PULSE-COM

Photo-Piezo-ActUators based on Light Sentive COMposite

Project Coordinator

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https://www.pulsecom-h2020.eu/
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Summary

Team

Coordinator

The National Research Council (CNR) is the largest public research institution in Italy, the only one under the Research Ministry performing multidisciplinary activities; The Coordinator Institute ISASI-CNR conducts research in the fields of Physics, Biology and Informatics. Within the Opto-electronic area, the skills in the fields of optics, nanotechnologies, photonic devices, new structured and polymeric materials, and spectroscopy, are applied in optoelectronics and sensors.

ENEA is a public-law body for research and technological innovation and the provision of advanced services to enterprises, public administrations and citizens in energy, environment, and sustainable economic development sectors. ENEA (SSPT-PROMAS-NANO Laboratory) is very active in the fabrication and characterization of organic and hybrid materials devices, in developing new class of energy-efficient optoelectronic systems, in study new concepts of organic devices and their exploitation.

UGA, University Grenoble Alpes is one of the largest universities in France. IMEP -LaHC has built for years a renowned expertise in devices physics, by combining experimental and theoretical approaches. UGA (IMEP-LaHC- Microelectronics, Electromagnetism and Photonics) is very active in the field of micro- and nano-electronics, micro-photonics, microwaves and photonics and micro- and nano-systems, in particular based on piezoelectric nanocomposites for sensing and energy harvesting applications.

CTEC is a growing high-tech SME involving 40 peoples based in the French Innovation Valley, close to Grenoble, specializing in the 4 following technology domains: Smart Actuators, Smart Sensors, Mechatronic systems, Detection systems. In all these domains, CTEC designs, manufactures and tests components, systems and associated electronics, following customer requirements and keeping the objective to achieve both technical and marketing success.

SITEX is an industrial SME with R&D activity industry oriented, located on MINATEC-RO / Scientific and Technological Park Bucharest deeply involved since 1992 in a wider range of activities. SITEX expertise focuses on design and engineering, prototyping and microproduction for sensors and microsystems by new materials applications including nanostructured as well sensing devices and microsystems integration/packaging technologies.

The National Institute for Laser, Plasma & Radiation Physics (INFLPR) is an independent, national importance research institution established by the Government of Romania. INFLPR conducts frontier research ranging from basic photonic materials and high-power lasers, nanomaterials and nanotechnologies, quantum dots and information technologies, plasma physics and X-ray microtomography to industrial photonics, biophotonics and plasma coatings.

CBRTP is a Polish private research and technology transfer center specialized in materials science (incl. photovoltaics, polymers, thin films), physics, geophysics, electrotechnics, robotics and automation. CBRTP conducts research in various areas of materials science, physics, geophysics, electrotechnics, robotics and automation.

Benkei, a French company, assists its clients, both public and private, in the definition, implementation and evaluation of their innovation strategy. It supports every client involved in innovation, technological or not: those who innovate as well as those who help innovators and wish to develop original approaches. Benkei favours co-development approaches and long-lasting collaborations, through missions specifically designed for their clients.

General information

Introduction and motivation

According to the European parliament, Research Europe's journey towards technological sovereignty should cover Key Enabling Technology (KET) which includes Advanced Materials. The new active material, that are presented here-after and that have been support by the UE R&D funded PULSE-COM project, are photomobile polymers. These active materials are characterized by their ability to generate significant stroke under light excitation, which allows the development of new actuation devices. The recent progress made in the manufacturing of new plasmonic photomobile films are offering innovative solutions for light induced motion actuators and devices. Indeed, such films can be assimilated as transducers thanks to their ability to convert light into displacement with strokes up to several millimeters. By adjusting the incident light parameters (wavelength, exposure time…) the photomobile films actuation can be controlled to answer many applications requesting high displacements and low forces. In these regards, the behavior of the photomobile films were characterized prior to their integration in more complex devices. Then, several proof-of-concepts of these devices were manufactured to try to bring new functionalities to the market such as light driven optical switch, optical micro-valve, and deflector, waveselector and spectrometer.

Targets

The aim of the PULSE-COM project is to realize a new type of piezoelectric devices (PZL) controlled by light using photo-mobile films (PMP) whose movement is induced and controlled by sunlight and/or artificial light. PULSE-COM aims to create a new class of photoactivable devices that will change the field of optoelectronic and piezoelectric devices by creating innovative devices for a wide range of applications. We developed optical switches and innovative systems, whose deformation can be easily controlled by the intensity of an incident light.

The consortium

8 partners

4 European countries

3 years project

2.9 M€ budget

Materials

Mixture of liquid crystals (LCs) including azobenzene moieties (Azo-LC-PMP)

Photo-mobile polymer (PMP) films are emerging as an important class of smart materials in various high-tech applications. The interest of such materials is to get a high stroke actuation driven with light. The energy used is low and is supplied remotely. The counterpart of such characteristics is the generation of a slow movement with low forces.

The photo-mobile polymers employed in this project were synthesized using specially selected LC monomers reported in Figure 1A, which enabled the creation of highly efficient liquid crystal elastomers (LCEs). These LC monomers possess unique properties, such as molecular orientation and specific interactions, which contribute to the formation of an ordered polymer network with a responsive mesophase. This organized structure allows the resulting LCEs to undergo a reversible phase transition, leading to deformation and contraction when exposed to proper stimuli. By fine-tuning the composition and properties of these LC monomers, researchers can tailor the performance of the LCEs to meet the requirements of specific applications, opening up new possibilities in the field of smart materials and soft robotics.

In details, the azobenzene-containing monomer exhibits photo-responsive properties due to its azobenzene core and it undergoes photo-induced isomerization between trans (E) and cis (Z) configurations (Figure 1B) producing the deformation at macroscopic level that is sensitive to the wavelength and polarization state of an impinging light. As schematized in Figure 1, the *trans* form (thermodynamically stable) can be converted to the cis form (metastable) using a UV wavelength of 300-400 nm. Visible illumination converts the molecule back to the *trans* form. Alternately, the molecule thermally relaxes to the stable *trans* form. At macroscopic dimensions the local deformation extends to the whole polymer film part and make it bend.

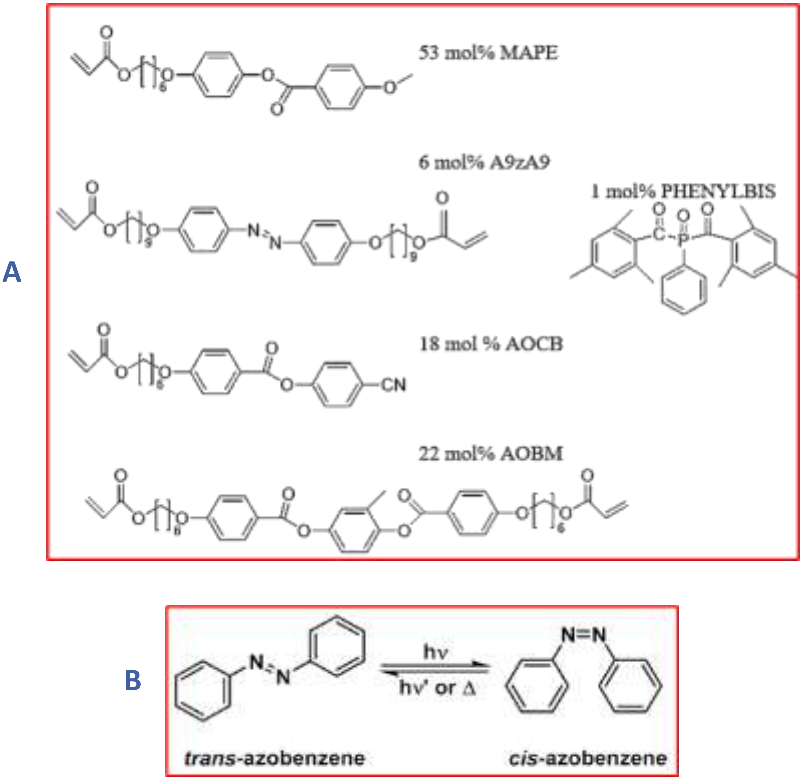
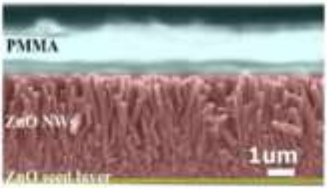


