Project No. 02513

Report form of Joint Research Project at ZAIKEN (FY2025)

Title of Project	**Micro-thermometer composed of DNA liquid crystals**		
Priority Area	**I-C Prolongation of service Life and Properties, II-C 4R and Properties**		
New proposal or **Continuation of**			
Name of Main Applicant	**Tommaso P. Fraccia**		
Institution	**Dipartimento di Scienze Farmacologiche e Biomolecolari, Università degli Studi di Milano**	**title**	**Associate Professor**
Name of partner applicants (if any)	**Professor Tommaso G. Bellini, Dipartimento di Biotecnologie Mediche e Medicina Traslazionale, Università degli Studi di Milano**		
Name of the host faculty at Waseda	**Yuka Tabe**		

Aim of the research project

We propose to combine the expertise of the applicant, Prof. Tommaso Fraccia, on structures and properties of DNA-LCs, and of the host at Waseda, Prof. Yuka Tabe, on thermomechanical dynamics of cholesteric LCs, to construct an eco-friendly micro-thermometer composed of DNA-LCs, which visualizes temperature distribution in various water solutions.

It is known that a chiral nematic (cholesteric) droplet under a temperature gradient shows a uniform rotation about the gradient axis. So far, the phenomenon has been academically investigated only with cholesteric LCs composed of synthesized hydrophobic compounds, which are harmful to the environment. In this joint research, we propose to replace cholesterics with DNA-LCs and try to realize their steady rotation driven by a temperature gradient.

Because of the self-assembling nature and the biological origin, the DNA device can be used repeatedly for long time without putting any burden on the environment.

The project aims to realize stable DNA-LC cholesteric coacervate microdroplets by complexation of DNA and polycations and subsequently test their behavior under a temperature gradient in the Tabe-lab in Zaiken, which owns a home-made controller to apply a precise temperature gradient to LC samples, attached to a modified microscope.

Then, we examine the dynamics of DNA-LC microdroplets under a temperature gradient, expecting that the thermomechanical coupling originating from the chirality of DNA-LCs should be observed.

Confirming the steady rotation of the DNA-LCs, we then investigate the following properties:

(1) the relation between the angular velocity ω of the local molecular rotation and the temperature gradient ∇T

(2) the relation between the rotational direction and the super-molecular structures of the DNA-LCs / the molecular structure of the constituent oligomers

(3) the dependence of the conversion efficiency from ∇T to ω on the concentrations of the DNA oligomers and of the polycations (Poly-Lysine, Poly-Arginine and Poly-Ammines)

In addition, we should reveal the induced mass flows in the solutions. The temperature gradient possibly causes convective flows of the isolated oligomers and polycations, which may drive the unidirectional rotation of the DNA-LCs as well. To visualize the flow field, we use Particle Tracking Velocimetry (PTV) method and ascertain the dominant flux to drive the rotation.

Phenomenologically, ω is expected to be linear to ∇T, given as $\omega = \nu \nabla T$. We measure the thermomechanical coupling constant ν under various conditions and optimize the system.

Once the complete correspondence between ω and ∇T under the given condition is obtained, we can construct a micro-thermometer by dispersing the DNA-LC microdroplets in an aqueous solution with unknown temperature distribution. The local rotation of the LC domains gives us the thermal map. Since the size of the DNA-LC microdroplets is typically few-tens of micrometer, the thermal map should possess the same spatial resolution. It can be applied to various aqueous solutions without contaminating and repeatedly used for a long time.

Contents and results of the research

The assembly of DNA-LC cholesteric coacervate microdroplets was achieved through the complexation of DNA with polycations and investigated as a function of various properties of the DNA oligomers, including:

- Length: from 6-mer to 24-mer DNA oligonucleotides;
- End-to-end interactions: blunt-end stacking and pairing of complementary GC and AT dangling ends.

These parameters were found to play a crucial role in determining the phase diagram of the coacervate phase as a function of monovalent salt concentration (NaCl) and temperature (T).
Complex coacervates assembled using the 12-mer DNA oligomer sDD (5'-GCGAATTCGCGC-3') and poly-L-lysine (PLL, MW 30–70 kDa) were shown to produce stable cholesteric DNA-LC microdroplets (Fig. 1) over a wide range of salt concentrations (0.75 M < [NaCl] < 0.95 M) and temperatures (10°C < T < 45°C). This system therefore represents an excellent candidate for investigating temperature-induced rotation of cholesteric droplets under thermal gradients of varying magnitude.

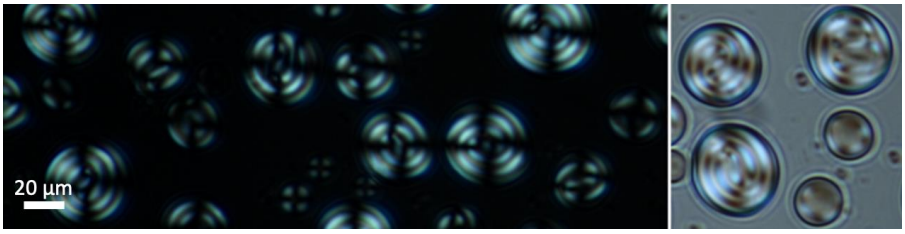

Figure 1 – Polarized optical micrograph of DNA-LC cholesteric coacervate microdroplets obtained in sDD–PLL mixtures at 0.85 M NaCl and T = 25°C. Left: perpendicular polarizers; right: partially de-crossed polarizers.

The planned investigation of the dynamics of DNA-LC microdroplets under a temperature gradient could not be carried out due to unforeseen circumstances that prevented the applicant's visit to the Tabe laboratory in Zaiken.

Outputs of the project (publications, presentations, patents)

The results of the joint project have been partially presented by oral presentations:
Fraccia T.P. "Multiphase liquid-liquid crystalline coacervates" invited seminar at LBE – ESPCI Paris, France on 23/10/2025
Fraccia T.P. "Liquid - liquid crystal phase separation in DNA - polycations mixtures", Report Meeting - ZAIKEN Joint Research Project on 03/03/2026

A manuscript is currently in preparation for publication on an international journal.