



# Magnetically induced alignment of FNS

O. Buluy<sup>a</sup>, E. Ouskova<sup>a</sup>, Yu. Reznikov<sup>a</sup>, A. Glushchenko<sup>b,\*</sup>, J. West<sup>b</sup>,  
V. Reshetnyak<sup>c</sup>

<sup>a</sup>*Institute of Physics, Prospect Nauki 46, Kyiv 03039, Ukraine*

<sup>b</sup>*Liquid Crystal Institute, Kent State University, Kent, OH 44242, USA*

<sup>c</sup>*Taras Shevchenko University, Kyiv, Ukraine*

---

## Abstract

In this work we report the observation of magnetically controlled anchoring of ferro-nematic suspensions. We found that application of a weak magnetic field to a cell with the ferro-suspension induces an easy orientation axis with weak anchoring energy on a glass surface. Varying the direction of the magnetic field can change the easy axis orientation. We believe that the magnetically induced alignment of the ferro-liquid crystal (LC) suspension is caused by adsorption of the ferro-particles on the glass surface and this alignment can be manipulated with a magnetic field. The developed system is very promising for ultra-sensitive magnetically controlled LC devices for information processing and storage.  
© 2002 Elsevier Science B.V. All rights reserved.

*Keywords:* Liquid crystal; Ferro-nematic suspension; Alignment

---

## 1. Introduction

Research into ferromagnetic particles suspension in liquid crystals (LCs) has a rather long history, beginning in 1970 with the work of Brochard and de Gennes [1,2]. They proposed to increase the magnetic sensitivity of nematic LCs by doping with small ferromagnetic grains. Several attempts have been made to realize this idea but agglomeration of the ferro-grains prevented their homogeneous distribution [3–5]. Treatment of ferro-particles with surfactant improved the stability of the ferro-nematic suspensions (FNSs). The authors of these publications reported uniform director reorientation of the LC matrix upon application of magnetic fields of about 1 G. Nevertheless, the ferro-nematic liquid crystal (FNLC) still agglomerates over time. Therefore most recent investigations of ferro-nematics have been done theoretically [6,7]. These studies determined that the spatial distribution of ferromagnetic particles was not homogeneous in the LC bulk and strongly depends on

the LC–particle interactions, the director field, and boundary conditions.

In this work we control the LC alignment in a cell using a magnetic field applied to a layer of ultra-fine magnetic particles concentrated on the aligning surfaces.

## 2. Materials and experiments

We studied a suspension of magnetic particles,  $\text{Fe}_3\text{O}_4$ , in the nematic LC pentyl-cyanobiphenyl (5CB). Needle-like ferromagnetic particles of about  $1\ \mu\text{m}$  size were mixed with a surfactant in a ratio 1:2 and milled in a vibration mill for 120 h. After the milling, we mixed the surfactant-covered ferro-particles with the LC in the ratio 1:65 at temperature above the clearing point of the LC.

The symmetric cells (thickness  $L = 50\ \mu\text{m}$ ) consisted of identical glass substrates. The cell was filled with pure 5CB or FNS. Non-homogeneous quasi-planar alignment of either 5CB or FNS was observed in the polarizing microscope (Fig. 1a). A magnetic field of  $\vec{H}_0 \geq 5\ \text{kGs}$  produced uniform alignment in pure 5CB. In

---

\*Corresponding author.

E-mail address: anatoliy@lci.kent.edu (A. Glushchenko).

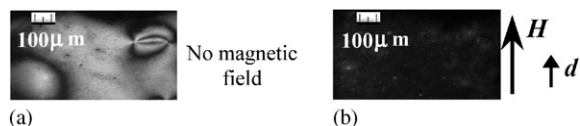


Fig. 1. FNS textures observed in crossed polarizers: (a) without magnetic field application, (b) after magnetic field application.

the case of the suspension a lower field,  $\vec{H}_0 \geq 1.2$  kGs, was enough to align the FNS uniformly (Fig. 1b). The LC director,  $\vec{d}$ , aligned parallel to the magnetic field vector.

