

“Nanostructuring the surface of polymer-based composite thin films for the enhancement of their magnetic-electric properties”

A/ Description of the project and objectives

1/ Composite polymer based materials and device: a promise land for new multifunctional technology

The realization of a device with simultaneous strong electric and magnetic order at room temperature would be a milestone for modern electronics and multifunctional materials. These systems offer potential for new generations of sensors, filter, and field-tuneable dielectric devices [1-2]. In this framework, the poly(vinylidene fluoride) (PVDF) is one of the most challenging and interesting organic materials for the development of advanced applications due to its high dielectric constant, piezo-, pyro-, and ferroelectric effects [3]. Despite all the recent advancements of PVDF-based materials, and more in general of hybrid systems, challenges remain before the commercial adoption of these latter [4]. In fact, although the promise of a large magneto-electric coefficient in nanocomposites based on organic ferroelectric phase coupled to magnetostrictive inorganic one, experimental investigations for a number of different configurations have still not yielded to values approaching those predicted by continuum mechanics, DFT (Density Functional Theory), and ab-initio calculations [5-7]. The complete understanding of the physical interaction between the magneto-elastic stresses and elasto-electric fields, which occurs in the composites with multi-dimensional connectivity, has not been reached. Despite all the possibilities offered by the numerous configurations artificially obtainable by coupling the organic ferroelectric phase and the inorganic magnetostrictive one, the lack of this understanding has limited the ability to achieve the theoretical response of the material by controlling the local electro-magnetic couplings, via coherent elastic interactions between phases. On the other hand, the emergence of portable, wearable, and implantable electronic devices still put the use of ferroelectric polymers as highly promising new systems for this purpose, without mentioning their potential use in non-volatile memory technology, which is currently one of the most essential technologies in the mobile industry.

One of the major advantages of using ferroelectric polymer-based composites in future devices is the solution compatibility of the polymer and, thus, the easy and simple elaboration process it offers for deposition of uniform thin films [8]. Successful development of ferroelectric polymer-based devices, therefore, depends on the effective fabrication of polar ferroelectric crystalline structures. A number of papers discuss the crystallization and the polymorphic changes of PVDF films prepared by different elaboration technics [9]. Most of these papers focus on post treatment methods (including mechanical stretching, high compression, rate of cooling and heating, and poling) [3,10] in order to achieve polar β structure in tens of μm thick films, which are rarely applicable in memory devices because of their very high operating voltage of more than 100 V. It is also important to underline that poling is now commonly needed as an additional step to polarize the polymers and fluoropolymers (*i.e.* to maximize the polar β structure and to orient it according to the electric field). However, this step is undesirable because it requires high temperatures and high electric fields. Methods to produce suitable polarized polymer-based materials for applications without post-poling are extremely interesting. The ability to fabricate composite devices in a shorter number of fabrication steps, without post-treatment and with less energy input is expected to be a key contribution in driving their

commercialization and further increase the prospects of sustainable energy methods. One exiting developing area in this framework is the incorporation of additives into piezoelectric polymers. Preferential reorganization of the crystalline phases of the polymer into the polar β phase was proposed as the standard mechanism of increasing the electromechanical conversion without post-treatment. Therefore, one needs to find an easy way to fabricate polar ferroelectric PVDF thin films of less than 200 nm thickness that require a reasonably low operating voltage of approximately 10 V and does not require high energy post-treatment and working point.