Figure 1. A: *Mixture of LCs with azobenzene moieties (6 mol%) used to produce our PMPs.* ***B:*** *The photo-isomerization reaction of Azobenzene molecule.*

However, this reaction is induced by polarized UV-rich irradiation, and it is not efficiently catalyzed by sunlight. We used a facile and effective approach to enhance the quantum yield of azobenzene and to extend its wavelength sensitivity by doping the PMP matrix with different selected materials: carbon black (CB) and zinc oxide (ZnO) nanoparticles of suitable shape. These doped PMP films showed faster and more significant bending under both UV as well as visible and near infrared light regardless of whether it was coherent, incoherent, polarized and unpolarized irradiation. This demonstrates the potential of these doped PMP films for producing sunlight-sensitive devices such as photomechanical actuators and a new generation of harvesting systems.

PZL layers were prepared based on ZnO NWs (see representative picture) and Poly(vinylidene fluoride) (PVDF). The synthesis of ZnO NWs based PZL was conducted on a substrate made of silicon wafer or polyethylene terephthalate (PET) polymer used as the base substrate for device processing. The bottom electrode was indium tin oxide (ITO) film, deposited by sputter deposition. The ZnO seed layer was deposited on the substrate. The wire growth happened by chemical bath deposition (CBD). The dielectric matrix was a poly(methyl methacrylate) (PMMA) matrix deposited on top of the NWs using spin coating. As a final step, a gold/chromium (Au/Cr) layer is deposited by thermal evaporation as the top electrode of the device.

ZnO based on piezoelectric transducer

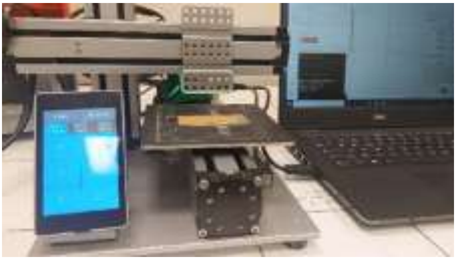


Methods

Materials preparation, morphology, optical properties and photomobile behavior at different wavelengths

Polymerization Cells for PMP production

Two glass slides and a plastic spacer are used to create cells for photopolymer synthesis. The glasses are coated with elvamide using either dipping or spin-coating to provide alignment. The elvamide layers are rubbed automatically using a homemade automated system (see Figure below), and the rubbed sides are faced in antiparallel mode, separated by 50 µm-thick Kapton layers as spacers to create a cell reactor as shown in Figure 2**(a).**



Synthesis of PMP Films

PMP films and doped PMP films are prepared using the mixture of LC monomers previously mentioned. The reaction mixture is dissolved in dichloromethane, heated, and left to recrystallize. The reaction cell is heated, and the mixture is infiltrated by capillarity see Figure 2 **(b).** The sample is photopolymerized using a UV lamp and left at 50°C for 24 hours (Figure 2**(c)**).

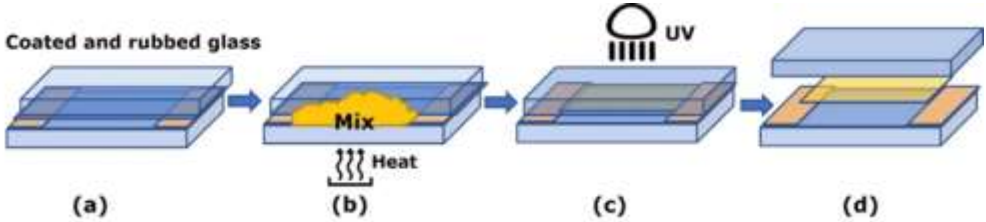


Figure 2. Steps for PMPs fabrication: (a) Coated and rubbed glass slides were glued to form the cell reactor (b) Injection of LCs mixture at T of isotropic phase (c) UV polymerization phase with a lamp at the nematic phase temperature (d) Final polymerized film peeled and collected.

CB-PMP composites (as shown in Figure 3b) are synthesized adding to the LC mix a CB suspension in order to obtain different final CB concentrations. The dispersibility of CB is examined in 1,1,1,3,3,3-Hexafluoro-2-propanol (HFIP), which is found to be the best solvent for dispersing CB.

ZnO-doped PMPs (as reported in Figure 3c) are prepared by adding commercial ZnO NPs to the reaction mixture before infiltration. The mixture is agitated, and the dry mix is delivered to a heated reaction cell. The polymerization process is carried out as described for control PMP films.

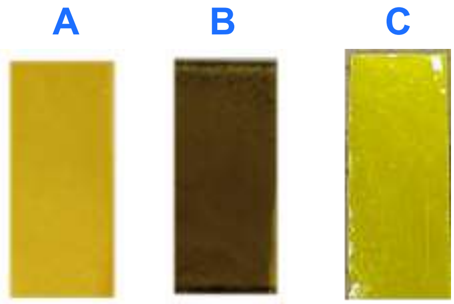


Figure 3. Photos of A) azo-LC-PMP, B) azo-LC-PMP/CB, and C) azo-LC-PMP/Zinc oxide. Doped films (B-C) are useful to enlarge the absorption spectrum and increase the efficiency.

UV/vis Spectral Characterization

UV/vis spectroscopy was performed using different spectrophotometers, to evaluate the absorbance of the different produced materials and composites.

Polarized Optical Microscopy (POM) Analysis

The experiments were performed with polarized upright microscopes. To study the proper alignment of the cells, this was verified using an optical microscope equipped with 2 polarizing filters oriented at 90 degrees to each other, with the polarized light microscopy (POM) technique.

Bending and speed characterization of PMPs

To study the dynamic response of the PMPs, both bare and doped Azo-LC-PMP were cut as cantilevers (5 mm x 1 mm) and irradiated at different wavelengths using different laser sources and led sources (solid state lasers @ 405 nm, 457 nm, 532 nm, 785 nm, supercontinuum centered @647nm and 747nm, LED sources @385 and 470 nm). These sources were used to perform the photoresponsivity measurements on the azo-LC-PMP films with and without dopants while the set-up with the optomechanical part was optimized according to the used laser sources. The set-up envisaged the use of a camera to evaluate the bending of the photopolymer during irradiation (which was always performed from the same direction), an anchoring system for the sample, and irises and mirrors to better select the light beam and direct in proper way the radiation.

In Figure 4A-C we report three different test-benches used at CNR, ENEA and CTEC, respectively. In Figure 4D it is reported a test-bench to perform measurements on PMP-PZL devices with a portable station at the exhibition “*Futuro Remoto*”.