The monodomain structures in the cells with pure 5CB or FNS behave differently in the magnetic field. We placed the cells between the magnet poles so that the magnetic field was aligned  $45^\circ$  to the LC director,  $\vec{d}$ , in the cells' plane. The LC and FNS orientation was analyzed after application of the magnetic field. The pure LC returns to its original orientation after removal of the magnetic field. The FNS is realigned by the magnetic field and does not return to its original orientation after removal of the field. The orientation of the director could be readjusted to any angle using the magnetic field. This new alignment of the FNS disappeared in several days after removal of the magnetic field. These results suggest that the magnetic field changed the surface alignment of ferromagnetic particles bound on the glass surface.

To conform our prediction and obtain quantitative information about the characteristics of the magnetically induced alignment we carried out the experiments with a combined cell (thickness  $L = 50 \mu\text{m}$ ) consisting of a reference and test surfaces. The reference, was a rubbed polyimide surface that produced low tilt angle ( $1\text{--}2^\circ$ ) planar alignment of pure 5CB or FNS parallel to the rubbing direction,  $\vec{d}_{\text{ref}}$ . An untreated glass substrate was used as the test surface. The cells were put between the poles of the magnet in the geometry depicted in Fig. 2. The rubbing direction,  $\vec{d}_{\text{ref}}$ , on the reference surface made an angle of  $\varphi_0 = 45^\circ$  with the magnetic field vector. Polarization of the input beam was parallel to the direction  $\vec{d}_{\text{ref}}$  on the reference surface. The polarization direction of the transmitted beam coincided with the director on the test surface,  $\vec{d}_{\text{test}}$ , and could be determined by rotation of the analyzer.

The dependence of a stationary value of the director reorientation angle,  $\varphi_{\text{test}}$ , at the test surface on magnetic field intensity is shown in Fig. 3 for the cells filled with FNS and pure 5CB. The director turns *toward* the magnetic field in all cases. The magnetic field required to reorient FNS is much smaller than for pure LC.

After the magnetic field was removed, pure LC relaxes rapidly and the angle  $\varphi_{\text{test}}$  becomes equal to zero (Fig. 4). For FNS the director on the test surface relaxes during tens of minutes to a quasi-steady value  $\varphi_{\text{test}} \approx 6\text{--}7^\circ$  (Fig. 4).

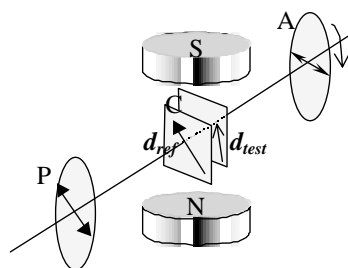


Fig. 2. Experimental set-up: P—polarizer, A—analyzer, S, N—magnetic poles, C—LC or FNS cell.

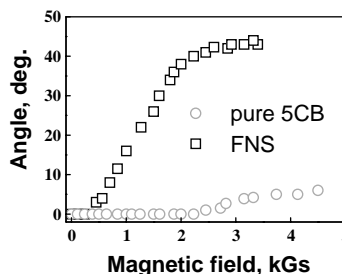


Fig. 3. Dependence of the  $\vec{H}$ -induced director reorientation angle on applied magnetic field.

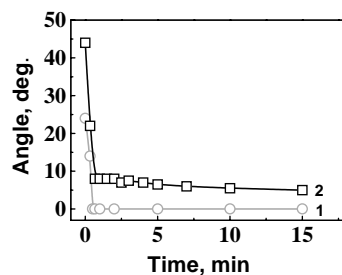


Fig. 4. Relaxation of magnetically induced twist angle after magnetic field removal.

