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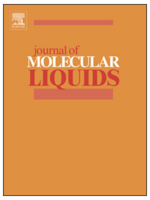

The effect of external applied fields on the third order nonlinear susceptibility of ferro-nematics

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ABSTRACT

This experimental work reports measurement of the third order nonlinear susceptibility of the nematic liquid crystals with the impurity of Fe_3O_4 nanoparticles with the mean diameter of 34 nm and weight concentration of 1 wt.%. The study was performed without and under the influence of electric and magnetic field consequently by applying different voltages and induction 0.5 T. The results show in the case of nematic liquid crystals with magnetic nanoparticles, the parameter changes caused by the external fields depend on the direction of external fields with respect to the director axis $\vec{n}$ and then the type of initial alignment. The direction of applied external fields is perpendicular to the cell surface, so there was no observable shift in the nonlinearity in the case of hemotropic alignment sample. The experimental results show that the change in the third order nonlinear behavior of homogeneous-aligned cells reoriented the ferro-nematic molecules to their homeotropic state.

1. Introduction

Small single-domain magnetic particles after wrapping by a kind of surfactant and dispersing in organic or inorganic carrier liquids can form a magnetic fluid (MF) [1,2]. By simply mixing of MFs and nematic liquid crystals (LCs), ferro-nematic (FN) materials can be obtained [2].

The applications of liquid crystals are mostly based on the reorientation of liquid crystalline molecules in external electric or magnetic fields [3]. In particular, nematic liquid crystal (NLC) has the crystalline axis (director axis $\vec{n}$) which is the most susceptible to small external perturbations (thermal, electric, magnetic, optical, etc.) [4]. In contrast to LCs with high sensitivity to electric fields, conventional LCs are relatively insensitive to magnetic fields [3,5]. This is due to the small anisotropic diamagnetic susceptibility ($\Delta\chi$) of the LC [1]. The idea to increase the sensitivity of LCs to magnetic fields was firstly done through doping the LCs with very low concentrations of magnetic particles [3,5–7]. Because of controlling magnetic impurity behavior in NLCs, they have to show some properties such as small size and controlled shape, without any reaction with the LC molecules and partially weak interaction with each other unlikely the LC molecules [8]. Magnetic nanoparticles (NPs) show all of these aspects and their preparation technology was successfully improved in these years [8]. In such systems the most important characteristic is coupling the molecular orientation of liquid crystal with nanoparticle properties [9].

In our previous work [10] we have studied the effect of initial alignment on the nonlinearity of pure and doped NLCs with different compositional percentages of Fe_3O_4 NPs. The goal of this work is analyzing the influence of external fields on third order nonlinear susceptibility of magnetic NPs doped E7 nematic liquid crystals (FNs) by using the single-beam z-scan method.

To study the particular initial stage of molecular rotational motion, the measurements were carried out under the influence of the electric and magnetic fields, the voltage and induction values of which were sufficiently more than those necessary for Freedericksz effect [8].

2. Experimental

2.1. Influence of external fields on the FN director

The influence of fields on fluctuations of the nematic director has been studied using continuum theory [11]. Consider a linear polarized light impinges on the ferro-nematics with initial director orientation $\vec{n}$. If the intensity of light is strong enough, a reorientation will occur [4]. The steady-state reorientation of director $\vec{n}$ can be obtained by minimizing the free energy density, *F* defined by Eq. (1):

$$F=\frac{1}{2}\left[K_{11}\left(\vec{\nabla}\cdot\vec{n}\right)^2+K_{22}\left(\vec{n}\cdot\left(\vec{\nabla}\times\vec{n}\right)\right)^2+K_{33}\left(\vec{n}\times\left(\vec{\nabla}\times\vec{n}\right)\right)^2\right] -\frac{1}{16\pi}\vec{D}\cdot\vec{E}+\frac{fk_bT}{V}\ln f+\frac{W}{d}f\left(\vec{n}\cdot\vec{m}\right)^2. \quad (1)$$

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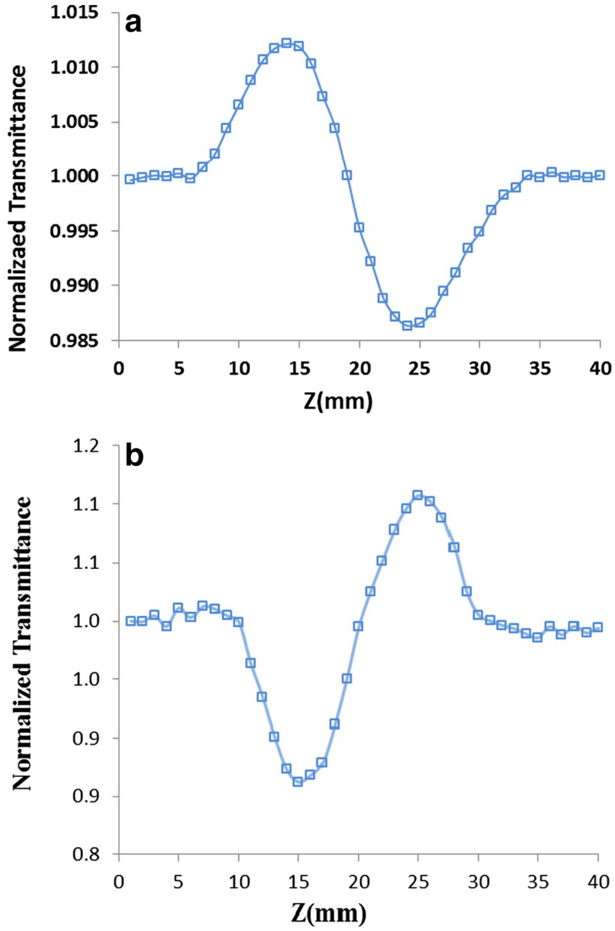

Fig. 1. Normalized pure nonlinear refraction curve for FNs in a) homogeneous alignment and b) homeotropic alignment.

