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Orientation of liquid crystalline materials by using carbon nanotubes

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Abstract

The solution of some problems, where the initial black field is necessary for the regime of light transmission through the electrooptical organic nematic liquid crystal structures has been considered via a homeotropic alignment of liquid crystal molecules on the substrate covered by carbon nanotubes. The results of this investigation can be used to develop optical elements for displays with vertical orientations of nematic liquid crystal molecules (for example, for MVA-display technology).

Keywords: Liquid crystals; nanotechnology; carbon nanotubes; laser-matter interaction; interface; relief ; display application.

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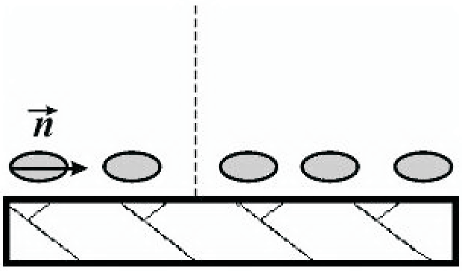
1 Introduction

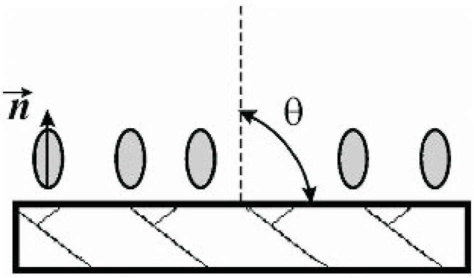
Electrooptical nematic liquid crystal (NLC) structure is a good model in order to consider the realistic technical cells as laser radiation switching devices, electrically and optically addressed spatiotemporal light modulators, and analogs of display elements [1-4]. It is well known that they mostly operate in S (splay deformation of NLC mesophase) and T (twist deformation of NLC mesophase) configurations, which realize a planar orientation of the LC mesophase on the substrate surface with some aligning layers. However, the solution of specific problems, where the initial black field is necessary under the regime of light transmission through the electrooptical structure, requires a homeotropic alignment of LC molecules on the solid substrate.

Figure 1 shows various types of alignments of LC molecules on a substrate surface, including planar (molecules are aligned parallel to the substrate surface, $\theta = 0$, see Fig.1a), homeotropic (molecules are perpendicular to the substrate surface, $\theta = 90^o$, see Fig.1b), and tilted (LC director is tilted at a certain angle, $0 < \theta < 90^o$, see Fig.1c) orientations of LC molecules.

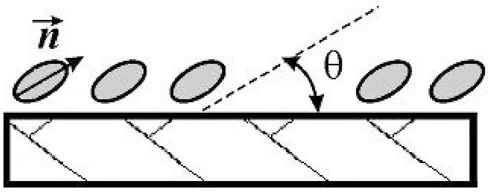
A planar orientation can be achieved using some oxides and polymer alignment coatings, such as cerium oxide (CeO), silicon oxides (SiO, SiO_2), germanium oxide (GeO), poly(vinyl alcohol), and polyimide nonphotosensitive coatings. As is well known, rubbing of the glass substrates or irradiation of them by holographic method also leads to a planar orientation of LC molecules. Homeotropic alignment is frequently obtained using surfactants, such as lecithin, fused quartz, etc. Some times an irradiation of polyimide by UV light provokes the homeotropic alignment. A new alternative method for obtaining a surface nanorelief that favors the homeotropic alignment of an LC mesophase is offered by the nanoimprinting technology [5]. Realization of this method, while making possible the formation of a surface relief with a good optical quality, requires the use of toxic substances, in particular, acids. This is a disadvantage of the nanoimprinting method.



(a)



(b)



(c)

Figure 1: Orientation of LC molecules on a substrate surface in cases of (a)planar, (b) homeotropic, and (c) tilted alignment. ($\vec{n}$- LC director.)

The importance of determining the type of LC alignment is related to the fact that the anchoring energy of LC molecules on a substrate and the alignment conditions significantly influence all physical properties of the LC mesophase and the electrooptical characteristics of related devices. For example, the free surface energy density F_s in traditionally approximation, is related to the surface anchoring energy W_s

and the LC direct tilt angle θ as follows [6]:

$$F_s = \frac{1}{2} W_s \sin^2 \theta. \tag{1}$$

It should be mentioned that the value of the anchoring energy W_s has been placed in the range of $10^{-2} - 10^{-8} J \times m^{-2}$. Therefore, various types of the alignment of LC molecules on a substrate correspond to different values of anchoring energy and different conditions for choosing a compromise between viscoelastic and dielectric forces applied to the LC mesophase. Figure 1b shows the homeotropic alignment of LC molecules on a solid substrate. In crossed polarizers, light will not be transmitted through the cell for the vertical orientation of molecules relative to the analyzer in the absence of a bias voltage; application of the voltage leads to rotation of the LC dipoles by 90^o, after which the light is transmitted to form a bright spot on a screen.

