MATERIALS SCIENCE AND TECHNOLOGY

INRIM - Advanced Metrology for Materials Science and Technology

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Context of the research activity	The Thematic Grant includes three research Topics (listed below), with a specific title and proponent Supervisor/s. The applicants have the possibility to identify the specific topic they are interested in. Topic 1: Development of micro-structured sensors based on responsive polymers Topic 2: Multiresponsive polymeric magnetic materials for sensing and actuating systems Topic 3: Development of innovative polymer-based materials for passive radiative cooling applications

	Topic 1: Development of micro-structured sensors based on responsive polymers Miniaturization of intelligent devices requires smart materials able to autonomously interact with the environment by modifying their properties. In this context, the PhD project aims to employ responsive polymers, such as liquid crystalline networks to realize sensors based on MEMS (Micro-Electro-Mechanical System) and MOEMS (Micro-Opto-Electro-Mechanical System) technologies. These devices promise to be a stable and cheap platform for sensing by offering remote measurements even in hostile environments. The integration and widespread adoption of MOEMS is guaranteed by their production workflows that is also used for large scale production of standard integrated circuits - like for instance, photolithography and etching - to add or remove layers on a 2D substrate towards a functional 3D shape. The PhD project tackles the design, the fabrication and the characterization of highly sensitive MOEMS sensors for the detection of chemical agents (such as solvent vapors, humidity, pH). The PhD candidate will engineer micrometric structures based on a three layer geometry (metal-responsive insulator-metal) where the sensing capability will be monitored by optical (Fabri-Perot spectra) or electrical measurements (variation of capacitance). The validation of both working regimes will result in a combined opto-electro mechanical response sensor.

Objectives	The analytical capabilities will be based on the anisotropic deformation of the dielectric layers in response to different external stimuli, and in particular to the different concentrations of chemical species in the surrounding environment that is translated in the variation of the optical/electrical properties of the sensor. Photopolymerizable dielectrics will be considered as the preferred choice for the possibility to micropattern them using photolithographic techniques compatible with the MOEMS technology. This goal will be pursued thanks to the expertises and strong collaboration of INRiM (National Institute of Metrological Research) and Polito. The miniaturization and integration of the MOEMS sensors will be performed at the new fabrication facility Piquet at INRiM in the context of the Next Generation project LCE-SENSE (Liquid Crystal Elastomer capacitive SENSors for multipurpose chEmical detection) taking advantage of cutting-edge tools for the characterization of nanostructures, for optical/electronic/ionic lithography, and for etching and thin film deposition. The final goal will be to measure and maximize the sensitivity of the MOEMS sensors through the material and structural engineering of the device to improve the stability and sensitivity of the measurements depending on the different external stimuli in the relevant scenarios. The new MOEMS will then be compared with standard sensors available on the market and an interlaboratory characterization will be performed at the European National Metrology Institutes. Topic 2: Multiresponsive polymeric magnetic materials for sensing and actuating systems The Ph.D. project aims to combine nanometer-sized magnetic materials (e.g. nanoparticles or thin film) with soft photo-responsive polymers to create multiresponsive materials applicable in various areas, mainly in sensing and actuating systems. The idea is to create a new class of composite materials having multi-response to environmental stimuli such as light, which can change the magnetic properties of a sensor, or magnetic field, which can steer the operation of shape-changing polymers. For sensing application, the PhD will focus on materials made by sputtering deposition of a magnetic film on smart polymer substrate. Composition and thickness of the film will be chosen to get a magnetostriction effect. Conversely, multi-responsive actuators, able to convert energy from magnetic field and/or light into mechanical action, will be constituted of magnetic nanoparticles (MNPs) embedded in a shape-changing polymer matrix. MNPs with different sizes and compositions will be synthesized by cost-effective, and environmentally friendly chemical and physical routes. For both classes of materials, the project will focus on the use of smart polymer materials, namely Liquid Crystalline Elastomers, already proved to be useful for the preparation of light responsive photonic devices or microrobots. Their preparation will involve photopolymerization approaches that allow also the micrometric fabrication of the proposed devices. The Ph.D. will have access to INRiM facilities for nano/micro-fabrication of polymers. Ultra-sensitive magnetometers will be used to investigate the magnetic properties of the multi-responsive materials. The magnetic parameters will be correlated to their morphological and structural properties. The multifunctional properties of the first class sensing material arise from the synergistic combination of the flexible character of the polymer and the magnetostrictive properties of the thin film. In fact, the actuation behavior of polymeric substrate when submitted to light induces deformation to the magnetostrictive thin film, affecting its magnetic properties. The link between mechanical stress and induced magnetic change will be studied by