Here, K_{11}, K_{22}, and K_{33} are splay, twist, and bend elastic constants; respectively, k_b is the Boltzmann constant, f is the filling factor that is the volume fraction of the magnetic grain, V is the volume of the particle, d is the transverse diameter of a particle; w is the surface energy density of the NLC molecules coupling with magnetic particles and $\vec{m}$ is the unit vector along magnetization of a suspension [4,7,12–14].

When the small electric field is applied to FN system, the electro-optical effects come of variation on the molecular orientations of the FNs and then the optical field induced effect is enhanced. This necessitates an addition of $(\Delta\varepsilon/8\pi)\left[\vec{E}\cdot\vec{n}\right]^2$ electric field contribution to the free energy in Eq. (1) [4,13,15].

In a magnetic field if the anisotropy of diamagnetic susceptibility χ_a of liquid crystal is positive, the director $\vec{n}$ orients in a direction of a magnetic field $\vec{H}$; otherwise is perpendicular to $\vec{H}$ [16]. Terms of $-M_s f \vec{m}\cdot\vec{H}-\frac{1}{2}\chi_a\left(\vec{n}\cdot\vec{H}\right)^2$ are magnetic field contributions for soft director coupling that added to the free energy in Eq. (1). Here M_s is the saturation magnetization of the ferroparticle material and χ_a is the anisotropy of a magnetic susceptibility [7].

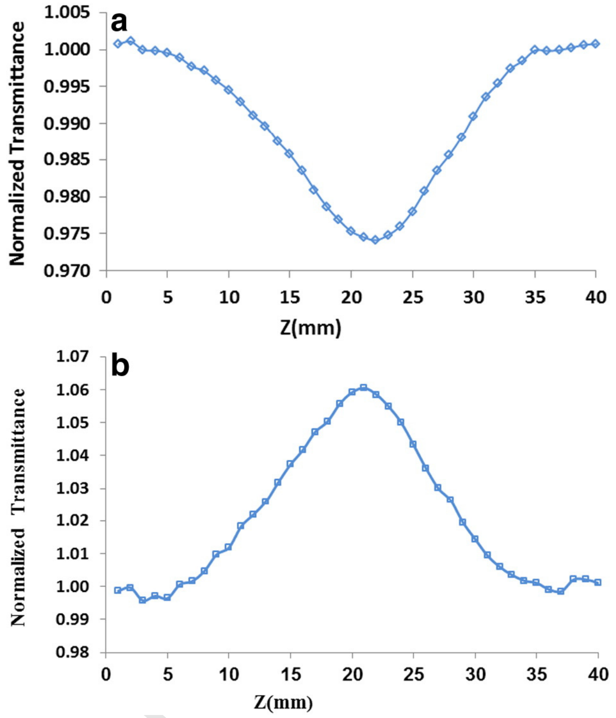

Fig. 2. Z-scan data for FNs obtained under an open aperture configuration in a) homogeneous alignment and b) homeotropic alignment.

2.2. Preparations of FNs

The NLCs used in the experiments for magnetic NPs doping were E7. Making a suspension of magnetite NPs in E7 liquid crystal without surfactant tends to unstable mixture. Therefore for avoiding of agglomeration of NPs we used dodecyl-trimethyl ammonium bromide (DTAB) as a surfactant. The NLCs were doped with a magnetic suspension that consists of nearly spherical Fe_3O_4 magnetic particles (diameter $d \approx 34$ nm). The magnetic particles were prepared by a co-precipitation method [17].

The cell was constructed from two glass substrates separated by spacers. A thin layer of alignment was coated on the glass surface. In such surface the liquid crystal is powerfully anchored and the surface interaction is enforcing a particular orientation on the liquid crystal. We used both homogeneously and homeotropically aligned cells in our experiment. If the polyvinyl alcohol (PVA) film is coated on ITO glass, rubs the homogeneous alignment will obtain but in the homeotropical alignment the ITO glass in a solution of lecithin in distilled water has to slide [18].

2.3. $\chi^{(3)}$ measurement

The z-scan method provides a sensitive and straight forward method for the determination of the sign and the values of the real and imaginary parts of $\chi^{(3)}$, respectively, proportional to the nonlinear refractive index (NLR), n_2 and the nonlinear absorption coefficient(NLA), β [16,19].

The measurement of the optical properties using the z-scan technique is based on the principle of spatial beam distortion due to the

Table 1
Comparison of third order nonlinear optical parameters of E7-based FNs for both alignments.

Alignment	n_2 (cm^2/W)	Re ($\chi^{(3)}$)	β (cm/W)	Im ($\chi^{(3)}$)	$\lvert\chi^{(3)}\rvert$(esu)
Homogeneous	-2.55×10^{-7}	-1.87×10^{-5}	-1.9×10^{-2}	-5.9×10^{-6}	1.96×10^{-5}
Homeotropic	1.15×10^{-5}	8.43×10^{-4}	3×10^{-1}	9.31×10^{-5}	8.481×10^{-4}

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