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Electro Optical Properties of MBBA Liquid Crystal Doped with Carbon Nanotubes

In this study, the effect of carbon nanotubes (CNTs) at various concentrations (0.05, 0.06, 0.08, and 0.1 wt.%) on the electro optical properties of liquid crystal (LC) has been studied. Results show that the threshold voltage, frequency response, rise time and response time of pure LC optical switch decreased with the concentration of CNTs. LC doped with 0.08 wt.% of CNTs revealed the most significant enhancement, resulting in a response time reduction of about 94%, confirmed that the doped LC is the best for the optical switch applications.

Keywords: Liquid crystals; CNTs; Electro-optical properties; Threshold voltage
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1. Introduction

Liquid crystals (LCs) are substances characterized by the presence of one or more mesophases that exist between their liquid and solid phases. LCs are materials which exhibit captivating properties [1-3] and recently has achieved remarkable advancements. They are anisotropic, as their physical properties vary with direction. Nematics are thermotropic LCs with long, rod-like molecules that exhibit orientational order in relation to their neighbors, but their centers of mass have no positional order. The study of LCs gained renewed interest due to their unusual properties, particularly their electro-optical effect [4-6].

The electro-optical effects in LCs arise from the anisotropic physical properties induced by the orientational ordering of rod-like molecules within them. The electro-optical properties of LCs make them indispensable in modern technology. Their ability to switch between different optical states under an applied electric field has revolutionized displays, imaging devices, and optical components [7,8].

LCs are very important materials due to their significant technological relevance; however, a single LC compound cannot fulfill all the requirements for practical applications. Consequently, the various mixtures of LCs and their doped variants have gained growing attention. These doped variants have emerging prospects with respect to their utilization in information processing applications [9,10]. The doping process can be done by incorporation of dyes, polymers, composites, and nanoparticles. Doping with minimal concentrations of nanoparticles can result in modifications to the electro-optical characteristics, such as response time and threshold voltage, thereby enhancing the display performance of LC [11-13].

Carbon nanotubes (CNTs) are defined as cylindrical structures composed of rolled graphene layers. They exhibit remarkable mechanical, thermal, and electrical properties. CNTs may exist as single-walled (SWCNTs) or multi-walled (MWCNTs) configurations [14]. When CNTs are dispersed in LCs, they form suspensions. The interactions that occur between CNTs and liquid crystal molecules facilitate the development of organized supramolecular structures [15,16].

Mixing of LCs and CNTs proposes exciting possibilities for advanced materials and devices. Whether in displays, sensors, spatial light modulators (SLMs), switchable windows, electro- optical shutters and tunable lenses, these hybrid systems continue to drive innovation [17-19]. The goal of the present study is to investigate the effect of different concentrations of MWCNTs on electro optical properties of nematic liquid crystal.

2. Experimental Part

In the current work, N-(4-methoxybenzylidene)-4-n-butylaniline (MBBA) LC and MWCNTs have been used. The methodologies for the preparation of materials were detailed in our previous publications [20,21]. LC doped CNT were prepared by incorporating MWCNTs at different concentrations (0.05, 0.06, 0.08, 0.1) wt.% into the liquid crystal, followed by the addition of tetrahydrofuran (THF) to the resultant mixture. An ultrasonic mixer was used to achieve homogenous dispersion, with the mixing time was one hour at a frequency of 23 kHz.

For the preparation of the sandwich-type sample holder, two indium tin oxide (ITO) coated glass plates with small conducting areas have been used. Aluminum electrodes were subsequently deposited onto the ITO glass substrate. The glass substrates were separated by 20 µm to make the cell gap filled with LC/CNTs. A total of four composite materials were prepared by

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adding specific amounts of CNTs, namely 0.05, 0.06, 0.08, and 0.1 wt.% to the pure LC.