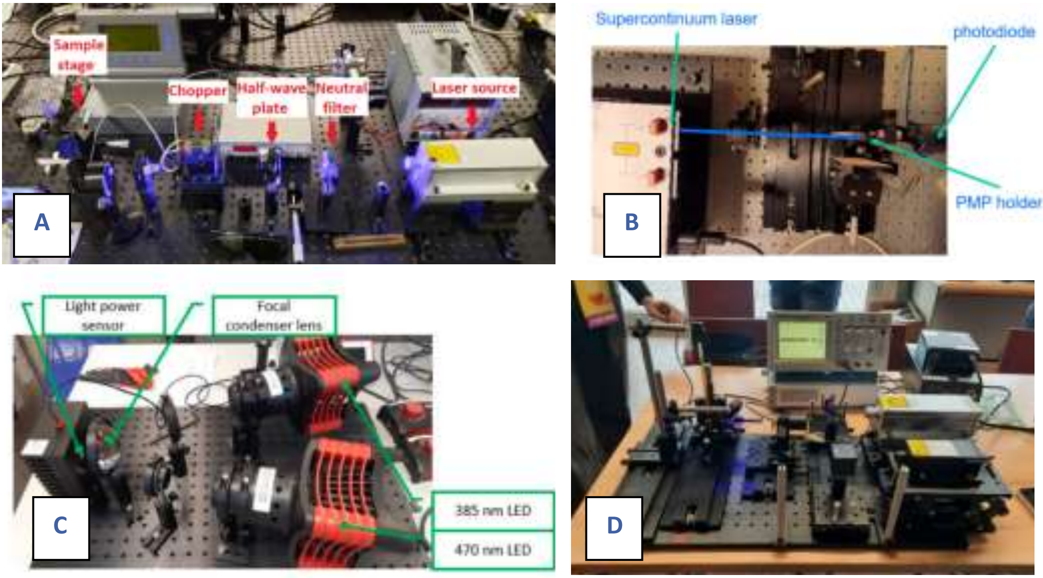


Figure 4. *A-B) Set-up to perform measurements on doped and undoped azo-LC-PMP films at CNR; B) with an AOTF module of the supercontinuum laser source at ENEA. C) Test bench for light power measurements at CTEC. D) Set up to perform measurements on PMP-PZL devices with a portable station at the exhibition Futuro Remoto (https://www.futuroremoto.eu/).*

Results

We studied the possibility to modify the photomobile properties of azo-PMP by introducing different concentrations of i) CB (from 0 wt.% up to 1 wt.%), ii) ZnO nanoparticles (from 0 wt.% up to 7.5 wt.%), and we investigated morphology, optical properties and photomobile behavior at different wavelengths.

Optical, Morphological, and Spectroscopic Characterization of Azo-LC-PMP/CB Composites to extend the usable spectral bandwidth of PMPs in visible region and towards the near infrared spectral region.

In this work, the preparation, and the characterization of an azobenzene-based photomobile polymer (azo-LC-PMP) and its composites with different concentrations of CB (from 0 wt% up to 1 wt%) were presented. All the samples were characterized optically and morphologically and photoresponsivity was analyzed using lasers with wavelength in the visible range (457, 532, 647 and 747 nm). The results showed wavelengths equal or higher than 532 nm induced photo-bending response only in the composites with CB. The introduction of 0.03 wt% CB is already enough to prompt photomobile behavior and the best performance in terms of bending properties was observed with 0.1 wt% CB concentration. These results open new perspectives through the employment of carbon-based materials in PMP films to exploit all the solar spectrum bandwidth.

A deep investigation of film morphologies was performed by optical and scanning electron microscopy.

Optical images were carried by using polarized light and they confirm what was observed by macroscopic analysis of the samples (Fig. 5-6). The change of intensity suggests that there is the presence of orientational organization both in azo-LC-PMP and still in low concentration azo-LC-PMP/CB films. Such results suggest that low concentration should be chosen not only to improve the homogeneity of the CB but also to preserve the nematic alignment of monomeric units along the rubbing direction.

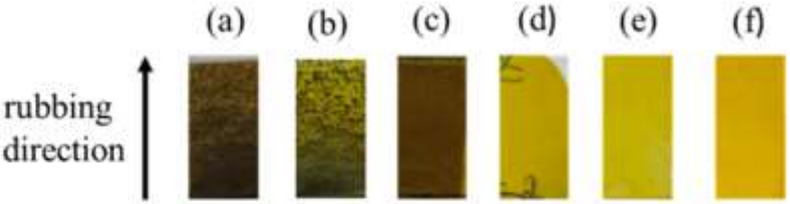


Figure 5. *Photos of azo-LC-PMP/CB films prepared with different wt% of CB: (a) 1wt%, (b) 0.2 wt%, (c) 0.1 wt%, (d) 0.07 wt% (e) 0.03 wt% (f) 0 wt%.*

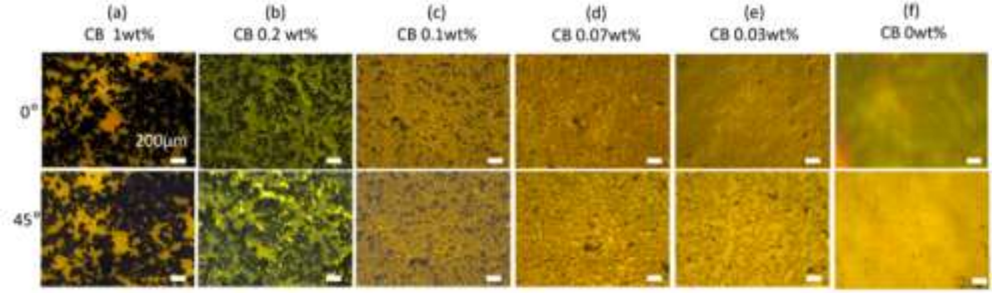


Figure 6. *Optical images of azo-LC-PMP/CB films (a-e) and pure PMP (f) obtained by polarized light microscope measured by putting the respective samples parallel to one of the two polarizers at 0° or at 45° degrees: (a) CB 1wt%; (b) CB 0.2wt%, (c) CB 0.1wt%, (d) CB 0.07wt%, (e) CB 0.03wt%, (f) CB 0wt%.*

In Figure 7, a comparison among the transmittance spectra of pristine azo-LC-PMP and its composites is reported. For all films a sharp drop in transmittance is observed for λ < 500 nm.

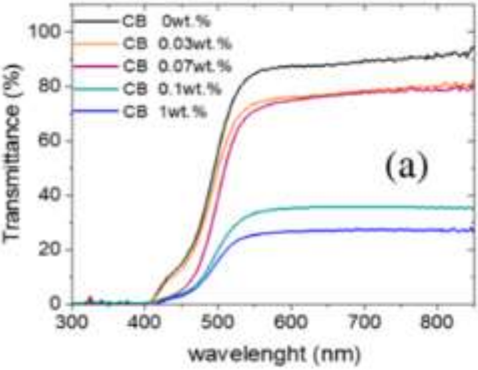


Figure 7. *Transmittance of pure azo-LC-PMP and its composites with CB (from 0.03 up to 1 wt%).*

The photoresponsivity behavior of the composites was assessed using lasers at different wavelengths in the visible range. Results, reported in Figure 8, showed that low CB concentrations improved the homogeneity of CB dispersion and preserved nematic alignment. The introduction of 0.03 wt% CB was sufficient to prompt photomobile behavior, with the best performance observed at 0.1 wt% CB concentration.

These findings suggest that CB NPs in PMP films can be used to exploit the entire solar spectrum bandwidth, opening new perspectives for applications in photonic devices. Choosing appropriately the CB concentration, we demonstrated that it is possible to enlarge the usable spectral bandwidth of the samples in visible region towards the visible and near infrared spectral region.