Previous studies, including ours [11], showed possibilities of maximizing the amount of β phase in composite thin films based on PVDF (thickness lower than 100 nm) but also put in evidence the on-going presence of the non-piezoelectric α phase melted with the predominant β one. The α phase is still present in the composite films although the inclusion of magnetostrictive nanoparticles is supposed to enhance the amount of the piezoelectric phase. In the case of PVDF copolymers with TrFE, it was shown that the delicate configuration balance provided by the addition of one more fluorine atom to the backbone always enhance the polar ferroelectric β structure [12]. Thus, the use of P(VDF-TrFE) copolymer, with TrFE composition ranging from 20% to 30%, has been pointed out as one possible way to overcome the crystallization of non-polar phases although showing a Curie temperature (ca. 100 °C) which does not exist for pure PVDF. Another possible way, which is also an important requirement for manufacturing polymeric memory devices, is to micro- and nano-pattern the PVDF thin films. Recent papers [12-16] showed that confinement of PVDF structures can be selective for polar ferroelectric micro- and nano-domains and, thus, enhances the piezoelectric properties of the polymer-based nanostructures. The capability of micro-/nanopatterning a large surface of the polymer-based composite thin film is mandatory to ensure high-density integration of the multifunctional “cells” per unit area and, thus, open the way to a new multifunctional nanotechnology. The selective etching of material using a patterned mask is common in complementary metal oxide semiconductor (CMOS) based memory fabrication. However, under harsh patterning conditions ferroelectric polymers are significantly damaged and alter their intrinsic properties, which suggest that a new non-destructive patterning technique should be applied. Soft lithography is one possible alternative. Previous studies, including ours [11,15], still do not provide a practical patterning technique that produces isolated polar ferroelectric micro- or nano-domains of PVDF on a large surface area. To the best of our knowledge, previous work did succeed in producing mainly micro-patterning where undesired (not well-lithographed) regions of polymer appeared in not well-controlled patterned areas alternating γ/α or α/β phases. In one of these previous works, an example of downscaling of the polymeric nanostructures and their confinement in columnar mesopores succeed in inducing their crystallization into the desired ferroelectric β -phase. A clear piezoelectric behaviour of PVDF was obtained, despite the absence of any pre-poling, mechanical stretching, or other conventional strategies, only by spatial confinement of very thin nanowires 10 nm of diameter and up to 60 μ m in length. Nevertheless, in this example, PVDF and P(VDF-TrFE) nanowires are tangled in complex agglomerates, which are not easy to post-organize in well-controlled arrays and thus in useful devices. Thus, challenges remain on how to achieve higher spatial resolution and better control over micro- and nanostructures (degree of order and desirable orientation), as well as how to scale them down properly.

2/ Coupled functionalities need peculiar characterization

In the framework of developing composite nanostructures presenting at the same time optimized ferroelectric and ferromagnetic order at room temperature as well as their cross-coupling, previous works have put in evidence a tremendous need to develop a suitable characterization method for in situ polarization measurements (electric and magnetic one). One major problem, pointed out by the literature, is to identify and quantify the content of the polar phase inside the continuous films and/or the nanostructures based on them. The quantitative measurement of the intrinsic electric polarization, as well as of the dielectric and piezoelectric coefficients, is still challenging the community, especially on the composite systems where the magnetic inclusions compromise the detection of the signal coming from the conventional techniques used for the purpose. In addition, the current spectroscopic techniques used to fingerprint the phases of the PVDF and related polymers, show clear limitations [17-21]. The FTIR, commonly used in the characterization of these polymers, often results in complex spectra with overlapping peaks for the β and γ phases. Previous results

(including ours) have also shown the limitation of the X-Ray standard diffraction analysis in the case of very thin films in which the volume of the probed material limits the signal/noise ratio and, thus, the phase identification [11 and references therein]. On the other hand, Raman spectroscopy and Grazing Incidence X-Ray Diffraction [15] can lead to characteristic peaks for the various phases with higher resolution respectively compared to FTIR and classical XRD.

Furthermore, current methods for measuring the net polarization vector are limited in their scope. The Polarization measurement (P-E hysteresis) uses an electric field that has the parasitic effect of poling the material, which only provides the maximum polarization that can be obtained in the polymer. Characterizing the net polarization within the sample without affecting it will provide insight into the intrinsic polarization response (dipolar vector) of the polymers. This is mandatory in order to control and study the working point of future electronics based on these composites. Besides, the optimization of crystallinity and polarization using additives (nanoparticles) has not been systematically explored to date. These factors influence the electrical output from electromechanical conversion in polymer-based device. Hence, it will be critical to investigate the influence and the underlying mechanism of nano-inclusions and other additives on the enhancement of these properties and their coupling. It has been shown that static magnetic measurements of the magnetization versus the application of a magnetic field (M-H) are a non-destructive way to analyse the behaviour of the magnetic additives inside the polymer film although these measurements can be affected by the diamagnetic behaviour of the polymer. Finally, previous results, including ours [14,22-23] have shown the potential of the local near field microscopy techniques. Imaging and dynamics of the piezoelectric response at the nanoscale is perhaps the most direct means of probing the electric and magnetic local polarization in thin films and nanostructures. The piezoresponse force microscopy (PFM) and switching spectroscopy PFM as well as the magnetic force microscopy (MFM) have shown huge advantages to image the ferroic properties, domain structure, and polarization switching of ultrathin films based on PVDF at the nanoscale. They open the way to a systematic study of the effective ability of the local transmission of the electric stress to the nano-inclusions in future devices based on PVDF and copolymers composite materials.