In this paper, we propose a new method to obtain the homeotropic alignment of LC molecules, which is based on a relief formation on the glass (quartz) substrate using the deposition of carbon nanotubes (CNTs) and their additional orientation in an electric field. Moreover, as an additional step in this technology, the surface electromagnetic wave (SEW) treatment has been applied to efficiently improve the obtained carbon nanotubes relief. It should be mentioned in the paper that we have already found the increase of laser strength of ITO (structures based on indium and stannum oxides) coatings covered with carbon nanotubes (cf. [7]).

2 Experiment

As a structure under study the NLC cell with thickness of 5-10 micrometers has been used. The pure and nanostructured LC films have been placed onto glass substrates covered with transparent conducting layers based on ITO contacts. ITO contacts have been modified by carbon nanotubes (CNTs). The initial CNTs were purchased from Alfa Aesar Co. (Karlsruhe, Germany). The laser deposition of CNTs and their SEW treatment were obtained using a quasi-continuous CO_2 laser with $p-$polarized radiation at a wavelength of 10.6μm and a power of 30W. CNTs were deposited on a substrate in the presence of an applied electric field with strength of $\sim 100 - 250V/cm$. The spectral data in a 400–800 wavelength range were obtained using an SF-26 spectrophotometer.

3 Discussion

Figure 2 shows an atomic force microscopy (AFM) image of the typical surface relief obtained using the proposed method. One can see that AFM images demonstrate the vertically aligned CNT relief (upper figure) and their modification with laser treatment (lower figure). The grating with dimension coincided with laser wavelength has been obtained. LC dipoles have been oriented vertically following this relief.

The homeotropic alignment of LC molecules was controlled using two sandwich-type cells with an LC mesophase confined between two glass plates. The reference cell represented a classical nematic LC structure, in which the alignment surfaces were prepared by rubbing. In the experimental cell, both alignment surfaces were prepared using CNTs as described above. Spectral experiments with the second cell confirmed that a homeotropic alignment of the LC molecules was achieved. The results of these experiments are presented in the Table 1 in detail.

It should be remarked that the reference samples with planar alignments and current homeotropically aligned samples prepared by new nanotechnology have been mounted in a holder and the transmission of both has been measured in the same spectral range. It should be noticed that the two cells had the same thickness of 10μm and contained the same nematic LC composition belonging to the class of cyanobiphenyls. The cells were treated without electric voltage, in passive mode. The experimental data were reproduced in several sets of cells. Black field has been obtained when the experimental homeotropic cell has been studied (for this case the transmittance is placed in the range $0.3 - 0.5\%$, see Table 1)