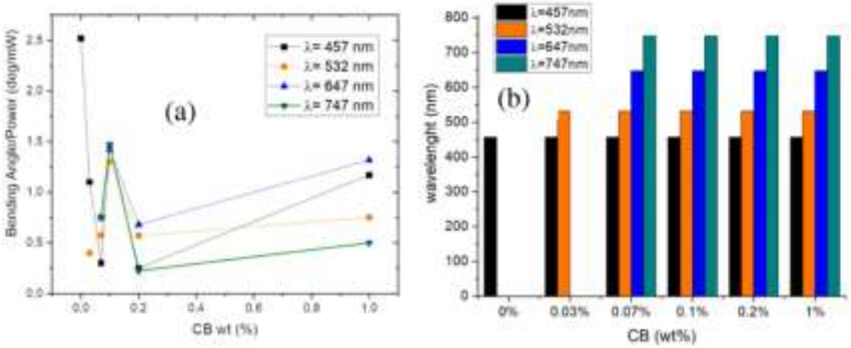


Figure 8. Maximum Bending Angles (a) and photoresponsivity behavior of film composites at different wavelengths and at different concentrations of CB.

To make it easier to understand the performances of doped PMPs, some explicative measurements are reported in Figure 9 where the images of pristine azo-LC-PMP and azo-LC-PMP with 0.1% CB films obtained before and during irradiation with 532 nm-laser at 40 mW power are shown.

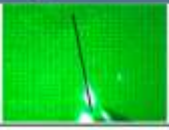
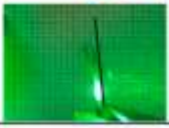
Wt (%) CB	Light off	Light On (40mW) @532nm
0 (a)		
0.1 (b)		

Figure 9. Images of pristine azo-LC-PMP (a) and azo-LC-PMP with 0.1% CB films (b) obtained before (left) and during (right) irradiation with 532 nm-laser at 40 mW power.

Optical, Morphological, and Spectroscopic Characterization of PMP Films Doped with ZnO NPs for Enhanced Photoresponsivity

CNR improved the properties of PMPs decreasing azobenzene concentration and doping the PMP with ZnO nanoparticles using a solventless approach. The nanocomposites are prepared with different concentrations of ZnO nanoparticles (NPs) embedded in the cross-linked polymer matrix.

The doped PMPs improved their bending capabilities and mechanical properties. In fact, the doped material could bend more as compared with control when irradiated with laser light. Furthermore, the ZnO nanoparticles could improve the material ability to store energy indicating that the sample had higher strength as compared to control. Interestingly, such doped material could self-vibrate when stimulated with laser light at 457 nm even if the nematic configuration was apparently disturbed by the nanoparticles.

Optical and mechanical, and thermal analyses (DSC, TGA, thermographic analysis) were also performed to characterize the PMPs. Spectral characterization in UV/vis range of the bare and doped films, optical and atomic force microscopy, were used to comprehend the role of ZnO nanoparticles and their distribution among the liquid crystals. To study the dynamic response of the PMPs and their mechanical properties, lasers at different wavelengths were used.

Polarized microscopy revealed the presence of nanostructures in ZnO-doped PMP films (Figures 10-11). However, no nematic alignment was detected for doped PMPs.

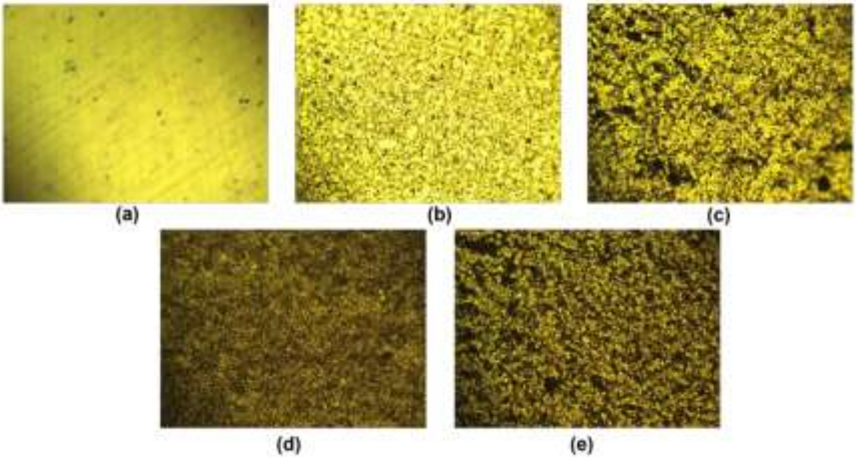


Figure 10. *Microscope optical images obtained with samples at 45 degrees to one of two crossed polarizers (a) PMP_Control (b) PMP_1.5% ZnO (c) PMP_3% ZnO (d) PMP_6% ZnO (e) PMP_7.5%ZnO.*

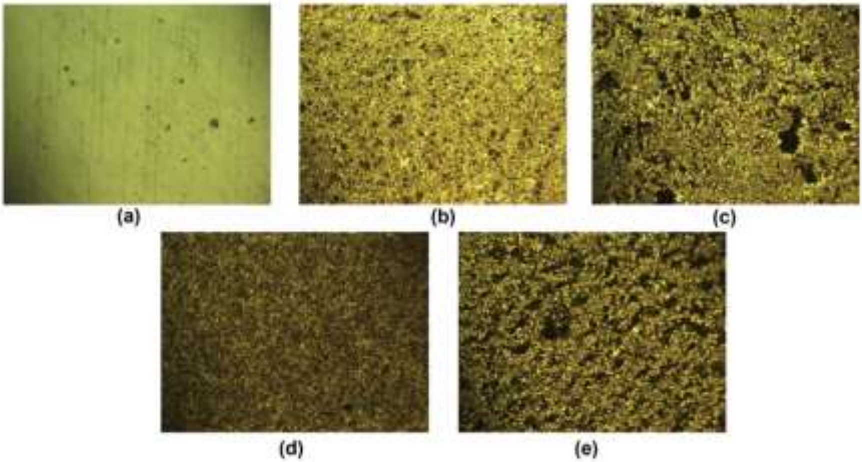


Figure 11. *Microscope optical images obtained with samples parallel to one of two crossed polarizers (a) PMP_Control (b) PMP_1.5% ZnO (c) PMP_3%ZnO (d) PMP_6% ZnO (e) PMP_7.5% ZnO.*