The response time was determined utilizing the optical switching technique, as illustrated in Fig. (1). The optical switch cell was positioned between two crossed polarizers oriented at a 90° angle relative to each other, with a 45° orientation between the plane of the polarizer and the rubbing direction of the polyimide layer. An alternating current (AC) voltage was supplied to the sample cell via a function generator. A digital oscilloscope was employed to record the electro-optical fluctuations. A He–Ne laser beam with a wavelength of 632.8 nm was used as an input signal, while the output signal was received by a photodetector and subsequently transmitted to an oscilloscope.

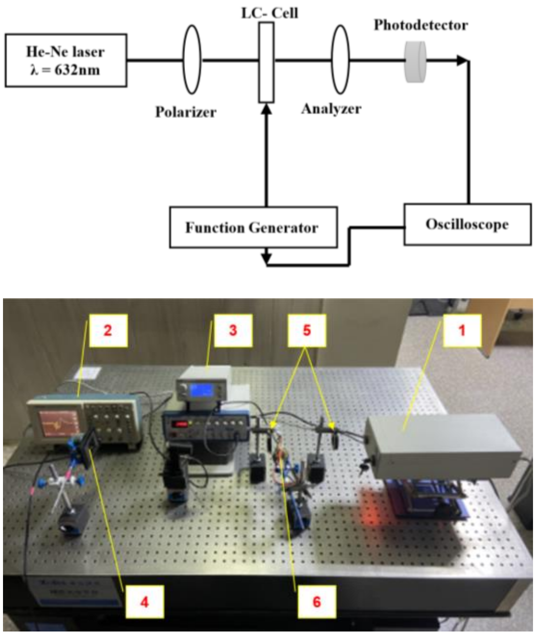


Fig. (1) The experimental arrangement for optical measurement of optical switch, (1) He-Ne laser, (2) Oscilloscope, (3) Function generator, (4) Photodetector, (5) Polarizer and Analyzer, (6) Optical switch device

3. Results and Discussion

The frequency response of a liquid crystal optical switch is a critical factor in its performance, especially, for high-speed applications. Pure LC optical switch device has frequency response of 300 Hz, while the frequency response of four devices that have concentrations of (0.05, 0.06, 0.08, 0.1) are found to be 120, 100, 190, 140, respectively as shown in Fig. (2).

The threshold voltage of optical switch devices is calculated when they start responding to alternating current (AC) applied voltage, thereby switching the optical signal as shown in figures (3) and (4). It can be seen that the pure LC responds to the applied voltage of 0.9 V, while the doped samples respond to the applied voltage and was determined to be 0.7, 0.8, 0.7 and 0.8 V for LC doped CNTs at 0.05, 0.06, 0.08 and 0.1wt.%, respectively.

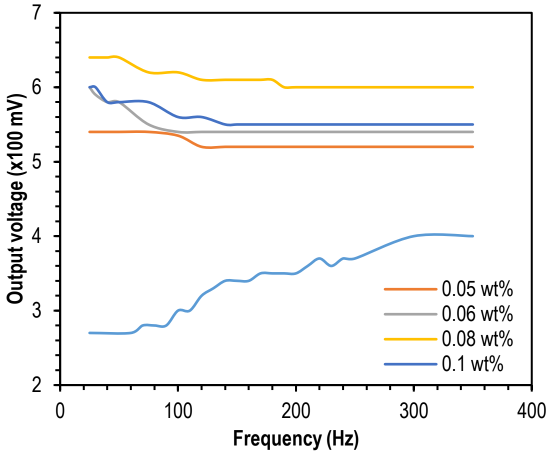
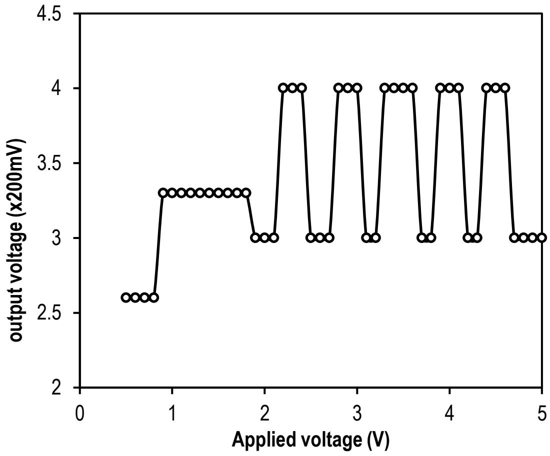
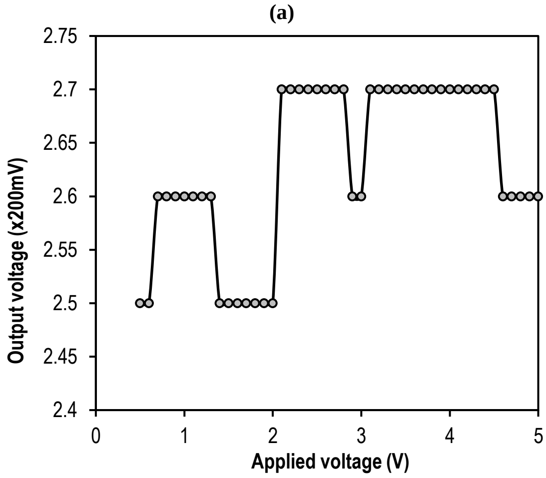


