# Ferroelectric Nematic Liquid Crystals: Mixtures and Applications

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## Abstract

***Ferroelectric nematic liquid crystals (FNLC) were first identified in 2017. FNLC are polar fluids with high spontaneous polarization and are SHG active. In this paper, we will describe some of the more unusual properties of FNLC and explore the development of room temperature stable ferroelectric nematic mixtures. We will also present potential application fields of these unique liquid crystals.***

## Author Keywords

Ferroelectric; nematic; liquid crystal; spontaneous polarization; FNLC

## Introduction

Since the 1930's, we have been developing and selling liquid crystal singles and mixtures to the display industry (1). Almost all current displays are based on calamitic nematic liquid crystals consisting of rod-like structures. The dielectric polarizability and dipole can be either along or across the director leading to positive or negative dielectric anisotropy respectively. The molecular dipole moments are randomly oriented.

In 1916 M. Born (2) predicted the existence of a polar nematic phase (Nf), where the molecular dipoles are correlated leading to a macroscopic polarization in the phase. It was nearly 100 years later that it was realized; Nishikawa (3) and Mandle (4) published almost simultaneously on a polar nematic phase in the compounds DIO and RM734 respectively. The ferroelectric nature was confirmed (5), and the miscibility and ferroelectric properties of the two compounds were investigated further in 2020 (6). The materials behave as nematic liquid crystals but with one important difference, they show ferroelectric properties with a spontaneous polarisation (Ps) of up to 7 $\mu C/cm^2$ significantly higher than the 10-100 $nC/cm^2$ typically observed in ferroelectric SmC compounds (7), but still an order of magnitude less than Lithium Niobate (8). In 2021 Manabe *et al* published on the presence of the Nf phase at room temperature in the compound UUQU-4-N (9). The structures are shown in Figure 1.

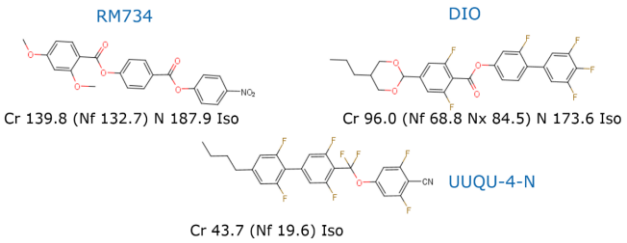


**Figure 1**: Structure and phase transitions (°C) of RM734, DIO and UUQU-4-N.

Figure 2 shows a cartoon representation of the FNLC phase. At lower temperatures polar smectic phases can sometimes be observed, (10-12), again the polarization lies along the long molecular axes (13).

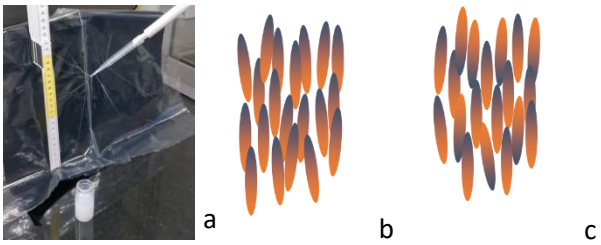


**Figure 2:** a) The physical appearance of Nf phase, b) orientation of dipoles in Nf and c) Nematic phase. The nature of the threads shown in (a) have been elucidated by Eremin *et al* and Jakli *et al* (14,15)

The FNLC phase does not align well on standard alignment polyimides, exhibiting spontaneously twisted alignment in antiparallel rubbed cells, see Figure 3. For an explanation of 3b, see reference (16)

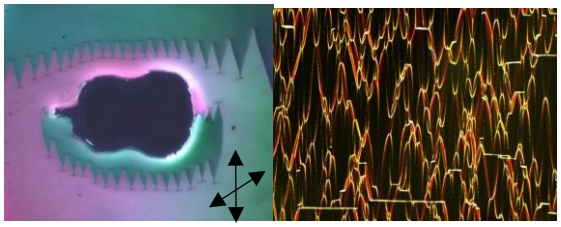

**Figure 3**: Example of alignment on standard PI: a) FNLC-919, two opposing twist domains in rubbed 5 um cell b) conics in FNLC-919, parallel rubbed 6 um cell

The Ps can be measured using the triangular wave (field reversal) method (17). A typical current response and hysteresis curve is shown in Figure 4. As a non-centrosymmetric medium, FNLC also exhibits Second Harmonic Generation (SHG) (18,19).

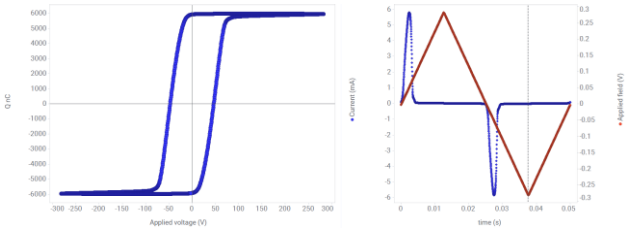

**Figure 4**: Measurement of spontaneous polarization, showing typical ferroelectric hysteresis loop

## Mixture Development

A review of LC singles in our portfolio revealed several highly polar candidates, which could be used for creating mixtures with the Nf phase. Mixtures have been developed with both direct and indirect transitions to the Nf phase between 0° and 100°C. FNLC-919 and FNLC-1571 have been extensively researched by the academic community.

## Applications

Applications of FNLC fall into two groups: Non-linear and linear electrooptical effects, and physical effects of a ferroelectric. Examples of the first group include patterned SHG, obtained by creating a photopatterned surface which, coupled to the flexoelectric response of the FNLC, aligns the polarization in FNLC-1571 (20). A very exciting use is the generation of tunable entangled photons, which has potential in quantum computing and cryptography (21).

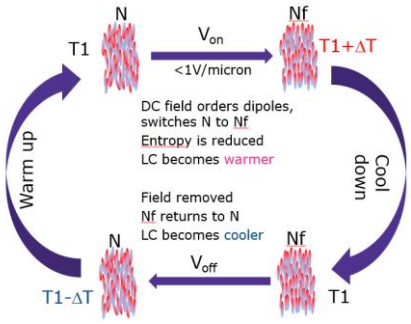


**Figure 5:** Electrocaloric cycle in FNLC

The electrocaloric effect in FNLC (fig 5) has been extensively investigated by Nikolova et al (22).

## Conclusion

Ferroelectric nematic and smectic liquid crystals are currently subject to intense research, with many potential applications which are yet to be fully discovered.

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