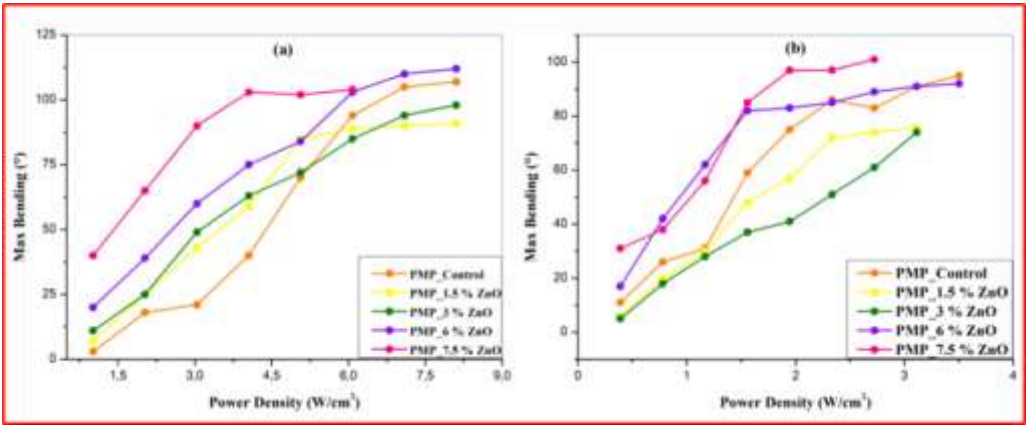


***Figure 12.** Bending capability of undoped and doped PMPs at different wavelengths (a) at 457 nm and (b) at 405 nm.*

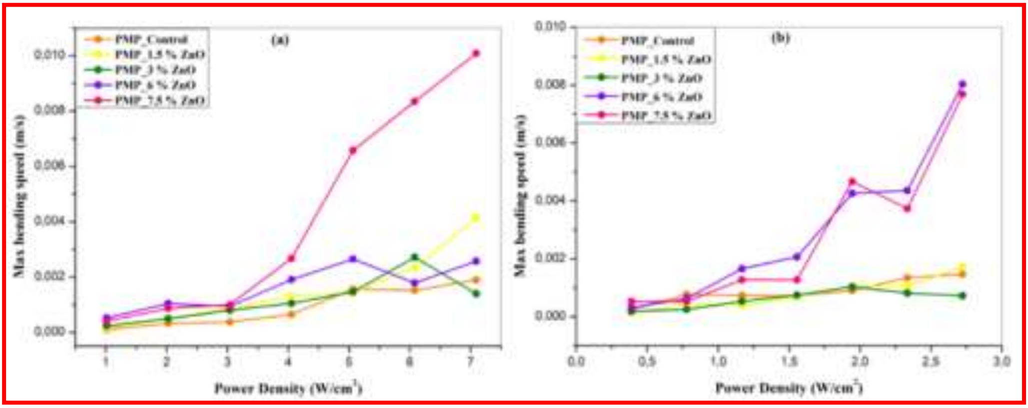


***Figure 13.** PMPs speed to obtain the max bending (a) under laser excitation at 457 nm (b) under laser excitation at 405 nm.*

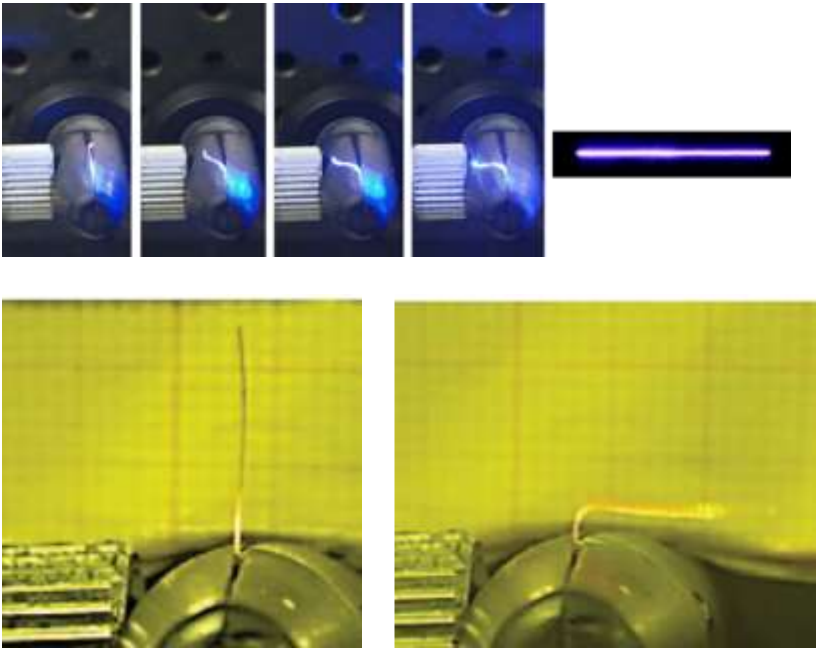


Figure 14. *Images of undoped AZO-LC-PMP film with maximum bending of 90°and speed between 1 and 4 mm/s (top Figure) and self-vibrating 6% ZnO doped AZO-LC-PMP films obtained before (bottom left) and during bottom (right) irradiation with laser light at 457 nm.*

The PMPs traction capability was evaluated subjecting the films to irradiation while clamped to a dynamometer. The reported measurements (see Figure 15) confirmed the improvement behavior of doped PMPs in comparison to the undoped ones.

The incorporation of nanoparticles in the PMPs led to enhanced mechanical properties of the material, as evidenced by a tenfold increase in the measured tensile force during mechanical testing.

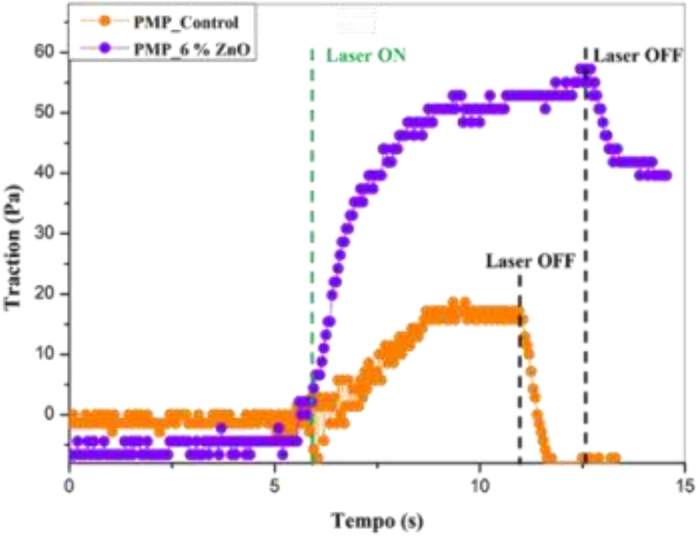


__Figure 15.__ Traction capability measurement of bare (control) and doped PMP films.

PMP-PZL prototype fabrication and characterization

PZL-PMP devices fabricated and characterized.

The PULSE-COM project intends to produce PMP/PZL devices by unifying two concepts: (i) the conversion of photon energy into mechanical work by means of a PMP and (ii) the conversion of mechanical energy into electrical energy by means of a piezoelectric material. The general process flow for the fabrication of PZL devices based on ZnO NWs is given in Figure 16.

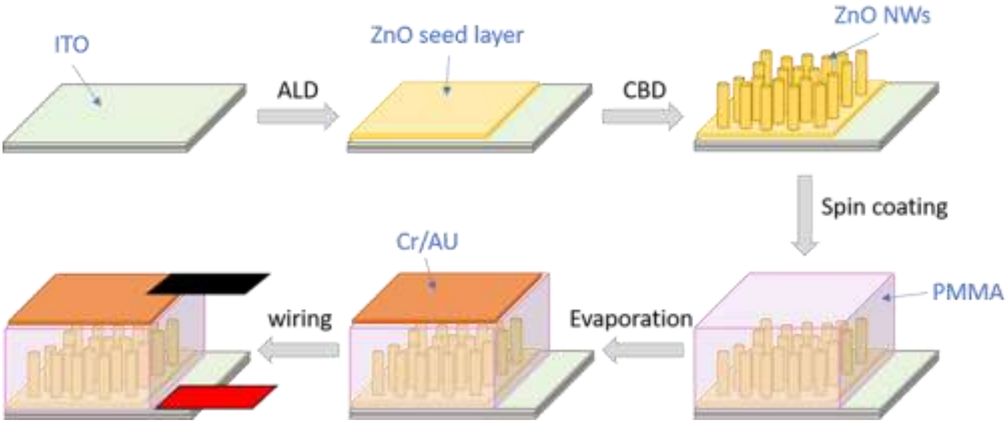


Figure 16. Process flow for the fabrication of PZL layers based on ZnO NWs.