Fig. (2) The frequency response characteristics of LC/CNTs samples



(a)



(b)

Fig. (3) Threshold voltage of LC/CNTs, (a) pure LC, (b) 0.05 wt.%

Rise time of the pure LC and LC doped CNTs optical switch devices is calculated from the duration of the response voltage signal to increase from 10% to 90% of its steady value. It was 22 ms for the pure LC

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optical switch device and decreased for LC/CNTs optical switch devices. Figure (5) shows the response signal of the LC/CNTs optical switch.

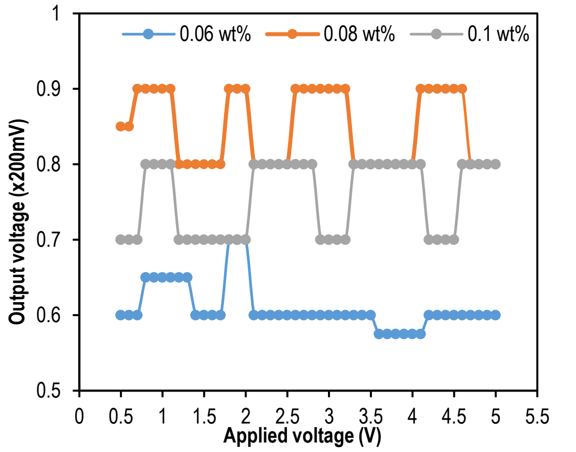
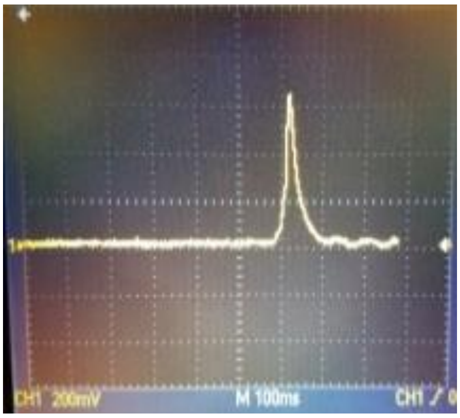
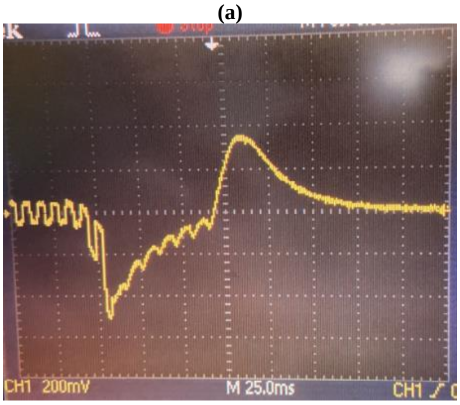


Fig. (4) Threshold voltage of LC/CNTs at 0.06, 0.08, and 0.1 wt.%

The fall time denotes to the duration for a signal to decrease from a 90% of the peak value to 10%, essentially, it measured how quickly a signal decreased after reaching its peak. The optical switch device incorporating 0.05 wt% LC doping showed the lowest fall time that equal to 11.045 ms.



