitiers
[2] Department of Physics, University of Helsinki, Finland
[3] LSPM, Sorbonne Paris Nord

The development of advanced nuclear reactors drives the search for more radiation-tolerant materials. Structural materials are indeed subjected to high He fluences leading to the introduction and accumulation of point defects that can drastically modify the mechanical properties of the materials. Multilayer systems offering a high density of interfaces, thus allowing the recombination of point defects, are among the solutions considered. Previous works have mainly focused on immiscible metallic multilayer systems [1]. Recently, systems combining amorphous and crystalline materials have been shown to be a promising route. In particular, immiscible multilayers of the MeN/SiNx type (Me being a transition metal), present interesting properties: good mechanical and thermal stability and tolerance to irradiation [2,3]. In addition, they offer sharp interfaces allowing the detailed study of their interfaces. In this work we have studied the microstructural modifications induced by high fluence helium implantion of MeN/SiNx-based thin films and multilayer (Me = Zr or Ti) deposited by reactive magnetron sputtering. A comparative study of the behavior of monolithic ZrN, TiN and SiNx thin films with bilayer systems having a single interface, then with multilayer systems presenting a (bilayer) stacking period between 8 and 42 nm was carried out. The influence of grain size, porosity or crystal orientation was studied by varying the deposition conditions or the nature of the substrate (epitaxial growth). The implantation-induced modifications were analyzed by coupling transmission electron microscopy, X-ray diffraction and elastic recoil detection analysis. Finally, the morphological modifications of the systems (swelling) were determined by step height measurements using atomic force microscopy. Helium implantation leads to the formation of cavities of few nanometers in diameter in the SiNx film while only 37% of the implanted He is retained. On the contrary, no cavity is observed in MeN films even though nearly 70% of the He is trapped. These He atoms induce compressive stress in the ZrN films, while the more porous TiN thin films do not undergo any modification of their stress state. These different behaviors are attributed to the presence of He atoms in substitution or to the formation of point defect complexes in the sub-stoichiometric TiN lattice, while the formation of biaxial strain in the over-stoichiometric ZrN films can be explained by the presence of He atoms and excess N interstitials in the grain boundaries. Similar behavior is found in bilayer and multilayer systems in which cavities are observed exclusively in the SiNx sublayers. These cavities are responsible for most of the swelling, which can reach 27 nm (i.e. 10% of the layer thickness) in the case of the monolithic SiNx film. In monolithic MeN films, swelling is proportional to the density of the material. We also note for TiN films an influence of texture on swelling. For multilayer films, interface density does not seem to influence swelling. On the other hand, the quantity of He trapped in the multilayers is a function of the interface density. In particular, there is a critical period of the multilayer for which the He trapping capacity is minimal (between 8 and 20 nm).

[1] M.J Demkowicz, et al., Curr. Opin. Solid State Mater. Sci., 16, (2012), p.101-108

[2] V.V Uglov, et al., Sur. Coat. Technol. 344 (2018), p.170

[3] V.V Uglov, et al., Nucl. Instr. Meth. Phys. Res., 435 (2018), p.228

Modeling and simulation of thermo-mechanical Coupling using a gradient-based Damage and Thermal degradation approach

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During the 1990s, research efforts increasingly focused on evaluating the mechanical resistance of materials subjected to simultaneous thermal and mechanical loading, aiming to replicate realistic fire conditions. This requires a comprehensive understanding of material behavior under coupled thermo-mechanical stresses, where key interactions such as the degradation of mechanical strength play a crucial role. Accurately capturing these couplings in predictive models remains a major scientific challenge in fire resistance assessment due to the inherent complexity and scale of the phenomenon. In this context, the development of advanced modeling approaches is essential to optimize material performance, particularly their time to failure, which is strongly influenced by the interplay between thermal degradation and mechanical damage. The objective of this study is to investigate the influence of mechanical and thermal degradation mechanisms on physical phenomena such as heat transfer, thermal decomposition, and cracking. The study aims to simulate the interaction between different degradation modes and their kinetics to assess their mutual impact on the material's behavior. To achieve this, a rigorous thermodynamic approach is adopted, introducing internal variables corresponding to each physical phenomenon, as well as their gradients. This modeling approach combines two methods: on the one hand, a phase-field gradient model is employed to describe thermal degradation, which evolves according to an Arrhenius law. This method is suitable for simulating phase transition phenomena and interface motion in a non-homogeneous material. This approach introduces a degradation gradient term to characterize the interface energy between degraded and sound regions, allowing the influence of microstructural fluctuations to be considered. On the other hand, a gradient damage model based on the principle of virtual powers distinguishes the thermodynamic forces associated with the reversible process, derived from free energy, from those associated with the irreversible process, derived from the dissipation potential. This modeling choice avoids issues related to damage localization and mesh dependency. By coupling these two approaches, it becomes possible to simulate the interaction between mechanical damage and thermal degradation of the material. The results show that, on the one hand, charred regions become areas where damage and cracking are easily initiated due to the degradation of mechanical properties. On the other hand, damaged or cracked zones act as thermal barriers, delaying heat propagation. Indeed, the presence of cracks reduces thermal conductivity in these regions, thereby limiting the advancement of the thermal front.

