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Characterization and control of the polar coupling to electric fields in the novel ferroelectric nematic liquid crystal phase

Supervisor: Prof. Liana Lucchetti

Department of Science and Engineering of Materials, Environment and Urban Planning - https://simau.univpm.it/

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Supervisor: Prof. Liana Lucchetti

Optics of Soft Matter group

Prof. Liana Lucchetti (Professor of Physics)

Past job positions:

- 1/11/2000 - 1/10/2015: Research Scientist, University of Ancona (now Università Politecnica delle Marche)
- 1/12/1998 - 31/10/2000: Postdoc fellow. University of Ancona (now Università Politecnica delle Marche).

Research interests:

- Nonlinear optical properties of liquid crystals
- Hybrid structures combining liquid crystals and lithium niobate
- Viscoelasticity of DNA liquid crystals
- Optical trapping and manipulation in liquid crystalline environment
- Ferroelectric nematic liquid crystals
- Wetting and electrowetting of complex fluids

Teaching activity: General Physics to first year students of Ingegneria Informatica, Experimental Physics to first year students of Ingegneria Biomedica and Bionanotechnology to students of the last year of the master's degree in Biomedical Engineering (in English).

Research grants:

- National Project INFM Structure, dynamics and memory effects in confined liquid crystals;
- National Project INFM (2002-2003) Light-Induced Molecular Adsorption and Orientation at Solid-Liquid Crystal Interfaces;
- European Thematic Network Photosensitive organic materials for optical processing –LC Photonet;
- National Project INFM – ASI (Italian Spatial Agency) Real time Holography in liquid crystals for aberrations compensation in large aperture space telescopes;
- European COST Action MP0604 Optical micro-manipulation by nonlinear nano-photonics;
- European COST Action MP1205 Advances in Optofluidics: Integration of Optical Control and Photonics with Microfluidics.

Academic duties: Member of "Gruppo del riesame" of the Department of Science and Engineering of Materials, Environment and Urban Planning

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Most recent publications relevant to the project

. *Fluid superscreening and polarization following in confined ferroelectric nematics*, Nature Physics, **2023**, 19(11), 1658.

. *Walking Ferroelectric Liquid Droplets with Light*, Advanced Materials, **2023**, 35(22), 2212067

. *On the Behavior of Ferroelectric Liquid Droplets in the Vicinity of a Ferroelectric Solid,* Crystals, **2023**, 13(5), 750

. *Optical control of mass ejection from ferroelectric liquid droplets: A possible tool for the actuation of complex fluids,* Journal of Molecular Liquids, **2023**, 384, 122287

. *Explosive electrostatic instability of ferroelectric liquid droplets on ferroelectric solid surfaces*, PNAS, **2022**, 119(32), e2207858119

. *Surface alignment of ferroelectric nematic liquid crystals*, Soft Matter, **2021**, 17(35), 8130

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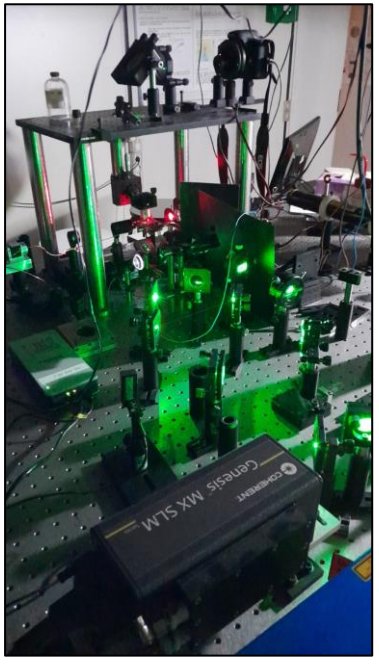
Research group

The Optics of Soft Matter group (https://simau.univpm.it/optics-of-soft-matter/) is currently composed by Prof. Liana Lucchetti (leader), Dr. Raouf Barboza (researcher) and Stefano Marni (PhD student). The research topics are mainly related to optics and nonlinear optics of liquid crystalline materials.
The group developed a novel strategy to characterize the viscoelasiticity of DNA-based liquid crystals and was among the first to combine liquid crystals with lithium niobate ferroelectric crystals both in conventional cells and in optofluidic configuration. It is also one of the pioneers in the characterization of the newly discovered ferroelectric nematic liquid crystal phase.



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The Department of Science and Engineering of Materials, Environment and Urban Planning

Director: Prof. Pierluigi Stipa

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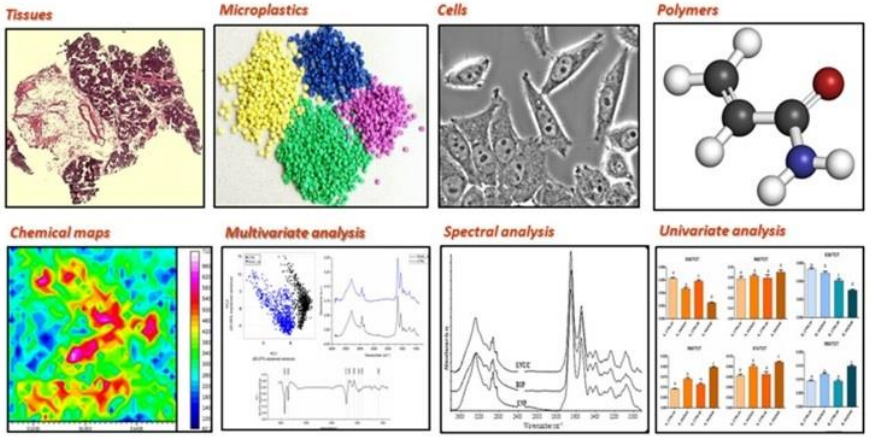
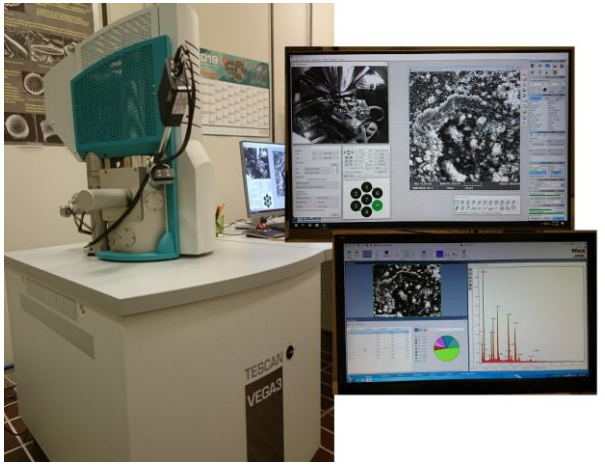
Structure in which the **confluence of different expertises** yield high-level teaching and high-profile international research in the field of **Science of Matter** and **Earth Sciences** with a special focus toward the **Environment**.

