Physica B 434 (2014) 165–170

Contents lists available at ScienceDirect

Physica B

journal homepage: www.elsevier.com/locate/physb

The effect of initial alignment on the optical properties of Fe_3O_4 nanoparticles doped in nematic liquid crystals

Z. Dehghani, E. Saievar Iranizad *

Department of Physics, Tarbiat Modares University, Tehran, Iran

ARTICLE INFO

Article history:
Received 6 October 2013
Received in revised form
4 November 2013
Accepted 9 November 2013
Available online 20 November 2013

Keywords:
Ferro-nematic
Z-scan technique
Homeotropic alignment
Homogeneous alignment
Nonlinear optical property

ABSTRACT

Recently the nonlinear effects of the different materials doped liquid crystals are more interesting. In all previous works, nonlinearity of samples with the homeotropic alignment is investigated because of the larger component of the refractive index in this direction. Here, there are spherical Fe_3O_4 nanoparticles that have both parallel and perpendicular components. We were looking for the effect of initial alignment on the nonlinearity of pure and doped nematic liquid crystals (NLCs). The experimental results emphasize, even the same compositional percentage of nanoparticles prepared by two different alignment configurations are showing different results when dispersed in the same NLCs. Comparing nonlinear studies, the magnitude of nonlinear refraction index, n_2 and nonlinear absorption coefficient, β increase 10^2 and 10^1 times, respectively, in homeotropic alignment samples and the sign of these parameters is changed rather than homogeneous ones.

1. Introduction

Although nematic liquid crystals do not have positional order, their long axes of them tend to align in the vector direction which is mentioned as the director [1–3]. The alignment of liquid crystal molecules (i.e. the director, $\vec{n}$) on the substrate is very crucial in all possible applications of them [4]. There are different initial alignments with different applications into liquid crystal that two most important of them are homeotropic and homogeneous. An appropriate alignment layer on the substrate can be used for controlling alignment of the director in a cell-type arrangement [1,2,5].

Recently, the modern technology of photonics has caused a great deal of interest in finding for nonlinear optical materials [6]. The addition of nanoparticles (nps) can be improved the nonlinear optical (NLO) properties of the pure nematic liquid crystals. *z*-scan technique, which was introduced by Sheik–Bahae et al. [7], has been used greatly in NLO characterization. This method is very useful for detecting both of the nonlinear refraction and the nonlinear absorption in solid and liquid samples [8].

Some aspects of Liquid crystals (LCs) are brilliant such as their inherent selfassembly, rich phase behavior and diverse anisotropic properties [9]. Dispersing colloidal nps into LCs are so important in order to affect on combining the orientational order of LCs and the physical and chemical properties of nps [10,11]. Since light induced refractive index changes in NLCs, the manufacturing of useful materials for dynamic holography make possible which shows new method for building of all-optical light modulators, phase conjugate mirrors, optical amplifiers, optical correlators and others [12–14]. In a transparent NLCs, the orientational nonlinearity refers to light-induced reorientation of director which is founded the function of the optical torque, $\vec{\tau}_{opt}$ that affects on molecules because of their optical dielectric anisotropy [15]. Similar to the case of static fields, the optical torque exerted by the electromagnetic field on the nematic molecules is:

$$\vec{\tau}_{opt} = \varepsilon_0 \varepsilon_a (\vec{n}\,\vec{E})(\vec{n} \times \vec{E}) \tag{1}$$

where, $\vec{n}$ is the director, $\vec{E}$ denotes the electric field strength and, $\varepsilon_a = n_e^2 - n_o^2$ and n_e and n_o are the extraordinary and ordinary refractive indices respectively [15–17].

In this work, the optical properties of pure and Fe_3O_4 nps doped NLCs by *z*-scan technique at 532 nm were investigated. The experimental results of *z*-scan for two alignment configurations and different compositional percentage of Fe_3O_4 nps are analyzed in detail.

2. Experimental

2.1. Materials

The studied ferro-nematics are NLCs doped with different compositional percentage of Fe_3O_4 nps. The liquid crystal used in this study is E7 that was produced by the liquid crystal laboratory at the Warsaw University of Technology. E7 is a eutectic mixture

* Corresponding author. Tel.: +98 2182883405; fax: +98 2182883402.
E-mail addresses: saievare@modares.ac.ir, saievar@yahoo.com (E.S. Iranizad).

0921-4526/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.physb.2013.11.018

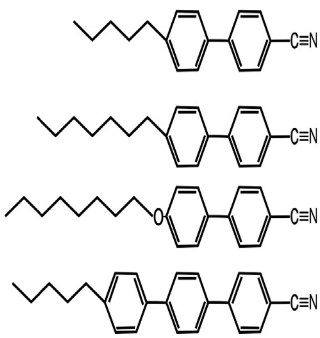

Fig. 1. Chemical structure of compositions of E7 liquid crystal.

that is made of four cyano substituted polyphenyls at a given composition [18]. Fig. 1 represents the molecular structure of compositions of E7 [1, 2]. The nematic-to-isotropic transition temperature (clearing temperature) of E7 is reported to be about ~60 °C [1,19,20].

