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CONDENSED MATTER

EFFECTS OF CARBON NANOTUBES ON THE ELECTRO-OPTICAL PROPERTIES OF NEMATIC LIQUID-CRYSTAL CELLS

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Abstract. We present results of carbon nanotubes electro-optical effect in nematic liquid-crystal cells under an applied dc voltage. The doped cells were fabricated with addition of single-wall nanotubes and multiwalled carbon nanotubes. We investigate the optical transmittance switching behaviors and time evolutions. It is shown that doping with nanotubes can effectively reduce the dc driving voltage and improve the switching behavior.

Key words: electro-optical, dispersed liquid crystal system, nanotubes, single-wall, multi-wall, carbon.

1. INTRODUCTION

The carbon nanotubes are fascinating new class of materials because of their properties, such as high tensile modules, good heat, electrical conduction, unique optical and electronic properties [1, 2].

Single walled carbon nanotubes (SWNTs) and multi walled carbon nanotubes (MWNTs) are produced by several technique of whom the most used are electric arc discharge, pyrolysis or spray pyrolysis of hydrocarbons over catalyst [3], chemical vapor deposition, laser ablation [4], or hydrothermal methods [5].

Due to unique optical and electronic properties, research over the last years has been focused on studying the effects induced by the carbon nanotubes in nematic liquid crystals for applications in electro-optical technologies.

For this applications, is essential that single walled carbon nanotubes and multi walled carbon nanotubes to have a uniform alignment and is important to give nanotubes a designated direction.

Liquid crystals are anisotropic fluids, that represent an intermediate state between crystalline solid and isotropic liquid. Liquid crystal molecules shows translational freedom, such as fluids, but tend to occupy positions and orientations in certain preferred directions as solids.

Nematic liquid crystal phase is characterized by molecules that have no positional orientation but tend to be oriented along the same direction, called the director [6, 7].

In order to impose an alignment of dispersed carbon nanotubes are used the liquid crystal self-organizing properties as well as Freedericks transition to a well-defined orientation of the molecular axis of the director [8].

This leads to the possibility of total change of orientation direction of carbon nanotubes and also mechanical and electrical anisotropy, which is confirmed by Monte Carlo simulation [9, 10].

In this paper we studied the changes induced by carbon nanotubes on electro-optical properties of liquid-crystal carbon nanotubes disperse systems and ON-OFF and OFF-ON switching times.

2. EXPERIMENT

The single-wall nanotubes employed in this study are commercially available materials. They were produced by the laser ablation technique and purchased as purified material. They were produced by chemical vapor deposition, purified by acid treatment and subsequently used as provided.

Liquid crystal-nanotube dispersions were prepared by adding small amounts of either SWNTs or MWNTs to the respective liquid crystals and sonicating the mixtures at 40 kHz for one hour to promote dispersion. It is presumed that this procedure reduces the nanotubes bundling and thus enhances their solubility.

The liquid crystals used, E7, are commercialized by Merck with a nematic phase at room temperature and positive dielectric anisotropy.

The measurements were made in standard cells, with ITO electrodes, having the thickness of 8 μm.

Applied voltage is DC voltage.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The E7 liquid crystal characteristics-mesophase between 20°C–61°C, dielectric anisotropy 13.8 to 20°C, refractive index $n = 1.6$ recommend it as a good host for nanotubes. Tube diameter was 20–30 nm, wall thickness 1–2 nm, and tube length 0.5–2 μm.

Particular problems arising in such systems are related to the nanotubes clustering tendency:

– multi-wall nanotube (MWNT) form fibrils (Fig. 1).

– single-wall nanotube (SWNT) form clusters (Fig. 2).

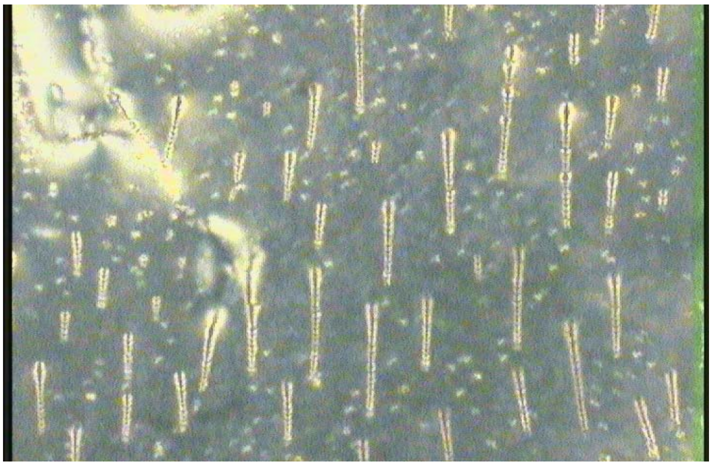


Fig. 1 – The view for the forming tendency of nanotubes MWNT fibrils dispersed in liquid crystal E7, $c = 0.01\%$.