The seed layer is one of the most important parameters for the good growth of ZnO NWs by CBD. To date, a large variety of techniques are used to obtain ZnO seed layers, such as RF sputtering, atomic layer deposition (ALD), spray pyrolysis, chemical vapor deposition, and wet chemical synthetic routes, including spin and dip coatings. In PULSE-COM, two methods have been explored: ALD performed at UGA and gravure printing performed at ENEA.

As a first study, gravure printing with crystalline ZnO nanoparticles (NPs) was attempted for the first time to produce a seed layer for ZnO NW growth on PET/ITO substrates. Gravure printing is a process which can be considered as a sequence of sub-processes (inking, doctoring, transfer, spreading, and drying, as shown in Figure 17.

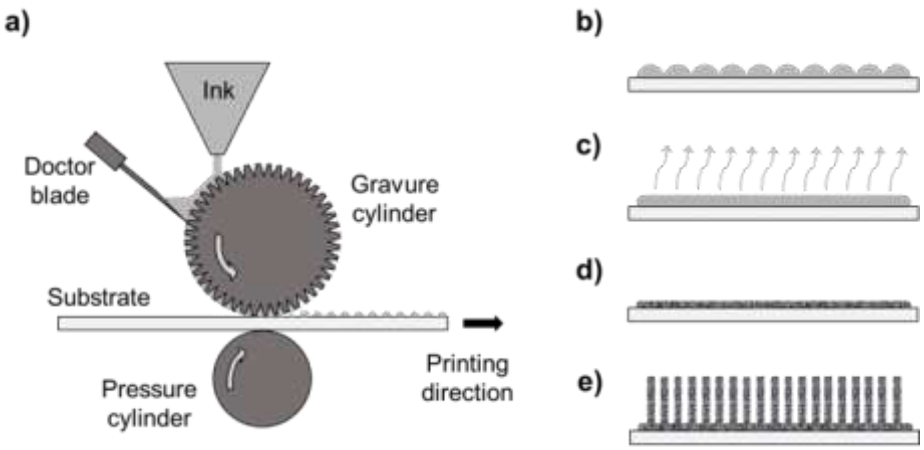


Figure 17. *Fabrication process of ZnO seed layers by gravure printing and subsequent NW growth. The gravure printing process can be divided in the following steps: (a) inking, doctoring, and transfer; (b) spreading; (c) drying; (d) production of the final solid thin film. (e) The final growth of ZnO NWs is performed via low-temperature CBD.*

As a second study, we focused on the inkjet printing (IJP) of crystalline ZnO nanoparticles (NPs) onto ITO/PET substrate to produce a seed layer for ZnO NW growth is investigated to define the potential of IJP technology in the in the flexible piezoelectric devices manufacturing. Inkjet printing (IJP) process, reported in Figure 18, is a high-throughput, low-temperature, versatile (in terms of employable inks and substrates) process that allows to deposit desired amount of ink with the possibility to pattern the deposition itself.

Figure 18. *(A) Schema of inkjet process used to produce ZnO seed layer onto ITO/substrate by multinozzle printer shown in (B).*

Once realized the PZL devices, thanks to close interaction between ENEA, CNR, CTEC and UGA, a first series of PMP layers have been successfully integrated on PZL layers based on PVDF using a perpendicular (or T-mode) integration strategy (Figure 19A). T-mode integration consisted of attaching, using Kapton tape, a PMP layer (PMP-Azo/Cu) to a PZL (20 µm and 50 µm thick) in a perpendicular way, so that the incident light only illuminates the PMP and not the PZL (Figure 19B). T-mode devices were tested under a laser light (457 nm and 445 nm @ 400 mW) and using a chopper (f ~ 2 Hz). With this configuration, as already stated, the incident light illuminates the PMP avoiding any PZL heating effect. The device using a 200 µm thick PVDF generated ~ 600 mV @ 1 Hz.

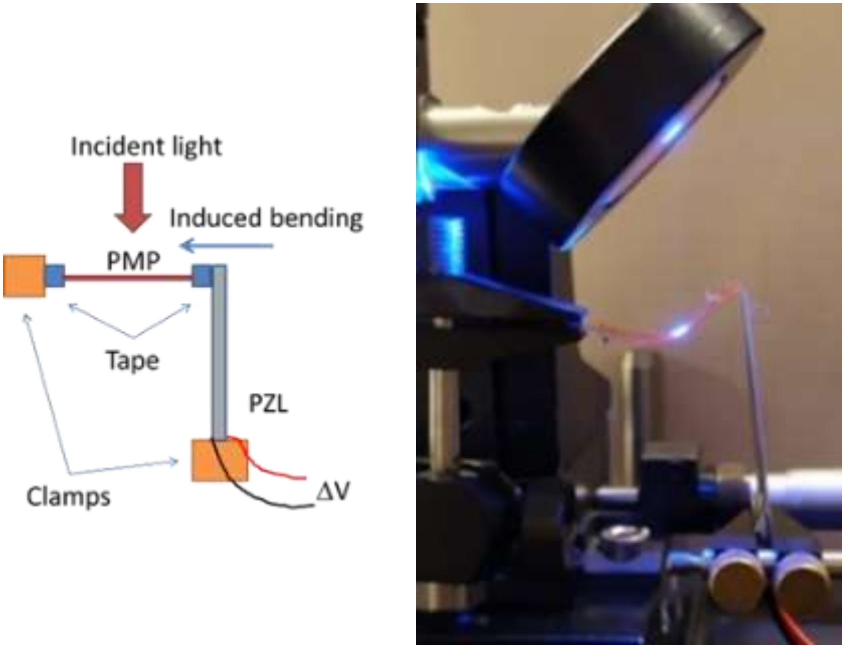


Figure 19. L-mode strategy to combine PMP/PZL: (a) Schematic of the combination principle. (b) Photo of a PMP-Azo / PZL.

PMP-PZL devices can be the core to realize a completely new solar energy system and the most challenging with respect to the state of the art.

Additionally, we performed experiments related to moving the PMP-PZL connection point away from the point where the PZL is blocked and which works as a fulcrum for a sort of pendulum. Here, we report an experiment, in which we increased the length of the PZL device by 10 cm with a double-sided adhesive kapton and which allows us to reach a peak-to-peak voltage difference of about 1.2 V from a single PMP movement. In Figure 20, it is possible to observe the setup of the pendulum configuration and three frames related to the actuation of the PZL and its release.

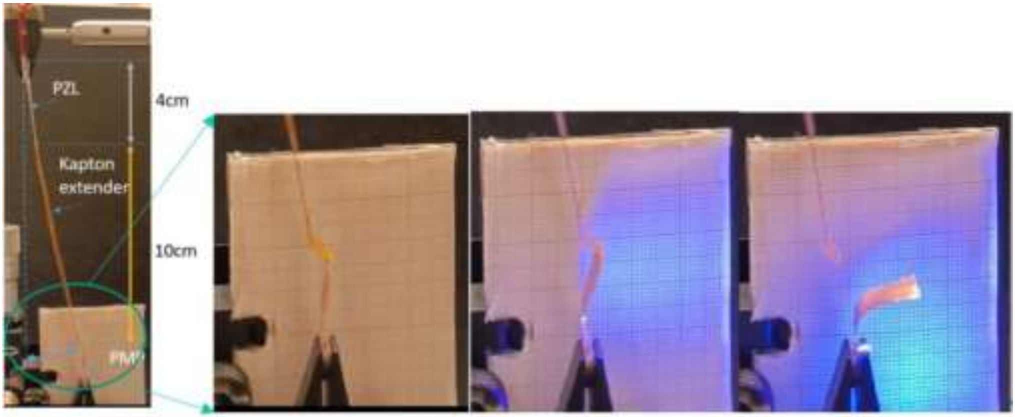


Figure 20. Setup of the pendulum configuration and four frames related to the a) starting configuration, b) zoom image of the actuating part, c) intermediate position after the switching on of the lasers sources and d) the release of the PZL extensor by the PMP film and the consequent creation of the voltage signal.

