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Dielectric anisotropy and electrical properties of the copper phthalocyanine (CuPc): 4–4′-n-Heptylcyanobiphenyl (7CB) composite liquid crystals

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ABSTRACT

Dielectric anisotropy and electrical properties of the copper phthalocyanine (CuPc): 4–4′-n-heptylcyanobiphenyl (7CB) composite liquid crystals have been investigated. Liquid crystals exhibit dielectrically-controlled positive dielectric anisotropy (p-type $\Delta\varepsilon$) and the dielectric anisotropy changes from positive to negative dielectric anisotropy (n-type $\Delta\varepsilon$) behavior with frequency of applied electrical field. The critical frequency f_c values for the 7CB and CuPc doped 7CB liquid crystals were found to be 602 kHz and 518 kHz, respectively. This indicates that CuPc doping causes a decrease in the critical frequency. The splay elastic coefficients of the 7CB and CuPc doped 7CB liquid crystals were determined and CuPc doping increases the splay elastic coefficient of 7CB liquid crystal. The 7CB liquid crystal exhibits a voltage-controlled differential negative resistance (VCNR) behavior and CuPc doping affects significantly VCNR behavior of 7CB.

1. Introduction

Liquid crystals have been extensively investigated due to the increasing importance of liquid crystals (LC) in science, technology, industry and medical applications [1–3]. To improve electrical, phase transition and dielectrical properties of the liquid crystals, the composites based on liquid crystals (LCs) have been prepared and investigated [1–3].

4-Heptyl-4′-cyanobiphenyl (7CB) is one of the best known liquid crystalline materials. The dielectrical anisotropy properties and optical properties of 7CB have been improved using various organic and nanomaterials. Copper phthalocyanine (CuPc) is one of the best known organic semiconducting materials and it exhibits interesting electrical, optical, photoconductive and photovoltaic properties [4–6].

The dielectric anisotropy and charge transport mechanism of 7CB can be changed by doping CuPc into 7CB. To obtain valuable information about the molecular properties of liquid crystals, impedance spectroscopy measurements can be used. In this method, the molecular properties of liquid crystals can be correlated with dielectric permittivity [7–9]. On the other hand, it is well known that the dielectric anisotropy of the liquid crystals has important rules on the image quality of liquid crystal displays (LCDs). Most of the active matrix displays require new liquid crystals with improved dielectric anisotropy. The dielectrical anisotropy and charge transport properties of liquid crystals can be developed by doping of different organic semiconductors. For this, we have used copper phthalocyanine organic semiconductor to decrease the critical frequency which provide the transformation from positive dielectric anisotropy to negative dielectric anisotropy and decrease dielectric constants of 7CB.

In present study, the dielectric anisotropy and molecular reorientation properties of copper phthalocyanine doped 7CB liquid crystal were investigated by current–voltage and capacitance–voltage methods.

To the best of our knowledge, there is no literature report on the dielectric anisotropy and charge transport properties of copper phthalocyanine doped 4-heptyl-4′-cyanobiphenyl (7CB) liquid crystal (7CB).

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2. Experimental details

2.1. Preparation of liquid crystal cells

The liquid crystal measurement cells were prepared by two glass slides separated by Mylar sheets [10]. The thickness of used cell is 5.3 μm. Firstly, indium tin oxide (ITO) coated glass substrates were spin coated with polyvinyl alcohol (PVA) at 2000 rpm and they were cured at 50 °C for ~2 h. The thickness of coating is 100 nm and these coating layers were exposed to surface treatment of unidirectional rubbing with velvet in order to obtain preliminary molecular orientation. The ultimate form of the constructed cell is planar with 2° rubbing tilt [11–12]. The copper phthalocyanine (CuPc) and 4–4′-n-heptylcyanobiphenyl (7CB) were purchased from Sigma–Aldrich company and their chemical structures are shown in Fig. 1a and b. 1% (w/w) of copper phthalocyanine was mixed to nematic 4–4′-n-heptylcyanobiphenyl (7CB) and stirred with ultrasonic effect. The prepared 7CB and CuPc doped 7CB liquid crystals were injected into sample cells by capillary action at 25 °C, i.e., both samples were filled at room temperature. The viscosity did not change during doping. For dispersion of CuPc into 7CB liquid crystal, the sonication process was done at room temperature. It is well known that the 7CB liquid crystal is room temperature nematic. Thus, we measured the dielectrical parameters of both the liquid crystal samples using a HIOKI 3532 LCR meter and Keithley 6517 electrometer at 25 °C.

3. Results and discussion

3.1. Dielectric anisotropy properties of 7CB and CuPc doped 7CB liquid crystals

The nematic phase at room temperature of the liquid crystal samples was confirmed by applying field (5 V/micron) and the *C–V* measurements were two times repeated for various frequencies of applied voltage. The obtained *C–V* plots exhibit the same characteristics with changing dielectric anisotropy from positive to negative. After confirmation of the nematic structure, the capacitance–voltage characteristics of the 7CB and CuPc doped 7CB liquid crystals cells at bias voltages of 0 and 20 V were measured and are shown in Fig. 2a and b.

