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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

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
- Optical trapping and manipulation in liquid crystalline environment
- Ferroelectric nematic liquid crystals
- Wetting and electrowetting of complex fluids
- Liquid crystal – based biosensors

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 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*.
- *Characterization and control of the polar coupling to electric fields in the novel ferroelectric nematic liquid crystal phase* - grant W911NF2410252 (September 2024 – September 2027)

Academic duties:

2010-2016 Member of the Faculty Committee of Università Politecnica delle Marche
2008-2011 Member of the Scientific Committee of the Department of Science and Engineering of Materials and Enviroment and Urban Planning (SIMAU)
2024 - Member of the “Riesame” Committee of SIMAU
2018 - Member of the PhD School in Ingegneria dell’Informazione
Member of Commissions in competitions for RTdA, RTdB, RTT, Postdoctoral and PhD fellowships.

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Most recent publications relevant to the project

. *Fluid jets and polar domains, on the relationship between electromechanical instability and topology in ferroelectric nematic liquid crystal droplets,* Soft Matter, **2024**, 20(25), 4878

. *A new twist in ferroelectric liquids*, Science, **2024**, 384, 1067

. *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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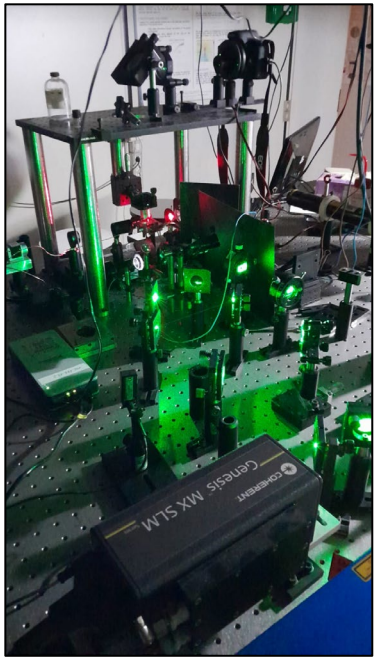
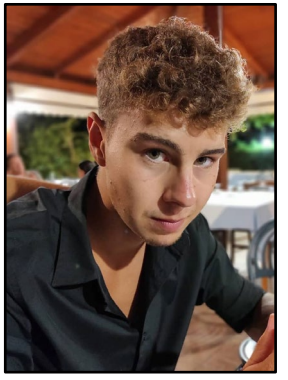
Research group

The Optics of Soft Matter group (https://simau.univpm.it/optics-of-soft-matter/) is currently composed of Prof. Liana Lucchetti (group leader), Dr. Raouf Barboza (researcher), Stefano Marni (former PhD student), Lorenzo Fiorentini (graduate student) and several master students. 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.

The group is a worldwide recognized pioneer in the characterization of the novel ferroelectric nematic phase. Remarkably, the first two Italian papers published on this topic (10.1039/d1sm00734c and 10.1073/pnas.2207858119) are based on its research work.





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Supervisor: Prof. Liana Lucchetti

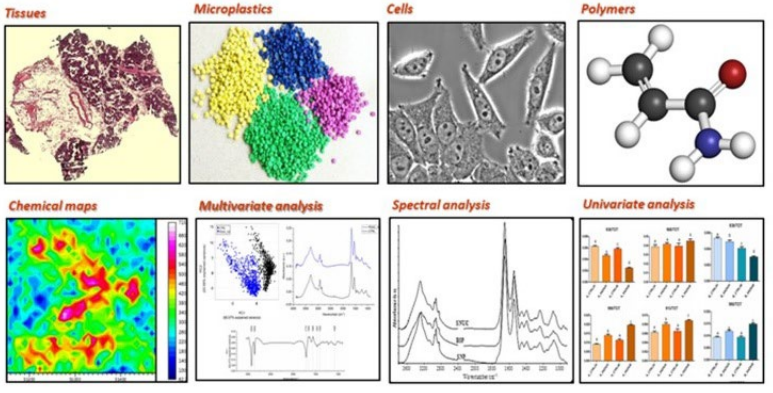
Department description

(https://simau.univpm.it/en/homepage-english/)

