

DMOAP-Aligned Bimesogenic Dimers for Wide-Band Spectral Tuning

Rohan Sonar¹, Agus Budi Dharmawan¹, Ismael Benito-Altamirano^{1,2,3}, J. Daniel Prades¹

¹ *Institute of Semiconductor Technology (IHT) & Laboratory for Emerging Nanometrology (LENA),
Technische Universität Braunschweig, Braunschweig, Germany*

² *eHealth Centre, Faculty of Computer Science, Multimedia and Telecommunications,
Universitat Oberta de Catalunya, Barcelona, Spain*

³ *Department of Electronics and Biomedical Engineering, Universitat de Barcelona, Barcelona, Spain*
Email: rohan.sonar@tu-braunschweig.de

Summary:

The objective of this work is to build a wide-range liquid crystal tunable filter (LCTF) designed using a simplified fabrication process, bypassing the need for specialized cleanroom facilities. A central concept involves using a strategic mixture of three commonly available liquid crystals and a chiral dopant to get the right HTP (Helical Twisting Power) and thus an initial pitch exactly where we needed it. For the assembly, since commercial agents like SE-1211 are harder to access, we coated our ITO (Indium Tin Oxide) substrates with DMOAP ((Dimethyloctadecyl[3-(trimethoxysilyl)propyl]ammonium chloride)), which has proved to be a reliable and cheaper alternative for homeotropic alignment. After assembly and filling the cells with our LC (Liquid crystal) mixture, we could precisely drive the device as a voltage-controlled variable optical filter. This approach shows that with a combination of bimesogens and surface anchoring, we can achieve high-end spectral tuning controlled via field-dependent modulation.

Keywords: Non-Mechanical Tunable Optical Filter, Wavelength Tuning, Liquid Crystal Optics, Hyper-spectral Microscopy, Lensless microscopy.

Background and Motivation

Optical filters are essential for isolating spectral bands in photonic systems, yet conventional static filters are limited by logistical and mechanical constraints. Tunable filters address these challenges by enabling real-time spectral characterization and improved experimental throughput. While many existing tunable systems are prohibitively bulky or expensive, LC technology is re-emerging as a powerful alternative. LCs provide a cost-effective, high-performance solution that is easy to handle and can operate without the need for specialized industrial hardware. This makes them an ideal platform for high-end spectral tuning that remains accessible to the broader research community. [1-4]

This study shows a wide-band tunable optical filter that operates across the visible spectrum. While most studies rely on restricted industrial polyimides like PI-1211 to achieve homeotropic alignment, we utilized a highly diluted DMOAP solution as a benchtop alternative [5]. This approach bypasses the need for specialized industrial hardware and proprietary chemicals, providing a reliable, cost-effective method for achieving alignment in a standard laboratory setting.

Methodology

For our system, the liquid crystal was optimized by substituting CB6OCB with the more commercially accessible CB9CB (4',4''-(nonane-1,9-diyl)bis([1,1'-biphenyl]-4-carbonitrile)), creating a novel ternary bimesogenic mixture with a chiral dopant concentration calculated to set the precise starting pitch. Our fabrication process compared a BY (Bright Yellow) planar alignment against a DMOAP-based homeotropic alignment; as expected, the planar configuration failed to allow for pitch tuning at lower voltages [6], whereas the DMOAP treatment, which was applied via a simple chemical bath, has successfully facilitated the heliconical transition as mentioned in literature [5]. The cells were assembled at a fixed thickness and filled with the LC mixture, and while the work is in its initial stages, we have successfully reproduced the Ch_{OH} (Oblique Helicoidal) state.

Specifically, the observed "blue-shift" (wavelength shortening) under increasing field strengths confirms the relationship described in Eq. 1 [7], where the heliconical pitch P exhibits an inverse proportionality to the electric field E

$$P(E) = \frac{2\pi K}{\epsilon_0 \Delta \epsilon E^2} \quad (1)$$

where, K = bend elastic constant, ϵ_0 = vacuum permittivity, $\Delta\epsilon$ = Dielectric anisotropy, E = Electric field. Furthermore, the continuous tuning of the reflection peak illustrates the direct proportionality between the pitch and the reflected wavelength (λ) as defined in Eq. 2

$$\lambda = n \cdot P \quad (2)$$

where, n is average refractive index and P is the helical pitch of LC.

Results

As seen in Fig 1, the device successfully demonstrated the tuning of this filter. Under a stable AC electrical field of 1 kHz (sine) on a temperature controlled stage, as the voltage was incrementally reduced, the system successfully transitioned through a sequence of distinct spectral peaks, shifting from blue to yellow and finally to red. Due to the manual assembly and variations in cell gap uniformity ($d \approx 7 \mu\text{m}$), the observed reflection was locally non-homogeneous; however, this is a minor technical variation that can be readily mitigated through the use of calibrated spacers or automated cell-sealing techniques.

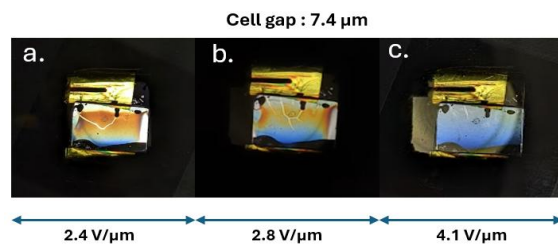


Fig. 3. Field-induced wavelengths in the optical filter. (a) Red, (b) orange, and (c) blue states under crossed polarizers as a function of voltage. Active area: 5mm x 5mm, Filter thickness: 2mm.

Under crossed polarizers, the cell appeared dark in its high-voltage state, indicating that the field had pushed the system beyond the critical threshold ($E_c \approx 5 \text{ V}/\mu\text{m}$). At this saturation point, the heliconical structure collapsed into a homeotropically aligned isotropic state, making the cell totally transparent. This transition was reversible.

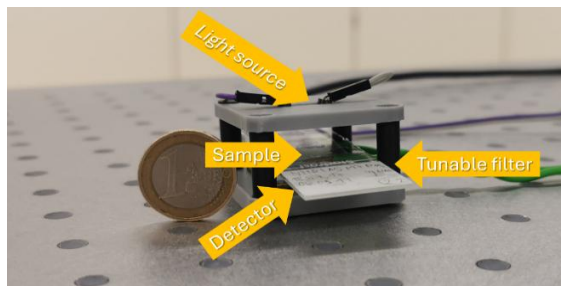


Fig. 4. The integration of the tunable filter and lensless microscope, facilitates a compact, portable imaging platform.

A prominent application for this technology is in lensless microscopy (Fig 4), where LCTFs enable a compact and versatile imaging platform [8]. By integrating tuning directly for either excitation or emission filtering, these systems provide high-resolution spectral data without the need for bulky mechanical hardware. This configuration captures enhanced spatial and spectral information while maintaining a portable, small-scale form factor.

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