This trend is accelerated by temperature and is independent of cell thickness. We can observe the clear fibrils tendency to orient in the same direction. We observed no dependence on the nanotubes concentration (under condition $c < 0.05\%$.).

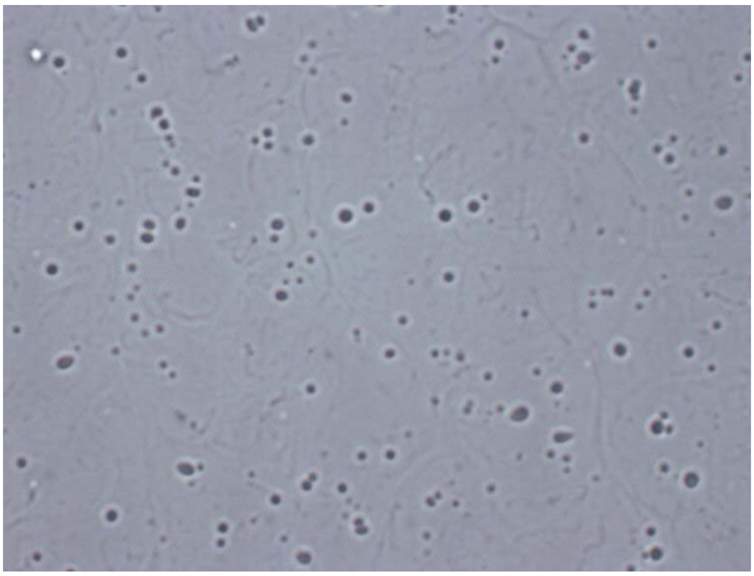


Fig. 2 – The view for the forming tendency of nanotubes SWNT clusters dispersed in liquid crystal E7, $c = 0.01\%$.

The classical ultrasonic technique is used in order to obtain a homogeneously dispersed system which will allow us to evaluate the electro-optical properties. For this purpose the mixture is dispersed by ultrasoning 40–45KHz (30–50Watt) for 1–2 hours at a temperature nearest to the nematic isotropic transition.

3.1. ELECTRO OPTICAL RESPONSE

Experiments aimed at obtaining information on MWNT nanotube-induced changes in electro optical response of liquid crystal E7 cells.

Concentration range investigated 0.001−0.015% .

Experiments were conducted at a temperature of 25^0C (thermostatic chamber), on a modified Toshiba optical microscope, the signal taken over being monitored by a multichannel oscilloscope YBR 1000.

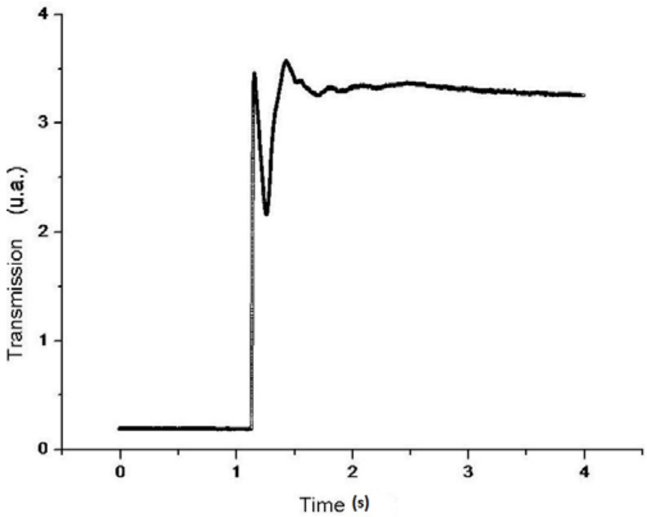
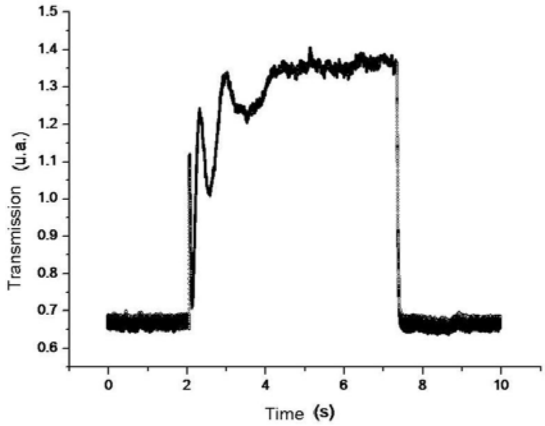


Fig. 3 – Electro-optical response of a liquid crystal E7 cell at applied voltage of 1.5V.