Applications

Integration in opto-electronic systems for industrial implementation.

The foreseen applications of PMP use their bending properties driven by light to construct specific mechatronic devices. This includes optical switch components, light driven valves, and optical deflectors developed by Cedrat Technologies, and a waveselector and spectrometrer prototypes developed by Sitex 45 and INFLPR partners.

The prototypes fully developed are related to optical switches, opto-valves and optical deflector. The Opto-switch would be used to open and close an electric circuit when light is switched from on to off (or inversely). The Opto -valve would be able to open and close a fluid circuit when light is switched from on to off (or inversely) without embedded electric power. The optical deflector would be able to change the orientation of an optical beam, depending on the amount of optical power received from the driving light.

The first application of PMP is the creation of electric switches. This is a particularly interesting application as the goal of a switch is the realization of a conductive path in a power circuit thanks to a low power command. The energy used by PMP to change state is effectively assumed to be low at term. Moreover, the use of light for the switch activation allows to suppress any conductor link between the power circuit and the command, which should simplify many electromagnetic compatibility (EMC) and electric insulation issues. Finally, the large stroke of PMP is particularly well suited for switch application as it allows a large air gap in open state which significantly reduces any risk of spark in case of noisy peak voltage.

Optical switch prototypes

Three kinds of switches have been considered. The principles and prototypes are presented in Figure 21. PMP film samples are produced with azobenzene materials by CNR/ISASI and ENEA/SSPT. The PMP has been integrated so that the film bends in the expected direction when light beam is applied on the right side. The 50 µm thick PMP film is equipped with a 10 µm thick copper layer which size and position depend on the type of switch. The surface of PMP covered by copper is on bottom side, or on top side or on both sides depending on the switch configuration.

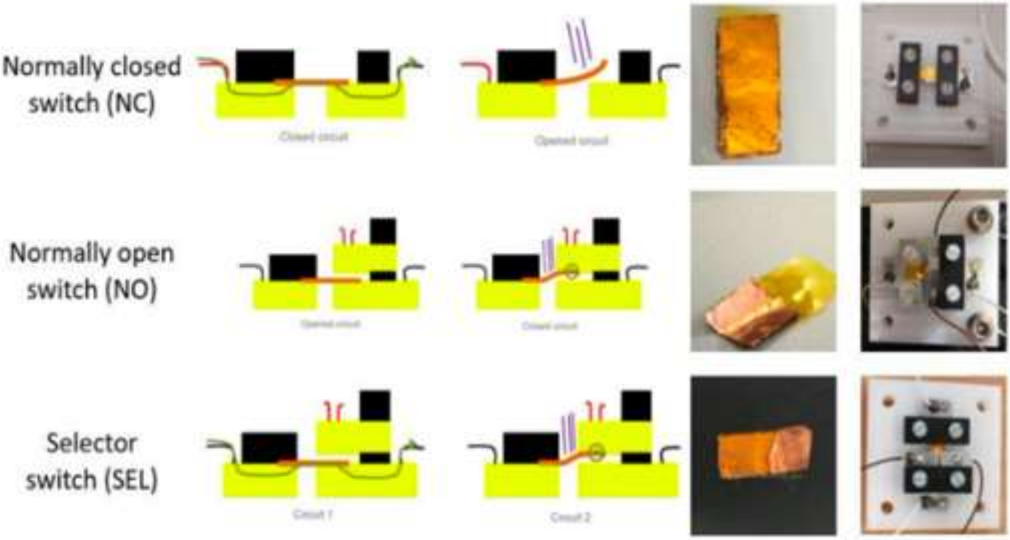


Figure 21. Switch principle and prototypes.

Opto-valves prototypes

A set of three types of optovalves have been designed and fabricated (see Figure 22) to test different technical solutions for the valve. The material is a PMP-azo with PDMS protective layer and has been produced by the laboratories CNR/ISASI and ENEA/SSPT.

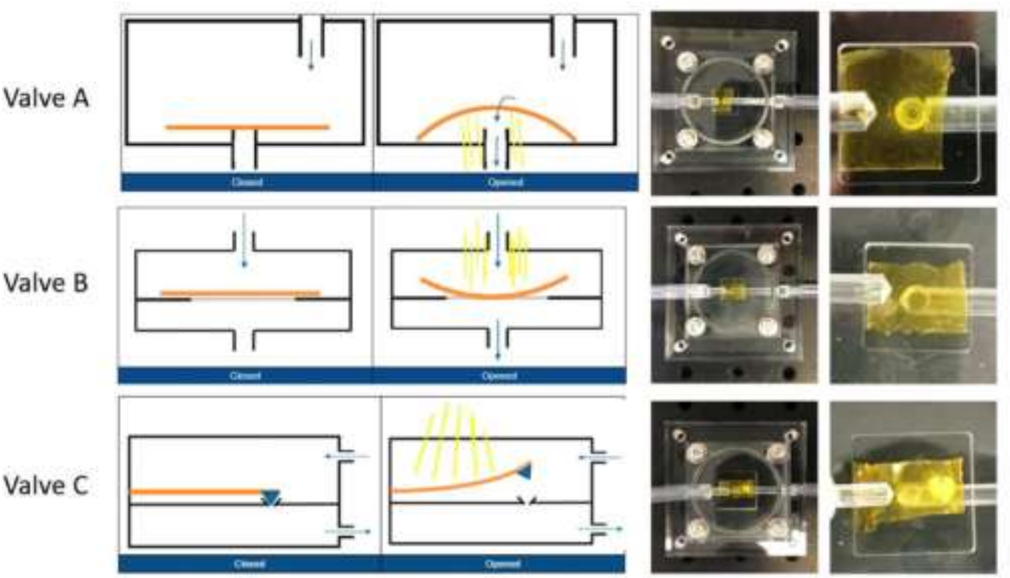


Figure 22. Optovalve A, B and C prototypes.

Optical deflector prototype

The test goal is here to check whether PMP may be used as a deflector (see Figure 23). The application consists of using the bending PMP as a support of a small mirror that reflects a laser beam towards a controlled direction. This implies equipping the PMP with a mirror and to develop a control strategy to drive the LED lights so that the output laser beam moves with a predefined angle. The PMP used is the normally close composite sample which is a PMP of type azobenzene covered by copper on one side. The sample is equipped with a reflective tape for position sensing by laser interferometer and with a mirror for deflector application demonstration.