### 3. Discussion and additional experiments

Our results show that the lower magnetic field is required to align FNS than pure 5CB. Since the magnetic dipoles of the ferro-particles are parallel to their long axes, the alignment of LC is parallel to  $\vec{H}$  in the symmetric cell. This alignment is preserved after removing the magnetic field because of an interaction between the ferro-particles and LC. Since the homogeneous alignment disappears in several days after treatment of the cell by the magnetic field, we suppose that the magnetically induced anchoring is very weak.

In the case of the combined cell due to a strong anchoring on the rubbed reference surface we obtained

the director reorientation on the test surface and as a result a twist structure of FLC in the cell. Slow relaxation to the equilibrium alignment after removal of the magnetic field can be explained either by the production of an easy axis on the test surface,  $\vec{e}_{\text{test}}$ , that gradually relaxes to the equilibrium alignment or by anomaly high surface viscosity of the suspension. To determine which explanation is correct we removed FNS from the magnetically aligned symmetrical cell and then we filled this empty cell with pure LC. If the surface viscosity controls the alignment then the re-filled cell would not retain the previous state. However, we observed the restored, durable, magnetically induced alignment of LC. From the experiment, we found that LC is oriented along the same axis as FNS magnetic particles. Therefore, we can conclude that the easy axis is produced on the test surface and caused by adsorption of the ferro-particles on the test surface. The average direction of the orientation of these particles is determined by interaction of FNS and the magnetic field.

In the case of the combined cell small anchoring energy on the test surface,  $W_{\text{test}}$ , causes collective reorientation of LC and ferro-particles *toward*  $\vec{d}_{\text{ref}}$  after removal of the applied magnetic field due to strong anchoring of LC at the reference surface and the LC volume elastic torque. It results in a slow drift of the easy axis,  $\vec{e}_{\text{test}}$ , to the equilibrium state determined by the torque balance on the test substrate:

$$\frac{\sin 2(\varphi_{\text{test}} - \varphi_0)}{\varphi_{\text{test}}} = \frac{2K_{22}}{W_{\text{test}}L} \quad (1)$$

where  $K_{22}$  is the twist elastic constant of LC and  $\varphi_0$  the direction of the magnetically induced easy axis. Assuming that the value  $K_{22}$  of the ferro-suspension is close to the twist constant of pure 5CB  $K_{22} \approx 4 \times 10^{-7}$  dyne,  $\varphi_0 = 45^\circ$  and  $L = 50 \mu\text{m}$ , we get an extremely weak anchoring energy  $W_{\text{test}} \approx 10^{-6}$  erg/cm<sup>2</sup>.

#### 4. Conclusions

We have produced liquid crystal alignment by a layer of magnetic particles bound to the substrate surface. Application of a magnetic field results in the orientation of FNS along the magnetic field. The value of the magnetic field required for the orientation of FNS is less than half that required for pure LC. The magnetically induced orientation is multi-stable and is characterized by weak anchoring energy. Changing of the magnetic field direction varies the direction of the resulting FLC alignment.

We believe that the magnetically controlled alignment is very promising for ultra-sensitive magnetically controlled LC devices and information processing and storage.

#### Acknowledgements

This work was supported by NSF ALCOM grant, DMR 89-20147 and INTAS grant # 99-00312.

#### References

- [1] F. Brochard, P.G. de Gennes, J. Phys. (Paris) 31 (1970) 691.
- [2] C.F. Hayes, Mol. Cryst. Liq. Cryst. 36 (1976) 245.
- [3] Shu-Hsia Chen, Nabil M. Amer, Phys. Rev. Lett. 51 (1983) 2298.
- [4] B.J. Liang, Shu-Hsia Chen, Phys. Rev. A 39 (1989) 1441.
- [5] M. Koneracka, V. Kelnerova, P. Kocansky, T. Kuczynski, J. Magn. Magn. Mater. 140–144 (1995) 1455.
- [6] Yu.L. Raikhler, V.I. Stepanov, J. Magn. Magn. Mater. 201 (1999) 182.
- [7] S.V. Burylov, Yu.L. Raikher, Mol. Cryst. Liq. Cryst. 258 (1995) 107.