3/ Future Challenges

To summarize the rising key questions from the fast-expanding literature on the composite based-devices, following points should be addressed:

- Is it **more appropriate** for the development of magneto-electric future devices to use **P(VDF-TrFE) copolymer** instead of optimizing PVDF one? As stressed out in paragraph 1 in the first case the polar β phase is directly obtained but the problem of a **Curie temperature** has to be addressed;
- Although previous results have shown great **potential of the nanostructuring** process over the piezoelectric behaviour of PVDF **in the absence of any pre-poling, mechanical stretching, or other conventional strategies** thanks only to spatial confinement of very thin unidimensional nanostructures [15], in the case of P(VDF-TrFE) copolymer the question of **how to enhance the polarization orientation of the β phase** through a simple process as well as how the **nanostructuring confinement may affect the β -phase orientation, domain size and polarization values** is still a key point;
- **How to enhance the fluoropolymer influence on the future device functionalities efficiency?** The good control of the inorganic/organic interphase (geometry and functionalization) as well as its confinement has to be deeply studied in the perspective of enhancing the magneto-electric coupling. Multi-parametric characterization strongly linked to the study of the polar β phase and its elastic coupling to the magnetic inclusions is still a major lack in literature;
- To conclude, the use of non-destructive techniques such as confocal Raman microscopy and near field microscopy ones (PFM, MFM) correlated with the structural and chemical

characterizations should be better exploited to provide valuable information resolved at the nanoscale.

We are willing to answer to most of them during this 3-years PhD project.

4/ PhD Project Objectives

In this context, it clearly appears that a research on composite thin films and confined nanostructures based on them should be done within the framework of varied areas of expertise. A multidisciplinary research starting from the elaboration and the nanostructuring up to the full characterization of the physical properties can open the way to fulfil the lack of understanding of the various aspects of this complex field. We are willing to put together the currently segmented and independent researchers exploring the easy-to-transfer processing techniques (spin coating and dip coating) of very thin films with materials scientists and engineers leading to innovative nanosphere lithography (NSPL). This will be done in tight connection with physicists focusing on the enhancement of the functional properties at room temperature. Our project, as well as the PhD students, will benefit from the several skills and experimental techniques available within the scientific consortium described in the following paragraphs.

The main objectives of this project are:

- (a) **To elaborate and characterize the optimized composite thin films resulting from Co/Fe-based inorganic nano-particles (nano-spheres and nano-rods) mixed to the organic PVDF or copolymers P(VDF-TrFE).** This will be possible thanks to a federative collaboration between the Labex SEAM laboratories: LSPM and C(PN)² (the clean room facility at USPN) as well as with the co-direction of ENSAM laboratory. First encouraging results have already been obtained during the collaboration started between these laboratories for the master fellowship in 2017 of Nguyen Ngoc Anh (see A. N. Nguyen CV and ref. 11 and 23). During this fellowship, very thin films (about 90 nm thin) have been elaborated with a controlled roughness quality and dispersion of nano-inclusions (the work was sponsored in the framework of Labex SEAM structuring project – NanoSmArc). The quality of the inclusion-matrix interfaces should be deeply investigated as well as the influence of the interface on the amount of polar β and γ phases without mentioning the coupled piezoelectric / ferromagnetic properties of the composite material. An important point in this elaboration optimization concerns the nano-inclusions that will be synthesized by the MINOS Team at LSPM. Pr. F. Schoenstein has already developed polyol synthesis optimized recipes in the last 10 years for different magnetostrictive nano-objects (Cobalt Ferrite nanoparticles, Cobalt/Nickel Nanowires, Iron Oxides nanorods)[24]. These systems will be available for the PhD students during the optimization steps of the composite thin films and nanostructures and will not need a synthesis optimization.
- (b) **To study the impact of the nano-inclusions on the crystalline morphology of PVDF and P(VDF-TrFE) thin films.** In this project, in addition to study of pure PVDF, we also propose to study a PVDF copolymer, which possesses a better electrical response than pure PVDF, since it spontaneously crystallizes in the β form. The use of P(VDF-TrFE) copolymers instead of the pure PVDF polymer gives access to easier processing conditions to promote the ferroelectric β phase content within the thin film. Indeed, the TrFE moieties along the PVDF polymer chain allow the stability of the β phase at room temperature without further processing step (inducing chain alignment). To induce a **high coupling between the nanoparticles and the organic matrix, the crystallization must be oriented so that the mechanical deformation ideally solicits the nanoparticles.** The surface chemistry of the nanoparticles must be adapted to orient the chains before initiating an epitaxial crystallization and, thus promoting oriented crystals. The chemical composition of the PVDF polymer (pure or copolymer), the solvent used, the processing techniques (dip-coating or spin-coating), the processing parameters (leading to different thickness, for instance), the annealing temperature as well as the chemical nature of the substrate will be potential leads to study their influence on the composite final properties. Thus this part of the project will allow selecting the optimized configurations for the nano-architectures to be used for the following step of nanostructuring.
- (c) **Nano-structuring of large surface area of thin films by innovative NanoSphere PhotoLithography (NSPL) technique:** In order to keep in mind the future electromagnetic-based applications, a nano-patterning of the optimized hybrid structures obtained will be achieved by a **specific nano-photo-**

lithography [25] based technique (see Figure 1) that can **overcome chemical processing limits** described in paragraph 1 and 2. This optical technique has been developed at C(PN)² and optimized on organic-based films [24]. Currently, the NSPL is developed in a quasi-artisanal way (see Figure 1): a mask of nanospheres is placed on the sample and a quartz plate block it under the mask aligner. An optical density filter is placed on this system to reduce the power of the light intensity. First successful results have been obtained on organic hetero-structures for optical purpose [25] that can be consider promising for nanostructuring organic PVDF polymer and copolymer. To **scale down to the nanometer size** the possible patterns and to make them reproducible on large surface area, we will develop during the PhD a better control of the quartz mask by using the silica nanospheres proposed before [24] and by using not only UV radiation for the resist (see Figure 1) but going down to deep UVs (financial cost demanded to the NAP MOSAIC federative institution of USPN – SOPHieS project – coord. J. Solard). We will obviously need to adapt this NSPL, which is so far developed for a lift-off process, to nanostructure PVDF and polymers in general. It is well known that the lift-off is not feasible in this case (non-compatibility of materials and solvents used during the processes), thus it will be necessary to **combine the NSPL technique with plasma etching** to transfer the resist pattern to the polymer layer. The PhD student will systematically study and analyse all the issues that this combination of techniques may bring up, in order to further reduce the size of the nanostructures obtained up to now by NSPL and for the nanostructuring of large surfaces.

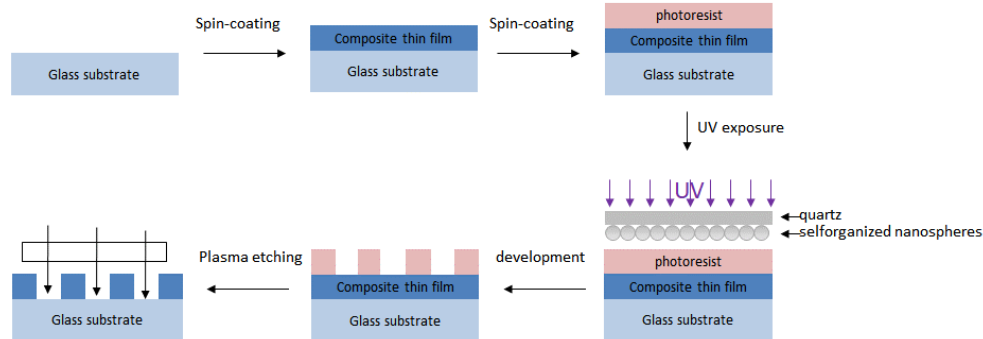


Figure 1: Fabrication process: Nanosphere Photolithography combined with plasma etching (LPL-C(PN)²).