(a)



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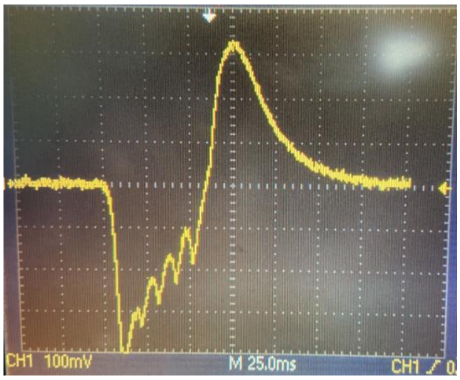
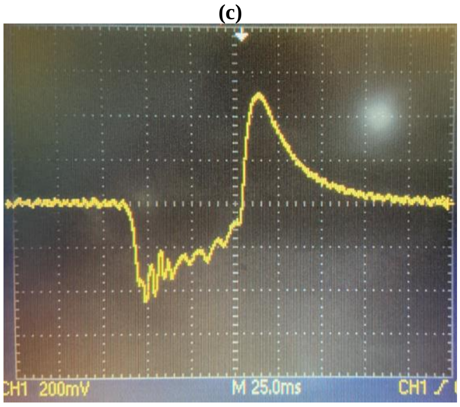
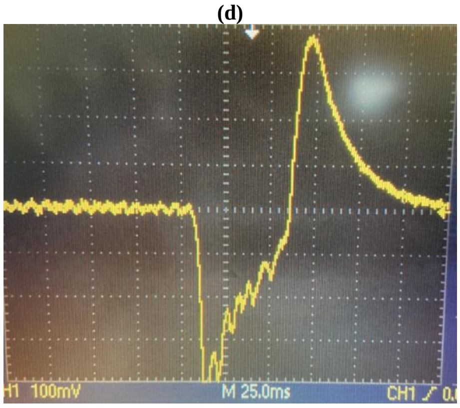


(c)



(d)



(e)

Fig. (5) The response signal of LC/CNTs, (a) pure LC, (b) 0.05 wt.%, (c) 0.06 wt.%, (d) 0.08 wt.%, and (e) 0.1 wt.%

The response time of an optical switch is a critical factor in determining its performance. As shown in table (1), when the CNTs concentration below 0.1 wt.%, the response time simultaneously decreased with CNTs concentrations increased. The optical switch device with 0.08 wt.% LC doping demonstrates faster in the comparison to other optical switch devices. This attributes to the shortest response time (2.57ms) due to the electric properties of nanoparticles used for doping MBBA LC as illustrated in table (1).

Conclusions

The electro-optical properties of LC doped CNTs were demonstrated in this experiment. The obtained results indicate that the doped CNTs has higher performance than the pure LC, mainly in terms of

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reducing the response time which drops from 44 ms to 5.8 ms after doping 0.05 wt.% CNTs. Moreover, it is observed that there is a reduction in the threshold voltage. The enhancement of the electro-optical characteristics of liquid crystals might be attributed to the adsorption of impurity ions by carbon nanotubes (CNTs). According to the previous findings, an optimal dopant concentration of 0.08 wt.% was identified to attain the maximum operational parameters of devices utilizing nematic liquid crystals that are incorporated with CNTs.

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Table (1) Electro-optical properties of pure LC and CNTs-doped LC

Samples	Frequency Response (Hz)	V_{th} (v)	T_{rise} (ms)	T_{fall} (ms)	Response Time (ms)
Pure LC	300	0.9	22	47	44
0.05 wt.%	120	0.7	6.47	11.04	5.8
0.06 wt.%	100	0.8	9.132	37.01	4.807
0.08 wt.%	190	0.7	5.512	54.41	2.57
0.1 wt.%	140	0.8	7.35	47.05	5.87