Study of electric charge distribution at solid/liquid interfaces using an acousto-electric method

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When a solid and a liquid come into contact, physicochemical phenomena poorly understood occur, resulting in polarization of the interface to form a layer of charges in the solid and a second of opposite polarity in the liquid (the Electrical Double Layer). The work presented in this manuscript follows on from feasibility studies into the use of the PWP (Pressure Wave Propagation) method for measuring charge distributions at solid/liquid interfaces. Through numerical and experimental studies, the performance and limitations of the measurement method are highlighted. The second part of the work consists in observing the effect of the application of an external DC electric field on the charge distribution at the solid/liquid interface..

Electro-Convective Flow Study of Hydro-fluoro-ether (HFE-7100) in Electro-Hydro-Dynamic (EHD) Systems

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This thesis investigates the electro-convective flow of Hydro-fluoro-ether (HFE-7100) in Electro-Hydro-Dynamic (EHD) systems, where fluid motion is induced by an applied electric field. EHD flow control is promising but not yet fully understood due to complex interactions between electrostatic forces and fluid dynamics. The research improves numerical modeling by refining electric force calculations and compares simulations with experimental results. Particle Image Velocimetry (PIV) is used to analyze flow patterns, and different particle materials are tested for compatibility with HFE-7100. Voltage variations and current measurements help determine flow behavior and electrical regimes. The study is extended to a dissymmetrical setup to examine the influence of polarity.

One-dimensional statistical modeling of a DBD reactor

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This presentation presents an original one-dimensional statistical model designed to complement experimental data from a practical DBD reactor. The experimental setup consists of a plasma-assisted reactor with gas injection composed solely of CH4 and O2. The numerical procedure uses electrical measurements to provide a realistic description of the power consumption and the current flowing through the gas, in a complex scenario where approximately one hundred current peaks are measured per electrical half-period. A plasma kinetic model is then used to analyse the chemistry and characteristic times of both isolated discharges and a representative train of discharges occurring within the reactor. These times are used to optimise the computational costs and to select the most appropriate kinetic schemes for the gas phase, whether in a plasma or quasi-thermodynamic equilibrium state. This approach also allows the separation of fast transformations (plasma) occurring at constant volume, from slower transformations occurring at constant pressure. The statistical approach, based on a Monte Carlo method, clearly identifies the assumptions required to reduce the real complexity of the DBD reactor to a 1D flow model. The combination of chromatographic measurements at the reactor outlet and numerical simulations provides the heterogeneity factor of the discharges, which is identified as a key parameter in the model. Although the flow can be considered stationary on average, the obtained value reveals a highly heterogeneous spatial distribution of the discharges within the reactor. Thus, the numerical results suggest that the gases passing through the reactor are rarely in a plasma state.

Simulation of wall damage induced by a bubble collapse using a strong coupling partitioned method.

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A strong fluid-structure coupling strategy, based on a partitioned approach, has been developed to analyse wall damages induced by a bubble collapse. The in-house multiphase code SCB (Finite Volume Method), the open-source solver FEniCS (Finite Element Method), and the coupling library preCICE are considered for this study. The originality of our approach lies in the use of a penalization approach to model the deformable interface. Two parametric studies showed that the deepest pits form after the collapse of a bubble initially very close to a material with a low yield strength. Weak coupling overestimates impact pressure (20 %) and material damage (50 %).

Self-organized chains of plasmonic nanoparticles in dielectric films: a reusable platform for SERS applications.

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This thesis develops durable, reusable Surface-Enhanced Raman Spectroscopy (SERS) sensors based on self-organized chains of Ag nanoparticles (NPs) protected by a thin dielectric film (some nm thickness). The sensors were fabricated via oblique-angle ion beam sputtering deposition of Ag on a nanorippled Al_xO_y surface, followed by thin film dielectric deposition (Al_xO_y or SiO_x), creating 2D large-area (some cm^2) arrays of Ag NPs with a high hot spots density (> 10^{11} cm^{-2}).

Transmission electron microscopy and extinction spectrophotometry showed that the anisotropic NPs' organization produces a dichroic response, characterized by two plasmonic resonances dependent on the incident field polarization. SERS response of 2,2'-bipyridine, a non-resonant molecule in the visible range, was studied as a function of excitation wavelength and laser polarization. This study enabled to identify two contributions: a continuous background from Ag NPs' response to the incident field and Raman peaks associated with molecule-local field interactions at the interface.

Temporal stability studies showed that Al_xO_y-capped substrates have maintained the plasmonic response of Ag NPs for several months while allowing cleanability and reusability. In contrast, SiO_x-capped substrates were limited to single use but still provided a basis for future improvements, such as surface functionalization.