- (d) **Combining together the use of standard XRD and IR spectroscopy with Raman one and non-destructive local microscopy in order to fully understand the effect of the hybrid interphase as well as of the nano-confinement on the multifunctionalities of the PVDF and copolymer based composite systems.** It is obvious that this work to optimize nanostructuring of single and two-phase material will be associated with a study of the physical (electromagnetic) and structural properties of the hybrid, polymer and / or inorganic material as a function of the change in morphology and distribution of nanostructures. This will be possible in the context of collaborations between the two axes of the Labex SEAM involved in the PhD project as well as with the ENSAM laboratory, via the easy access to several characterizations techniques like AFM, IR, Raman spectroscopy, X-ray diffraction, magnetometry, and PFM (ENSAM/LSPM). The use of PVDF polymers and copolymers to access an organic electrical response is well known in the literature. However, the influence of the inorganic nano-inclusions on their crystallization behavior appears to be lacking. The crystalline polar β phase is of real interest to promote the ferroelectric properties of the thin films. These crystals must be oriented not only compared to the surface of the nanoparticle but also macroscopically in the confined domain to exert the maximum response. Adding these nanoparticles would possibly change the crystalline structure of the organic matrix, thus changing the final properties of the composites. It is thus mandatory to analyze the microstructures induced during the film processing. A fine characterization of this microstructure at the nanoparticle/PVDF interface, which strongly depends on the processing conditions and on the chemical nature of the nanoparticle surface, must be carried out through techniques such as AFM or PFM in order to relate the microstructural morphology to the final properties of the composite (ENSAM/LSPM). In addition, the macroscopic orientation of these confined crystals should also be oriented in the direction of the (magnetic or electric) fields. GI-SAXS

and GI-WAXS (Grazing Incidence Wide or Small Angle X-Ray Scattering) are ideal techniques to probe the lamellae orientation in the confining domains (ENSAM).

Besides all these techniques, the PhD will profit of more specific PFM possibilities thanks to an international collaboration between Ing. A. Gómez and Dr. S. Mercone. They have been developing through European NFFA project a tight collaboration since 2016 in order to optimize Direct Piezoelectric Force Microscopy (DPFM) [26], Piezoresponse Force Microscopy (PFM) [27] as well as Magnetic Force Microscopy (MFM) adaptable to hybrid nanostructures by using a specialized Zurich Instruments Lock-In Amplifier HF2LI. This equipment is property of LPSM and currently at SPM LAB in ICMAB as part of a collaborative project (in the frame of *ArchiMEdes* IDEX project –coord. S. Mercone). The lock-in will be used to carry out Frequency Modulation (FM) possibilities of MFM and the implementation of an improvement of DPFM (PCT Patent “PCT/ES2017/070581” property of ICMAB CSIC) in which modulation signal will be used in order to provide a modulation of the acquired signal. This possibility will vastly expand the use of Atomic Force Microscopes and standard PFM accessible at ENSAM and previously described. As explained in the introduction, new development of local techniques to carry out measurements of the *in-situ* application of a magnetic field (H) and electric one (E), in which dynamic and static piezoelectric response will allow the full reconstruction of the piezoelectric performances of the polymer nanostructures as function of the magnetic nano-magnet organization and as well of the geometry of the nanostructuring “cells”.

5/ Expected Results

During the 3 years of fellowship, we expect:

- To elaborate optimized composite thin films with a small number of easy-to-control fabrication steps and without post-treatment. These films will be obtained by including ferromagnetic/magnetostrictive Fe and Co based nano-particles into PVDF and/or P(VDF-TrFE) copolymers organic material. A proper choice between the PVDF and the copolymer will be possible on the basis of our study in order to select the polymer which is better suited to enhance the polarization properties of the composite film;
- We will identify the key parameters (geometry, size and shape of the composite nanostructures and the hybrid interface) that are willing to enhance the orientation of the polar β phase of the organic phase as well as the magnetoelectric properties of the final nanostructured composite film;
- To develop an easy-to-transfer clean room nanostructuring process based on the NSPL-adapted to composite thin films which will be able to well-control the geometry and the distribution of the nanostructures on a large area;
- To use a considerable number of non-destructive techniques (*i.e.* spectroscopies and local microscopies) to experimentally evidence the ME coupling in the elaborated optimized composite nanostructures and to correlate them with the crystallinity and nanostructuring characteristics. All those techniques will be available to the student inside the rich consortium hosting the PhD project.
- Finally, the comparison between the continuous film and the corresponding nanostructures will allow a clear identification of the nanoconfinement effect on the physical properties and their coupling, which is a mandatory study to fully understand the effective ability of the local transmission of the electric stress to the nano-inclusions. This study will open the way for the use of our results in future composite device based on PVDF and VDF-copolymers including magnetic nano-particles.

A rough estimation for the organization in time of the PhD project is given in the following table.

Time	Laboratory	Activities
18 months	C(PN) ²	Film and Nanostructures Elaboration

12 months	LSPM/ENSAM	Inorganic and Organic chemical and physical characterization and study
3 months	SPM/ICMAB-CSIC	DPFM/MFM
3 months	LSPM	PhD thesis writing

B/ Description of Involved teams

1/ LSPM-Axe MINOS: Dr. S. Mercone and Pr. F. Schoenstein

MINOS is the team of LSPM lab involving 10 researchers working on the preparation and study of functional nano-materials mainly focusing on optical or magnetic applications. The team has different chemical reactors for standard polyol synthesis elaboration and for polyol synthesis supplied by an external magnetic field. It also has a glove-box with a gas flux control (O₂, H₂O, N₂), high temperature oven for thermo-treatments (700-1500°C), and also for flux-controlled Hydrogen reduction treatment at low temperature, a spectroscopy platform including FTIR, UV-Visible-NIR, and Raman technics as well as all the standard equipment for material characterization such as XRD, BET, TGA, SEM and TEM. Besides, it has a privileged access to a regional SPS platform (CNRS, Thias) and to a SQUID (MPMS3) magnetometer (ESPCI-Paris). MINOS has also participated, thanks to Dr. S. Mercone, to the developing of a vectorial magnetometer facility inside the Labex SEAM consortium. This is in collaboration with Prof. S. Ammar-Merah team at ITODYS and started in 2014 in the frame of a structuring project (NanoSmArc) supported by the Labex SEAM.

2/ ENSAM TEAM (PIMM laboratory):

The Polymer & Composites group aims at understanding the relationships existing between **processes, microstructure, properties and durability** of amorphous and semicrystalline thermoplastics, networks (elastomers and thermosets) and multiphased materials (composites, micro- and nanofilled materials, polymer blends...) using a multiscale approach (investigation at molecular, macromolecular, macroscopic scale). Those research axis lead to one peculiar topic, which is to understand the role of confinement and interphases in multiphase systems. This topic directly relates to this Ph.D. project. In addition, the existing industrial chair between Arkema and the PIMM favors the access to adapted polymers (PVDF and derivatives), which might be useful to this project. For instance, the ANR-funded project FETA (2019-2022, ANR-PRCE) is also related to the understanding of PVDF-based relaxor ferroelectric terpolymers to be used as actuators. Finally, the PIMM laboratory gives access to classical polymer characterization techniques, such as Differential Scanning Calorimetry, FT Infrared spectroscopy, heating stage AFM/PFM microscopy, heating stage optical microscopy, Scanning Electronic Microscopy, Dynamic Mechanical Analysis, Small and Wide Angle X-Ray Scattering (SAXS-WAXS), Synchrotron experiments (GISAXS-GIWAXS)...

3/ LPL-C(PN)²: Eng. J. SOLARD

C(PN)² (Centrale de Proximité en Nanotechnologies de Paris Nord) is the cleanroom facility of University Sorbonne Paris North for micro and nanotechnologies research. This cleanroom is open to academic and industrial laboratories in the field of material science, nanophotonics and nanotechnologies. It is equipped with a bunch of process and measurement tools providing a broad platform for the development and testing of new concepts in micro and nanotechnologies. The generic processing technologies are thin film deposition, lithography, etching and characterization. One of the specific technique developed in C(PN)² is the “nanosphere photolithography” (NSPL) which consist of a photolithography process with a mask constituted with self-organised nano or microspheres (in material such as SiO₂ or TiO₂ or plastics as Pe or Ps) . This technique provides a 2D micro- or nano-structured lattice into resist that can be transferred to thin films.