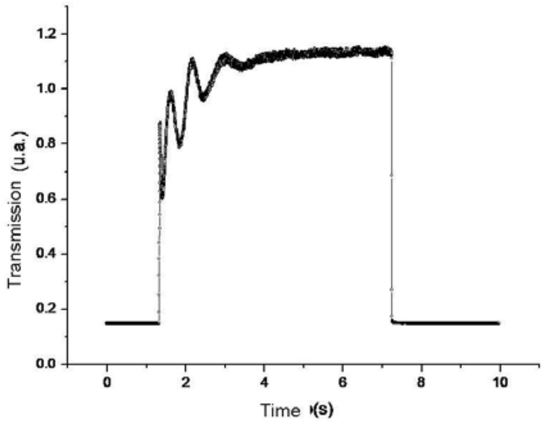
The initial oscillation is obtained due to the weak electric field reflected in the liquid crystal molecules oscillation around the average equilibrium position.
The electric field increased intensity in the cell makes the electro optical response to follow the electric field variation with higher fidelity.

Conducted experiments confirm that nanotubes insertion in the liquid crystal significant changes the dielectric anisotropy and the system viscosity as well as the threshold voltage and the electro-optical switching speed.

Those mentioned are confirmed by Fig. 4 where the electro optical response of a cell with E7 doped with different MWNT concentrations is represented.



A



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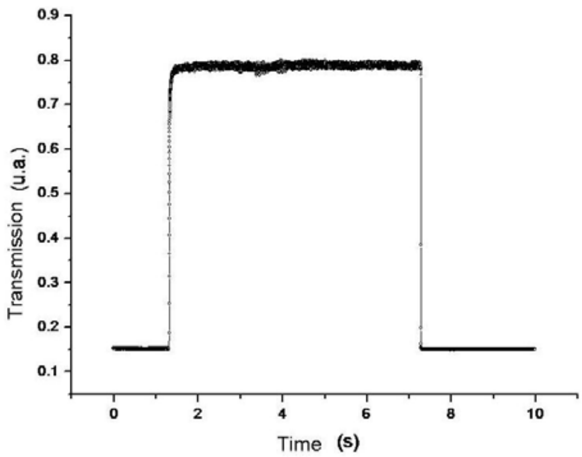

C

Fig. 4 – The form of electro-optical response of cells with E7 having different MWNT concentrations: A) $c = 0.001\%$; B) $c = 0.005\%$; C) $c = 0.01\%$.

Operating voltage 8V (DC). During the experiment the following parameters were followed:

- **Switching Time ON** (Fig. 5). Is defined as the timeframe in which the transmitted intensity changes in between 10%–90% of maximum intensity. We observed a practically liniar rise of the “switching time on” according with the nanotubes concentration.

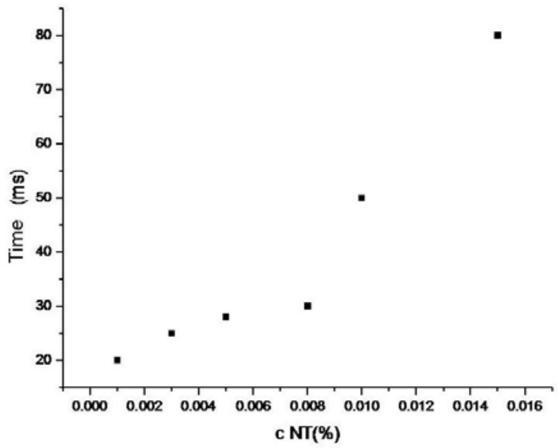

Fig. 5 – ON switching time dependence on the NT concentration (U = 15V).

- **Switching Time OFF** (Fig. 6). Is defined as the timeframe in which the transmitted intensity changes in between 90%–10% of maximum intensity. In this case the nanotubes influence is also significant.

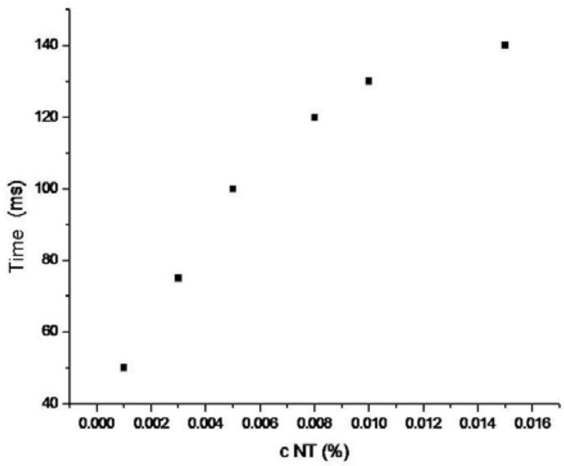

Fig. 6 – OFF switching time dependence on the NT concentration (U = 15V).