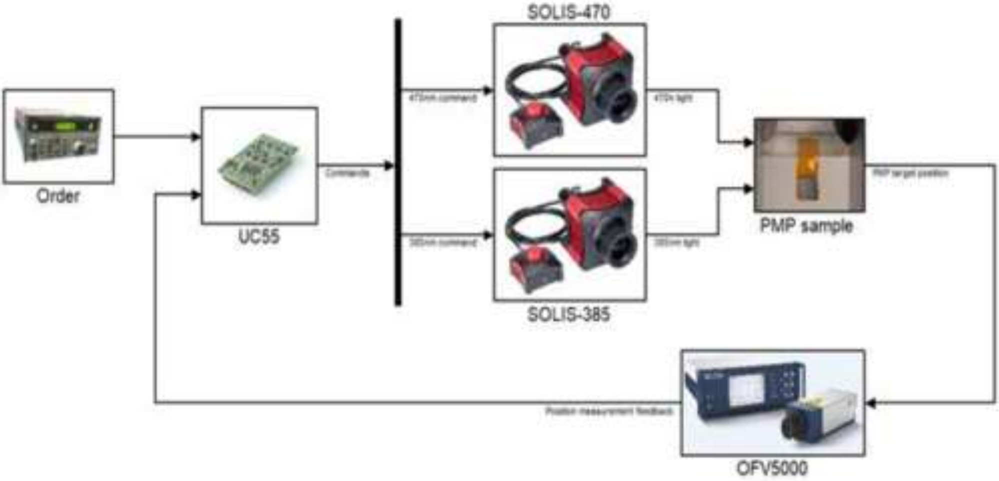


Figure 23. LED light control.

The Figure 24 presents the PMP used which is the normally closed composite sample. It is a PMP of type azobenzene covered by copper on one side and a glued mirror used to reflect the laser beam. The demonstration set up (see Figure 23) is made of a laser source, a first mirror fixed on an in-house double angle actuator (miniaturized Fast Steering Mirror), the mirror fixed on the PMP, two redirection mirrors and the visualization panel. The miniaturized Fast Steering Mirror is activated at high frequency on the two angular axis and transforms the single laser beam into a rosace pattern. When the LEDs are activated, the PMP bends and the rosace is shifted on the visualization panel. The last photo of Figure 24 is an assembly of two photos corresponding respectively of blue LED activation and UV LED activation. Thus, this picture shows the two superposed rosaces corresponding to extreme positions of the rosace.

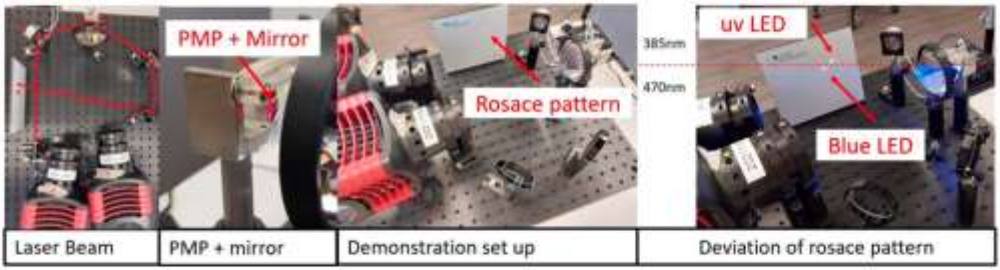


Figure 24. Deflector demonstration with shift of the rosace.

When using PMP as deflectors the stroke is large compared to the component dimensions, but generated forces are low and response time is in the order of a few seconds. Therefore, the optical deflector application suits well to PMP actuator, as the light beam deviation does not bring significant constraints on the PMP. One very positive point is that a servo-control has been successfully implemented with a PI linear control on a adapted range of actuation. As the time response is significant, the bandwidth of the servo control stays low. The corresponding advantage is the PMP actuation should be a very soft actuation without noisy vibration. This is very interesting in optics applications. An additional advantage of the PMP used in deflector application is that the stroke obtained is large versus the mass (or volume) of the actuator. the optical deflector application particularly suits the PMP actuation technology.

Waveselector and spectrometer

Design and manufacturing (by Sitex45 and INFLPR) of waveselector and spectrometer prototypes based on PMP-PZL films with 2D-Photonic Crystals integration for the selection of the desired wavelength will be implemented into reconfigurable optical networks. The prototypes shown in Figures 25-26 are realized as the portable instrumentations and could operate on-site or in-lab environment.

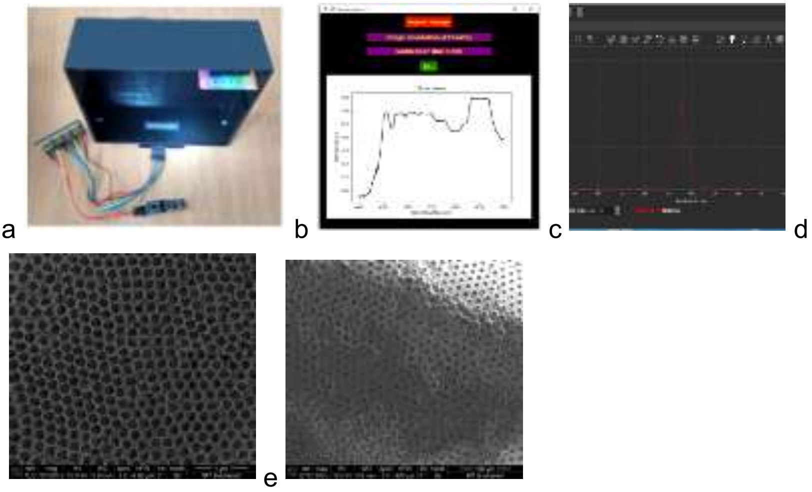


Figure 25. a) General view of Spectrometer instrumentation with main components. b) The spectrometer Interface with full spectral diagram of light source; c) The spectral diagram for a selected wavelength of 635nm with 10nm of FWHM bandwidth; d) e) f) The Photonic Crystals on Optical Fiber substrate manufactured.

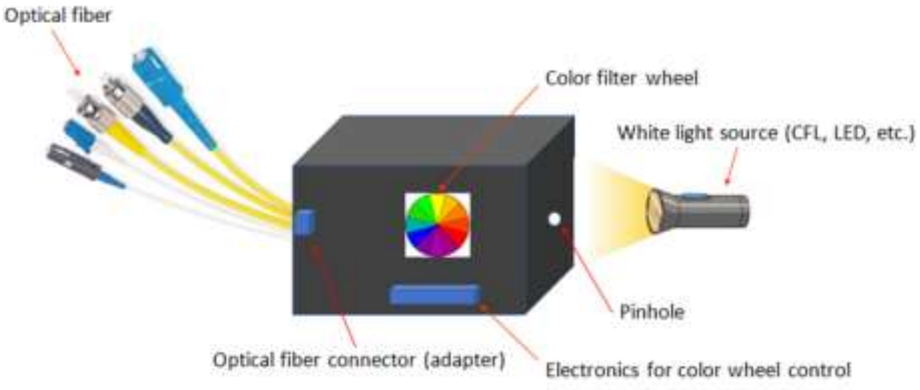


Figure 26. a) Schematization of the waveselector prototype.

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Summary

The EU-funded PULSE-COM project is exploring a radical new class of photo-activated devices that could revolutionise the field of activated piezoelectricity. The project investigates and enhances the properties of photo-mobile polymer films combined with modern lead-free piezoelectric materials to produce new composites that could find use in a wide range of applications. Proper optical techniques have been explored to increase and tune light absorption. The ultimate device combining the photo-mobile polymer films and the lead-free piezoelectric materials are integrated into more complex optoelectronic systems through high-risk incremental research. Applications include photo-activated meso-scale machines such as opto-switches and opto-microvalves, reconfigurable optics and photoenergy harvesting systems.

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PULSE-COM