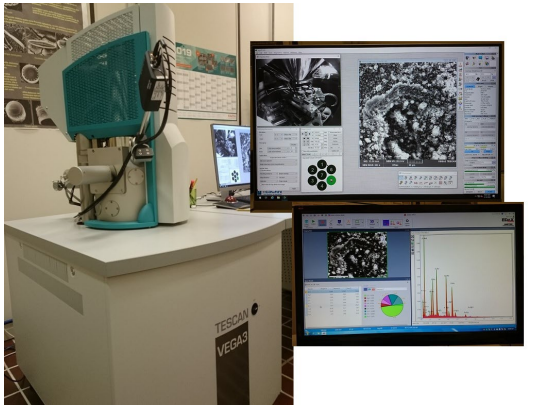
The **Department of Science and Engineering of Materials, Environment and Urban Planning** (**SIMAU**) is a structure in which the **confluence of different expertises** yield high-level teaching and high-profile international research in the field of **Science of Matter** and **Earth Sciences** with 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 teachers involved in more «applicative» fields, such as **Materials Engineering**, **Geotechnics**, **Geology**, **Environmental Engineering** and **Urban Planning**.

- **TECHNICAL ARCHITECTURE**
- **BIOINFORMATICS AND BIOCHEMISTRY**
- **ECOLOGY**
- **ECONOMICS AND MARKETING**
- **EXPERIMENTAL PHYSICS**
- **CHEMICAL FOUNDATION OF TECHNOLOGIES**



Research Areas



- **APPLIED GEOLOGY AND HYDROGEOLOGY**
- **ENVIRONMENTAL AND SANITARY CHEMICAL ENGINEERING**
- **GEOTECHNICAL ENGINEERING**
- **MATERIALS SCIENCE AND TECHNOLOGY**
- **URBAN PLANNING TECHNIQUES**

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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 the ferroelectric nematic liquid crystal phase[1] (NF) opened a new field of research with a highly competitive and dynamic international 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[2-14]. 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, that we called fluid superscreening[9], 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. Our first experiments related to the response of NF to electric fields in confinement and in combination with active ferroelectric surfaces revealed a variety of unprecedented behaviors, such as the explosion of sessile droplets[10-11] and the guiding of electric fields along winding paths[9], all related to fluid superscreening. Starting from these observations, we are planning to explore and understand the wide phenomenology related to the coupling of fluidity, polarization and electric fields in two specific conditions: when NF is in contact with ferroelectric photoresponsive solids and when it is combined with a polymer matrix to form ferroelectric nano Polymer Dispersed Liquid Crystals (nPDLC).

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Project Idea

The proposed experiments have the potential of unveiling a host of new phenomena, such as the coupling of the polarizations of fluid and crystalline ferroelectric materials at their interface and the formation of superparaelectric NF nanodroplets.

The Optics of Soft Matter group has access to a wide range of instrumental and technical facilities relevant to the project. These include tools for the optical, electrical and structural characterization of liquid crystalline materials and of their response to external electric and optical fields.
Polarizing transmission optical microscopy equipped with a CCD camera with high frame rate, and occasionally confocal microscopy and scanning electron microscopy, will be used for ferroelectric fluids characterization in the different geometries investigated in the project. The static and kinetic behavior of ferroelectric sessile 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.

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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

See for example:

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

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

[11] S. Marni et al., *Optical control of mass ejection from ferroelectric liquid droplets: A possible tool for the actuation of complex fluids,* J. Molecular Liquids, 2023, 384, 122287

[12] Kumari et al., *Chiral ground states of ferroelectric liquid crystals,* Science, 2024, 383, 1364

[13] Marchenko et al., *Polar Self-Organization of Ferroelectric Nematic-Liquid-Crystal Molecules on Atomically Flat Au(111) Surface,* Phys. Rev. Lett. 2024, 132, 098101

[14] Ma et al*., Topological defects induced by air inclusions in ferroelectric nematic liquid crystals with ionic doping,* Soft Matter, 2025, https://doi.org/10.1039/D4SM01261E