- **Delay time.** In the case of liquid crystal NT doping a very interesting phenomenon appears – the delay time.

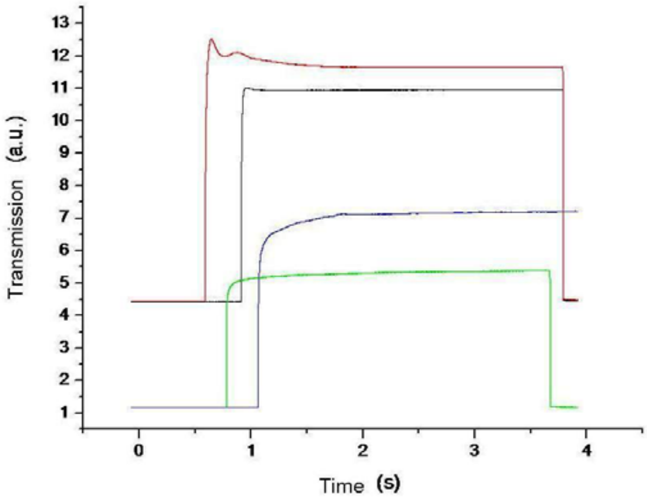

Fig. 7 – NT-induced delay time for *c* = 0.015% (red E7 – black E7+NT) and *c* = 0.005 (E7 green – blue E7+NT).

Note how the NT changes the cell transmission depending on the NT concentration.

Delay Time dependence on concentration is shown in Fig. 8.

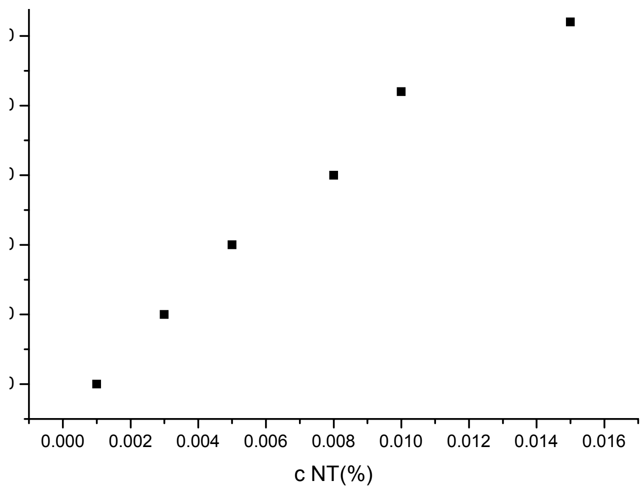

Fig. 8 – Delay Time induced by NT concentration (U = 15V).

4. CONCLUSIONS

We have demonstrated that liquid crystals self-organizing in the presence of nanotubes of 0,001 – 0,015% concentration, leads to significant changes with synergic influences on the system properties.

– The CL + NT system has significantly changed dielectric anisotropy, viscosity, threshold voltage and electro optical switching speed;

– The ON and OFF response time is dependent on the NT concentration; in both cases they increase with increasing concentration;

– Delay time is a new phenomenon observed during the electro-optical response with possible future technology applications;

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REFERENCES

1. M. S. Dresselhaus, G. Dresselhaus, A. Jorio, *Unusual properties and structure of carbon nanotubes*, Ann.Rev. Mater. Res., **34**, 247-78, 2004.
2. R. Saito, G. Dresselhaus, and M. S. Dresselhaus, *Physical Properties of Carbon Nanotubes,* Imperial College Press, London, 2001.
3. T. Guo, P. Nikolaev, A. Thess, D.T. Colbert, R. E. Smalley, Chem. Phys. Lett., 243, 49, 1995.
4. L. Jin, C. Bower, and O. Zhou, Appl. Phys. Lett. **73**, 1197, 1998.
5.W. Wang, J. Y. Huang, D. Z. Wang, Z. F. Ren, Carbon 43, 1317, 2005.
6. P. G. de Gennes, The Physics of Liquid Crystals, Clarendon, Oxford (1974).
7.S. Ferjani, V. Barna, A. De Luca, N. Scaramuzza, C. Versace, C. Umeton, R. Bartolino, G. Strangi, Applied Physics Letters **89**, 121109 (2006).
8.V. Barna, A. De Luca, T. Atherton, G. Carbone, M. Sousa, C. Rosenblatt, Nature Physics, **4**, 869 (2008).
9. C. Berlic, V. Barna, J. Optoelectron. Adv. Mater. **12**, 1427 (2010).
10. C. Berlic, V. Barna, Optics Express, **18**(23), 23646 (2010).