In order to analyze dielectric anisotropy $\Delta\varepsilon$ using $C_\perp$ and $C_{||}$ values, we show an example graph plotted according to the information available in literature and is shown in Fig. 2c [12]. Note that the dielectric constants at bias voltages of 0 and 20 V, correspond

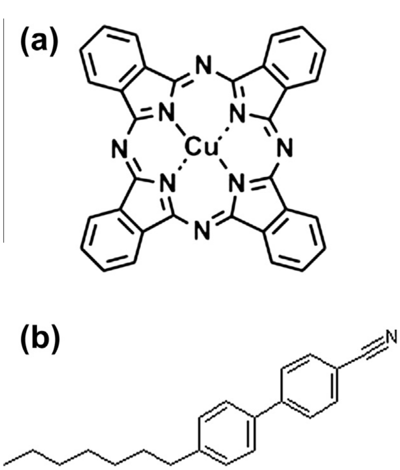

Fig. 1. Chemical structures of copper phthalocyanine and 4–4′-n-heptylcyanobiphenyl a) CuPc b) 7CB.

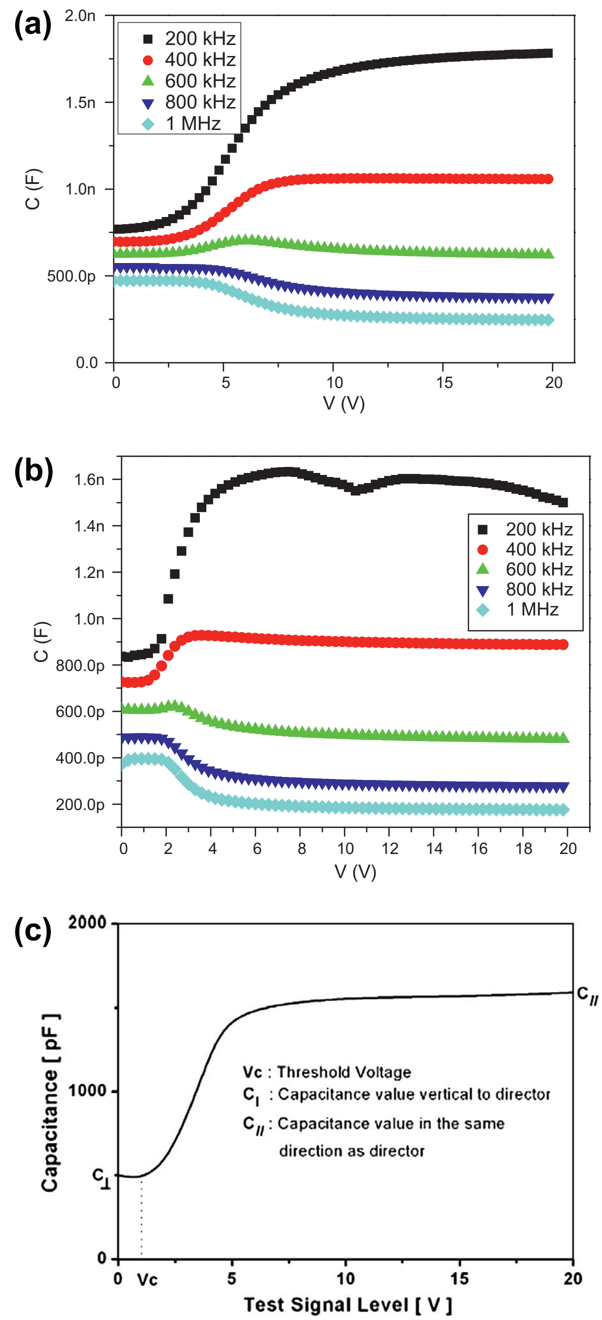

Fig. 2. Capacitance–voltages characteristics of the liquid crystals under various frequencies (a) 7CB, (b) CuPc doped 7CB and (c) example graph for $\Delta\varepsilon$ [12].

to the perpendicular and parallel dielectric components, $\varepsilon_\perp$ and $\varepsilon_{||}$, respectively.

With applied electric field, the director of the liquid crystals tends to orient in the direction of electric field. The *C–V* plots exhibits a threshold voltage which is required to increase the capacitance by 10% of the original capacitance. This behavior is so-called Frederiks threshold, V_{th}. This voltage is expressed by the following relation [13–15]

$$V_{th} = \sqrt{\frac{K_{11}\pi^2}{\Delta\varepsilon\varepsilon_o}} \quad (1)$$

where K_{11} is splay rotation coefficient, $\Delta\varepsilon$ is the dielectric anisotropy and ε_o is the dielectric permittivity of free space. The V_{th} values were determined to calculate splay elastic coefficients of the liquid