C/ Tutoring Team of the PhD project

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D/ Short Curriculum Vitae of Dr. Silvana MERCONE

Silvana MERCONE, is an Associate Professor at LSPM (CNRS UPR3407), USPN since 2014 (HDR - “*Multi-phased nanostructures: ferroic orders and their coupling*”). She obtained the “*Italian Laurea*” in Solid State Physics at University of Rome “La Sapienza” in 2000 and her PhD sponsored by Marie Curie fellowship (EC) in Material Science in 2003 at the University of Caen (Normandy, France) - Laboratory CRISMAT. She became Assistant professor in 2006 after 3 years of post-graduate fellowships abroad (University of Federico II (Naples, Italy), GREYC Laboratory (ENSICAEN-Caen-France) and Columbia University (New York City-USA)). She has mainly worked on magnetic and electric properties of complex nanostructures (thin films and devices, nanoparticles and nanowires) focusing on the coupling between the structure and the ferroic properties (magnetic/electric). She has a good experience and knowhow on a broad number of experimental technics allowing the full study of the static and dynamic ferroic behaviour of complex materials (SANS and Polarized Neutron Reflectivity for magnetic phase homogeneity investigation, Broadband ferromagnetic resonance and electron paramagnetic resonance, static magnetization studies by SQUID and VSM) as well as of local near field microscopy (MFM, PFM). She has been coordinator and collaborating on several national and international projects. She directed 16 Master degree internships (first and second year of master), directed and co-directed 8 PhD Thesis and collaborate on 5 others. She has also directed and co-directed 5 post-doctoral fellowships and she trained the engineer responsible of the near field microscopy facility at LSPM to the SPM equipment. She has been responsible during 5 years for the second year of Master in Nanoscience at USPN during which she could participate to the pedagogical upgrade of the master structure and she was pleased to be talked for few collective responsibilities (CNU28, laboratory committee, PhD jury member, undergraduate students tutoring...). She is responsible since 2016 of the 2nd year of the Physics&Chemistry undergraduate degree (Licence 2) at USPN. In 2011 she was an invited researcher at Hebrew University of Jerusalem at Racah Institut of Physics and she is also an invited researcher since 2012 at ESPCI (Paris). She has 55 publications referenced on WoS, 50 conferences and 8 invited seminars (H Factor: 18).

E/ Short Curriculum Vitae of Dr. Sébastien ROLAND

Sébastien Roland has been Associate Professor since 2015, when he joined the PIMM laboratory (Procédés et Ingénierie en Mécanique et Matériaux, UMR 8006). He obtained his PhD (related to block copolymer thin films) in Polymer Physical Chemistry in 2012 from the Université de Montréal, supervised by Prof. R. E. Prud’homme and co-supervised by Prof. C. G. Bazuin. He currently participates in several multidisciplinary projects involving academics and industrial partners (ANR IMPEKKABLE 2015-2020, ANR-PRCE FETA (Principal investigator for ENSAM and WP Leader) 2018-2022, H2020 TeamCables, 2017-2022). He is specialized in thin polymer films characterization via different microscopy techniques such as AFM, SEM or TEM, WAXS, and SAXS experiments, both on lab and synchrotron set-ups (Soleil and ESRF). He supervised 5 Master internships as well as 3 post-doc research fellows. He coauthored 18 articles from 2012 until date.

F/ Estimated Budget between partners:

Institution	Budget Item	Amount (Euros)
USPN	Demanded Salary	50 k
LabeX SEAM	Demanded Salary (under evaluation)	50 k
C(PN) ²	Clean room products, access to the facility materials (SOPHieS Project-demanded at NAP MOSAIC (under evaluation))	15 k
MINOS Team (LSPM)	Valorisation of the PhD: Computer, Conferences, Schools and open access publications)	8 k

PIMM	Polymer and copolymer supply, AFM/PFM consumables, X-Ray scattering experiments and expertise	5 k
		128 k

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