Surface tailoring and characterization techniques for enhanced understanding and control of properties

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The ability to tailor surface properties is crucial for optimizing material performance across various applications, from structural components to hydrogen storage systems. Ultrasonic shot peening (USP) and nitriding are two complementary surface modification techniques that enhance mechanical properties and/or hydrogen storage behavior. USP induces surface nanocrystallization, strain hardening, compressive residual stresses, and hydrogen diffusion characteristics, while nitriding modifies surface chemistry to improve hardness, wear resistance. This talk will also present advanced characterization techniques, including scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), high-resolution EBSD (HR-EBSD), and electron channeling contrast imaging (ECCI), to investigate the micro-/nano-structural evolution and property enhancements induced by these treatments. Additionally, fundamental questions regarding the correlation between surface and bulk characterizations will be explored. The findings contribute to optimizing material design for high-performance applications in aerospace, automotive, and hydrogen storage technologies.

Damage mechanism by buckling: Influence of plasticity and interfacial delamination

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Thin films and coatings used in a wide range of technological applications are often industrially produced by physical vapor sputtering techniques, which may lead to very high levels of internal stresses in compression. These high stresses trigger damage mechanisms, such as buckling-driven delamination. Preventing buckling is hence a major issue for industrial applications of coatings to ensure their mechanical stability. Various buckling morphologies have been commonly observed, such as straight-sided buckles and circular blisters. Those buckle morphologies often evolve into more complex buckles by a combined effect of secondary buckling and crack front propagation, giving rise to other usual structures such as telephone cords or varicose buckles. In this work, we report on straight-sided buckles and circular blisters experimentally observed by optical and atomic force microscopy on gold ductile thin films deposited by physical vapor deposition on silicon wafers. It is shown that, whatever the buckle dimensions, their maximum deflections are higher than those expected by the elastic theory (based on the Föppl-Von Karman plate equations). By using finite element method simulations, it is shown that taking into account plastic deformations in the film well explains the buckling structures experimentally observed. In this way, the elastic moduli of the thin film, as well as the full set of parameters of the plasticity hardening law, have been identified using nanoindentation tests coupled with finite element solutions. The numerical results are presented, discussed, and compared to the experimental observations, shedding some light on the genesis of those structures, highlighting in particular the importance of taking the film loading history (buildup of stress inside the film during deposition) into account. In addition, we investigate the growth of circular blisters from initial debonding defects. For elastic thin films, this growth is known to be unstable, leading to non-axisymmetric shapes (flower-like buckles). This result is confirmed by our FEM calculations, coupling elastic buckling of a plate with a cohesive zone model allowing to take into account the crack propagation at the film/substrate interface. We show that plastic deformation plays a key role in stabilizing the circular shape of the blisters during their growth. This explains why circular buckles of very large dimensions can be experimentally observed on gold (ductile) films.

Structural and property engineering of 2D titanium carbides (MXene) thin films using ion irradiation

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MXenes are a large family of two-dimensional transition metal carbides and/or nitrides combining hydrophilicity with metallic conductivity, thereby leading to a plethora of potential applications. In this presentation we will illustrate how medium energy range ion irradiation, a controllable and flexible approach, can be used for the structural engineering of MXenes with particular focus on $Ti_3C_2T_z$ thin films. By adjusting the fluence of a 180 kV He^+ ion beam, we evidence the gradual modification of the different structural elements of typical MXene multi layers, inducing well-defined impacts on properties. Low fluences allow modifying the interlayer spacing, inhibiting the long-term rehydration capacity of the thin films with expected major benefits on MXene aging issues. In addition to this, irradiation allows affecting the layers functionalization with major impact on the normalized optical transmission profile, suppressing the absorption valley at IR-visible limit and expanding their transparency in the UV. These effects, combined with improved electrical contact between the $Ti_3C_2T_z$ layers, can be interesting for different applications including transparent conductive electrodes. Finally, higher fluence irradiations induce preferential sputtering of titanium atoms. Transition metal vacancies being known to be highly relevant to deeply modify properties beyond those investigated here, these results show the large benefits of ion irradiation for MXene design.

New nanostructured Cu-Ag for application in severe environment (high stress and high strain rate)

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The objectif of this work is to characterize the local mechanical properties of nanostructured Cu-Ag nanocomposite wires using nano-indentation technique, and to assess the relationships between these local mechanical properties and microstructure features. Cu-Ag conductor wires, developed for applications in intense magnetic fields, are produced by powder metallurgy and severe plastic deformation. A mixture of spherical copper powder (diameter 0.5-1 μm) and silver nanowires (diameter 200 nm, length 30 μm) is consolidated via spark plasma sintering (SPS) into cylindrical shapes. These cylinders are then cold-drawn into fine wires. Wires with different silver contents (1 % and 5 %) and diameters (1 mm and 0.5 mm) were studied. Nanoindentation allowed mechanical characterization on several scales: on a mesoscopic scale to characterize composite properties, but also on a submicrometric scale, in particular with hardness mapping, to investigate the role of silver microchannels and Cu-Ag interfaces. The various microstructures were analyzed by transmission electron microscopy to characterize copper nanograins and silver microchannels (STEM-EDS), as well as by scanning electron microscopy (SEM) and electron backscatter diffraction (EBSD). Finally, the tomographic atom probe (TAP) technique was employed to characterize silver diffusion in copper, and to clarify the combined effects of work hardening and silver diffusion on the evolution of copper matrix properties.