anisotropic magnetoresistance measurements. Resistance variation will allow integration in sensors.
The second class of multi-responsive materials will exhibit tunable mechanical and magnetic properties by changing the mass of MNPs embedded in the polymer. Following this way, actuation behavior in magneto-responsive materials is induced by external magnetic fields. The actuation mechanisms under magnetic fields or light irradiation will be tested inside microfluidic channels.
In summary, this Ph.D. project aims to contribute to the current technical challenge of realizing multi-responsive polymer materials with tunable magnetic properties. The Ph.D. student will develop advanced skills in the realization and characterization of multi-responsive materials.
Topic 3: Development of innovative polymer-based materials for passive radiative cooling applications
Context of the research activity
Passive Radiative Cooling is a renewable cooling method by which an object on Earth can cool below ambient temperature, even during the day, by reflecting all solar radiation and emitting its thermal energy through the atmospheric transparency window of atmosphere. Among several materials that have been proposed in the literature, fluoropolymers exhibit several desirable properties such as their compatibility with scalable fabrication methods, their characteristic and selective thermal emissivity in the atmospheric transparency window, marked hydrophobicity and superior resistance to weathering and atmospheric agents, which are necessary for this inherently outdoor application. This research fits into the context of the recently started PaRaMetriC project https://www.euramet.org/project-21grd03 (17 partners, total EU contribution of 2.347 M€).
Objectives
The research activities will be focused on the design, fabrication and characterization of polymer-based materials for passive daytime radiative cooling applications. To this purpose, fluoropolymers can be the material of choice thanks to their high emittance in the atmospheric window, and hybrid systems can be developed to further increase the materials performance. Scalable fabrication methods, such as phase inversion or electrospinning, will be considered due to their ability to generate highly scattering membranes and coatings with good mechanical properties, hydrophobicity and UV resistance. Several fabrication parameters will be considered to tailor the distribution of pore sizes and/or fiber diameters and their degree of structural anisotropy, in order to maximize the overall scattering efficiency across the whole solar spectrum and the thermal emissivity in the atmospheric transparency range. The obtained materials will be additionally characterized in terms of their spectral properties and cooling power at INRiM (in collaboration with the Nanofacility Piemonte, the physical thermodynamics group, and the INRiM unit at the LENS laboratory in Florence), as well as through the network of institutes participating in the PaRaMetriC project. Simultaneously tuning the chemistry and the morphology of the materials will allow to optimize their performance for passive daytime radiative cooling applications. Envisioned applications of the resulting materials may include the passive cooling of electronic devices, batteries, vehicles. Additionally, they can also be used to cover panels and wrap up pipes for the on-demand, non-evaporative cooling of water to be used as a heat dissipation vector.

Topic 1
This multidisciplinary PhD project will allow to gather knowledge in different fields spanning from materials science to micro opto-electro mechanical system (MOEMS) characterization also exploiting cutting edge fabrication

Skills and competencies for the development of the activity	processes and exploring novel challenges for next generation sensors. The PhD candidate must hold a master degree in chemistry, materials engineering, physics or electrical engineering. Positive evaluation will be given to knowledge of polymer science, lithographic processes, metal deposition techniques, design and characterization of simple electrical circuits. Topic 2 This multidisciplinary PhD project will allow to gather knowledge in fields spanning form materials science to magnetic characterization also exploiting smart responsive polymers. The PhD candidate must hold a master degree in scientific disciplines such as chemistry, materials engineering or physics Positive evaluation will be given to knowledge of magnetic properties characterization, polymer processing and characterization. Topic 3 Candidates should have a solid background in material science and engineering, with expertise in polymer processing and characterization. Good English knowledge is required. Familiarity with multi-physics modeling tools and electrospinning is a plus. Good knowledge of practical attitude for the lab activities and problem solving skills, and high motivation to learn through advanced research are appreciated. The PhD candidate will work in contact with different research groups on a highly multidisciplinary project, hence they must demonstrate adaptability in different environments, and be able to interact positively with the other group members.