Fe_3O_4 nps (synthesized by chemical co-precipitation) with diameters of 34 nm and cubic structure used as the source of the magnetic nps. It is known that the degree of aggregation of the nps due to attractive van der Waals and other electrostatic forces can be reduced by adding the particles with a suitable surfactant [10]. We added a surfactant (dtab) to Fe_3O_4 nps to prevent their aggregation. The measurements were performed with ferro-nematics for two commonly initial alignments with different compositional percentage of magnetic nps (i.e. 0 wt%, 1 wt%, 5 wt% and 10 wt%).

2.2. Initial alignment configuration

For nematics, two commonly used alignments are the so-called homogeneous (or planar) and homeotropic alignments. The alignment of the liquid crystal axis in flat thin cells is essentially controlled by the cell walls, whose surfaces are treated in a variety of ways to achieve various director axis alignments [2]. Both homogeneously and homeotropically aligned were used in this experiment.

2.2.1. Homeotropic alignment configuration

For homeotropic alignment, the director is perpendicular to the face of the substrate. The homeotropic alignment configuration was achieved by depositing of a thin layer of lecithin on the clean glass surfaces by dip coating method. These surfactants are basically soaps, whose molecules tend to align themselves perpendicular to the wall and thus impart the homeotropic alignment to the liquid crystal. The glass slides should then be dried in an oven. Maylar films were used as the spacers. The plates were sealed together by epoxy resin glue [2,21,22]. Fig. 2 show the homeotropic alignment configuration for different compositional percentage of Fe_3O_4 nps.

2.2.2. Homogeneous alignment configuration

In the homogeneous alignment, the directors in the front and back substrates are parallel. These substrates are first coated with thin polyvinyl alcohol (PVA) layer on inner surface of the optical glass plates to create microgrooves by the rubbing process. This process creates elongated stress/strainon the polymer and facilitates the alignment of the long axis of the liquid crystal molecules along the rubbed direction. The rest of the procedure for cell assembly is the same as that for homeotropic alignment [2,5,21]. Fig. 3 show the homogeneous alignment configuration for different compositional percentage of Fe_3O_4 nps.

The assembled cells were filled with sample at a temperature higher than the isotropic temperature of the NLCs by capillary method. After the NLCs was mixed with the Fe_3O_4 nps, the sample remained at room temperature for about one day before it was used for next measurements, thereby allowing any aggregation and separation of particles to take place. Pure liquid crystal and ferro-nematic were studied in standard, glass cell format. The cell thickness was set by 28 μm spacers. The homotropic and homogeneous cells were used for studying nonlinear optical properties. The optical quality of suspension and liquid crystal alignment in the cells was observed with a polarizing optical microscope (POM, Leica).

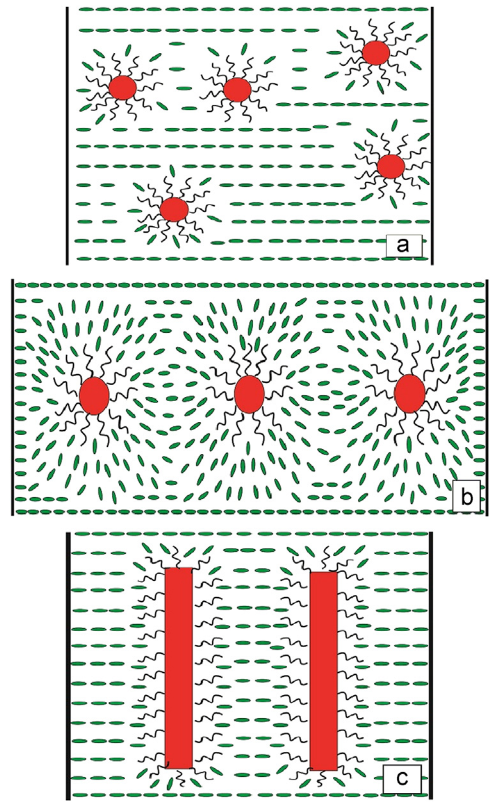

Fig. 2. The homeotropic alignment configuration for (a) 1 wt% (b) 5 wt% (c) 10 wt% compositional percentage of Fe_3O_4 nps in NLCs.

2.3. Z-scan theory

z-scan is a simple and sensitive single-beam method to determine the magnitude and sign of optical nonlinearity of a material. The *z*-scan experimental setup details have been reported elsewhere [23,24] and therefore, only a brief description is presented.

2.3.1. Close aperture z-scan

The *z*-scan measurement with an aperture (linear transmission of $S=0.32$) was performed for the investigation of nonlinear refraction, n_2 of samples [25]. To measure the optical nonlinearity, *z*-scan measurements were done at 532 nm from a Ne:YAG laser. The experimental setup for close aperture *z*-scan is shown schematically in Fig. 4 [26]. The samples were moved in step of 1 mm during the scan. For the close aperture condition n_2 is given by,

$$\Delta T_{p-v} = 0.406(1-S)^{0.25}(2\pi/\lambda)n_2 I_0 L_{eff} \quad (2)$$

where ΔT_{p-v} is the difference between the normalized peak transmittance and valley transmittance, S is the aperture's linear transmittance, $L_{eff}=(1-e^{-\alpha L})/\alpha$ is the effective thickness of the sample, α is the linear (low intensity) absorption coefficient, L is the thickness of samples, $I_0=2P_{in}/\pi\omega_0^2$ is the incident intensity