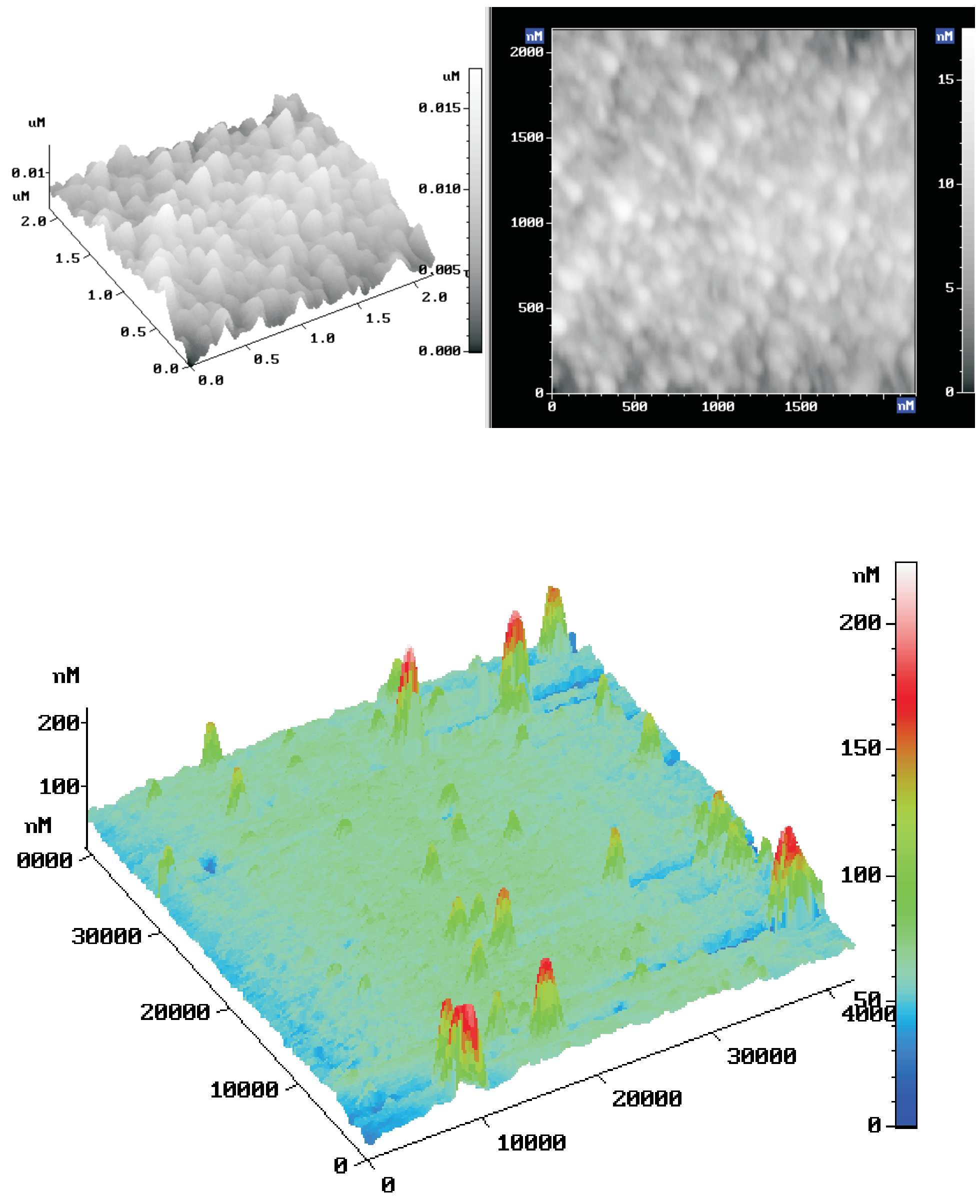


Figure 2: The view of relief obtained after carbon nanotubes deposition (*up*) and after SEW treatment (*bottom*).

Table 1: Transmission of LC cells depended on method to orient the LC dipoles.

	Transmittance,%	
Wavelength, nm	Etalon test cell (*planar*)	Experimental cell (*homeotropic*)
400	0	0
410	2.8	0
420	11.1	0
440	23.2	0
460	26.7	0.5
480	27.6	0.5
500	27.4	0.5
520	27.0	0.5
560	26.6	0.5
580	26.1	0.4
600	25.6	0.4
620	24.1	0.4
630	23.8	0.4
640	23.3	0.4
660	22.1	0.3
680	21.4	0.3
700	20.6	0.3
720	20.0	0.3
740	19.0	0.3
760	18.2	0.3
780	17.4	0.3
800	16.7	0.3

4 Conclusion

In conclusion, we have demonstrated the possibility and feature of obtaining a homeotropic orientation of LC molecules using nanoobjects deposition on a substrate in an electric field with strength of $\sim 100 - 250V/cm$ and then treated by SEW. It should be mentioned that this orientation can be applied for pure and nanoobjects-doped nematic LC cells. The results of this investigation can be used to develop optical elements for laser switching, for displays with vertical orientation of NLC molecules, for example for MVA (Multi-Domain Vertical Alignment)-display technology.

Acknowledgments

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Orientacija tečno kristalnih materijala korišćenjem nano cevi

Razmatra se rešenje nekih problema gde je potrebno početno crno polje za režim prolaska svetlosti kroz elektrooptički organsko nematski tečni kristal kroz homeotropno redjanje molekula tečnih kristala na podlozi pokrivenoj nano cevima. Rezultati ovog istraživanja mogu se koristiti za razvoj optičkih elemenata u monitorima sa vertikalnim orijentacijama molekula nematskih tečnih kristala (kao kod, recimo, MVA-displej tehnologije).

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