Two-mode photo-switchable LCD on the base of liquid crystals with a minute amount of carbon nanotubes

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Abstract

We report on a new type of LCDs photo-switchable between the reversible and memory modes. These LCDs are based on LCs with slight chirality doped with a minute amount of carbon nanotubes.

1. Introduction

In recent years, doping liquid crystal (LC) layers by nanoparticles (NPs) is considered as one of the promising approaches to improve performance of LCDs. The intensive researches are conducted aimed at expanding the range of properties of LC layers and eliminating their inherent parasitic effects such as backflows and optical bounces, image sticking and optical flicker, etc.

Among various types of NPs special attention is currently paid to carbon nanotubes (CNTs) [1]. Having a shape similar to the shape of LC molecules and effectively interacting with them, the nanotubes fit well in LCs host and copy their orientational order. The introduction of nanotubes makes it possible to improve operational parameters of LC layers such as controlling voltage and response time, and reduce the above mentioned troublesome effects.

Besides influencing intrinsic properties of LCs, introduction of CNTs result in a number of new effects. One of them is the effect of electro-optic memory, which we recently discovered [1]. It consists in the fact that a cell with homeotropically aligned LC ($\Delta \varepsilon < 0$) doped with a minute amount of CNTs demonstrates irreversible electro-optic response. The cells placed between crossed polarizers swhich from originally dark to bright state after the electric voltage is applied. However, this bright state does not completely relax after the voltage is off. In other words, LC memorizes the state achieved in the electric field. In the transmittance vs. voltage plot, it reveals itself in the residual transmittance T_m after the applied field is ramped down to zero. The memory efficiency was introduced according to formula $M = (T_m - T_0)/(T_s - T_0)$, where T_0 and T_s are the transmission values in the initial (zero field) state and in the state of saturation.

The described phenomenon is caused by stabilization of LC alignment realized in an electric field by a continuous network of CNTs formed in this alignment state. The stabilizing effect comes from the partial alignment of CNT

network according to the alignment of LC host and effective LC-CNT interaction. The network acts as a spatially distributed alignment surface and counteracts the elastic torque caused by anchoring with the aligning substrates.

The memory efficiency was radically improved by adding chiral dopant (ChD), which induced slight chirality in LC. This is due to the fact that introduced twisting force, which is destructive for homeotropic alignment, additionally stabilizes the state of random planar alignment realized in an electric field. By thorough optimization of concentration of ChD we obtained the LC-CNT suspensions with the efficiency of electro-optic memory approaching unity [1].

In development of this idea, in the present study we replace non-photosensitive ChD with a photosensitive one undergoing *trans-cis* photoisomerization under UV light. Since twisting power of the *cis* isomers was considerably lower than that of the *trans* isomers, we were able to control with a UV dose twisting tension in LC material and, in this way, (1) optimize concentration of ChD for high memory efficiency, and (2) switch the cells from the memory mode in the reversible mode.

2. Experimental

We used VA LC MLC6608 from Merck and photosensitive ChD 2-(4'-phenylbenzylidene)-*p*-menthane-3-one (PBM) synthesized in Singe Crystals Institute, NAS of Ukraine. The PBM molecules undergo irreversible *trans-cis* isomerization under UV irradiation [2]. The concentration of PBM was fixed at 1.4 wt. %. This LC with induced chirality was mixed with multiwalled CNTs by tip sonication. The concentration of CNT was 0.05 wt %; it corresponded to efficient memory of LC-CNT composites .

The cells were made from glass substrates containing patterned ITO electrodes. The substrates were coated with the layers of VA type polyimide SE5300 (Nissan, Japan), which were subsequently backed and unidirectionally rubbed. The cells were assembled so that the rubbing directions of the opposite aligning layers were antiparallel. A cell gap was maintained by 16 μ m glass spacers. The cells were filled with LC-CNT composites using a capillary method.

The structure of the composites was monitored by observation of the filled cells placed between two crossed polarizers. The optical transmission vs. applied voltage curves were measured by the in-house made set up.

3. Results

The UV light exposure of the samples resulted in continuous decrease of twisting tension that eventually resulted in transition from the "finger print" to homeotropic texture. This means that the routine ex-situ optimization process earlier used can be replaced by the in-situ optimization. At some exposure dose, *i.e.*, some conversion rate of ChD, favorable conditions for the memory effect was met. At these conditions, almost perfect homeotropic alignment was obtained; the individual filamentous defects evidenced about just onset of destruction of this alignment. After the field application cycle, the homeotropic alignment was transferred to the random planar alignment that macroscopically manifests itself in the residual brightening, which is registered both visually and in electro-optical tests (Fig. 1b). The induced memory state was erasable by heat and mechanical stress.



Fig. 1. *T-V* curves for the cells subjected to different doses of UV irradiation. Cells (a) and (b) show reversible and memory response, respectively.

Further increase of exposure dose resulted in exhaustion of ChD. At small concentration, ChD does not appreciably influence affinity of LC to planar alignment. On the other hand, the network of CNTs by itself is not able to withstand strong homeotropic anchoring caused by aligning substrates. As result, homeotropic alignment strongly prevails and the cells demonstrate reverse electro-optic response (Fig. 1a).

The optical adjustment of our samples for the memory and reversible modes is additionally demonstrated by Fig. 2. This figure shows that the cell can potentially work in two modes and the desirable mode can be set by the light dose. Furthermore, the memory images can be photo-erased.

Because of irreversible photochemistry of ChD PBM, we can only photo-switch the cell from the memory to the reversible electro-optic mode. But we believe that in case of ChD with the reversible transitions between the *trans* and *cis* isomers switching between these two modes in both directions will be possible.



Fig. 4. Photographs of LC cell viewed in crossed polarizers. The cell is filled with the MLC 6608-PBM (1.4 wt.%)-CNT (0.05 wt.%) composite. The regions in "2" form are exposed to UV light for 5 (area 1) and 3 (area 2) min (I=4 mW/cm²). Photographs (a) and (b) correspond to the initial state and the field off state, respectively. There is evident that area 1 switches in reversible mode, and area 2 in the memory mode.

4. Conclusions

We obtained LC cells with two mode operation. The cells can be optically adjusted for the memory and reversible mode of electro-optic response or switched from the first to the second mode. Reversible switching between these modes is also potentially possible.

References

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