It operates within the **Engineering Faculty** offering teachers specialised in the so-called «hard sciences» (**Chemistry** and **Physics**) as well as theachers involved in more «applicative» fields, such as **Materials Engineering**, **Geotechnics**, **Geology**, **Environmental Engineering** and **Urban Planning**.

- **TECHNICAL ARCHITECTURE**
- **APPLIED GEOLOGY AND HYDROGEOLOGY**
- **ENVIRONMENTAL CHEMICAL ENGINEERING**
- **GEOTECHNICAL ENGINEERING**



Research Areas



- **CHEMISTRY (ORGANIC)**
- **MATERIALS SCIENCE AND TECHNOLOGY**
- **EXPERIMENTAL PHYSICS**

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Project Idea

Characterization and control of the polar coupling to electric fields in the novel ferroelectric nematic liquid crystal phase

The recent discovery of ferroelectric nematic liquid crystals[1] (NF) opened up a new field of research with a highly competitive and dynamic research environment. Indeed, this new liquid crystalline phase exhibits a peculiar combination of fluidity and polar coupling to electric fields and is rapidly becoming the focus of the liquid crystals and soft material scientific communities[2-8]. The proposal focusses on a crucial consequence of such a combination: the readiness by which NF can displace polarization charges at the interfaces by small collective rotations of the mean molecular axis. This extreme electric responsivity leads to the cancellation of the electric fields inside the material, a condition reminiscent of the electric properties of conductors, but made more complex by the possible formation of bulk polarization charges due to divergences of the polarization field. We made preliminary observations on the response of NF to electric fields in conditions still unexplored for these materials, i.e. in confined geometry and in combination with active surfaces. The experiments revealed a variety of unprecedented behaviors, such as the explosion of sessile droplets[9], the guiding of electric fields along winding paths and the formation of soliton-like field-responsive defect structures[10]. These observations represent the starting point of the proposed research, **whose primary goal is to explore and understand the wide phenomenology related to the coupling of fluidity, polarization and electric fields**. The interplay of these three factors has the potential of unveiling a host of new and potentially relevant phenomena, such as the coupling of the polarization of fluid and crystalline ferroelectric materials at their interface.

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Project Idea

The Optics of Soft Matter group has access to a wide range of instrumental and technical facilities relevant to the project. These include micro-fabrication techniques for the realization of plain, structured surfaces with electrodes and confined structures and characterization of liquid crystalline materials and of their response to external electric fields.

Polarizing transmission optical microscopy equipped with a CCD camera with high frame rate, and occasionally confocal microscopy, will be used for ferroelectric fluids characterization in the different geometries investigated in the project. The static and kinetic behavior of ferroelectric droplets on ferroelectric substrates, will be investigated with custom made optical set-ups enabling a variety of illumination, polarization and detection schemes at different temperatures. An optical tweezer-like set up will also be used for the study of the NF droplets shape and stability during light irradiation of the substrate.

A large variety of arbitrary wave generators and amplifiers will enable addressing the patterned electrodes with tailored ac and dc fields.

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References

[1] Xi Chen et al., *First-principles experimental demonstration of ferroelectricity in a thermotropic nematic liquid crystal: Polar domains and striking electro-optics*, PNAS 2020, 117, 14021–14031

[2] F. Caimi et al., *Surface alignment of ferroelectric nematic liquid crystals,* Soft Matter 2021, 17, 8130–8139.

[3] M.T. Mathè et al., *Ferroelectric nematic liquid crystal thermo-motor,* Phys. Rev. E 2022, 105, L052701.

[4] N. Sebastian et al., *Polarization patterning in ferroelectric nematic liquids via flexoelectric coupling,* Nature Comm. 2023, 14, 3029

[5] B. Basnet et al., *Soliton walls paired by polar surface interactions in a ferroelectric nematic liquid crystal,* Nature Comm. 2022, 13, 3932

[6] S. Marni et al., *Walking ferroelectric droplets with light*, Adv. Mat, 2023, 35, 2212067

[7] M.T. Mathè et al., *Electric field-induced interfacial instability in a ferroelectric nematic liquid crystal,*2023, Scientific Reports 13, 6981

[8] H. Nishikawa et al., *Rapid, solvent-minimized and sustainable access to various types of ferroelectric-fluid molecules by harnessing mechano-chemical technology,* Journal of Materials Chemistry C, 2023, 11, 12525

[9] R. Barboza et al., *Explosive Electrostatic Instability of Ferroelectric Liquid Droplets on Ferroelectric Solid Surfaces*, PNAS 2022, 119, e2207858119.

[10] F. Caimi et al., *Fluid superscreening and polarization following in confined ferroelectric nematics*, Nature Phys., 2023, 19, 1658