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INVESTIGATION OF DIELECTRIC PROPERTIES OF MBBA-5CB NEMATIC LIQUID CRYSTAL STRUCTURES

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Abstract

The dielectric anisotropy ($\Delta\varepsilon'$) is the response of the LC molecules to an applied electric field. In this study, the dielectric properties of 4-pentyl-4'-cyanobiphenyl (5CB) and N-(4-methoxybenzylidene)-4-butylaniline (MBBA) nematic liquid crystals with positive and negative dielectric anisotropy were investigated in detail. In addition, a structure with zero dielectric anisotropy was obtained by mixing MBBA and 5CB liquid crystals in certain rate (1:0.02). The behavior of the samples under 0V and 20V voltages was investigated in detail. Dielectric measurements were made with dielectric spectroscopy technique, which is a powerful method to investigate the molecular interaction mechanisms of liquid crystal materials, at a frequency of 1 kHz-10 MHz and a voltage of 0-20 V at room temperature. Some important parameters such as dielectric anisotropy ($\Delta\varepsilon'$), relaxation frequency (f_R), relaxation time (τ) were determined for the samples. When electric field is applied to nematic liquid crystals, it is seen that, depending on the voltage, the relaxation frequency decreases, and the relaxation time increases.

Keywords: Nematic liquid crystal, 5CB; MBBA, dielectric properties, dielectric anisotropy.

MBBA-5CB NEMATIK SIVI KRISTAL YAPILARIN DİELEKTRİK ÖZELLİKLERİNİN İNCELENMESİ

Özet

Dielektrik anizortopi ($\Delta\varepsilon'$) sıvı kristallerin elektrik alana karşı gösterdikleri tepkinin bir ölçüsüdür. Bu çalışmada pozitif ve negatif dielektrik anizotropiye sahip olan 4-pentyl-4'-cyanobiphenyl (5CB) ve N-(4-metoksi benziliden)-4-butilanilin (MBBA) nematik sıvı kristallerin dielektrik özellikleri ayrıntılı olarak incelenmiştir. Ayrıca MBBA ve 5CB sıvı kristalleri belli oranlarda karıştırılarak (1:0,02) sıfır dielektrik anizotropiye sahip bir yapı elde edilmiştir. Örneklerin 0V ve 20V gerilim altında davranışları ayrıntılı olarak incelenmiştir. Dielektrik ölçümler, sıvı kristal malzemelerin moleküler etkileşim mekanizmalarını araştırmak için güçlü bir yöntem olan dielektrik spektroskopi tekniği ile 1 kHz-10 MHz frekans ve 0-20 V gerilim aralığında, oda sıcaklığında yapılmıştır. Örnekler için dielektrik anizotropisi ($\Delta\varepsilon'$), relaksasyon frekansı (f_R), relaksasyon zamanı (τ) gibi bazı önemli parametreler belirlenmiştir. Nematik sıvı kristallere bir elektrik alan uygulandığında, voltaja bağlı olarak relaksasyon frekansının azaldığı, relaksasyon zamanının ise arttığı görülmüştür.

Anahtar Kelimeler: Nematik sıvı kristal, 5CB, MBBA, dielektrik özellikler, dielektrik anizotropi.

Cite

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1. Introduction

Liquid crystals (LCs) exist in a unique state of matter between solid and liquid. Physically, these materials are fluid like liquids, but they also exhibit an anisotropic character like solids. Nematic, smectic, and cholesteric are the three main classifications of liquid crystals. In the nematic phase, the long axes of liquid crystal molecules show approximately the average orientation, indicated by the index $\hat{n}$. It is well knowledge that nematic LCs are commonly utilized in screen technologies due to the fact that an electric field may simply control their molecule orientation. In addition, increasing the electric field, particularly when applied to devices containing nematic liquid crystals, decreases the response time of molecules [1]. Due to these benefits, they are used in compact displays such as smartphones, calculators, and digital cameras, midsize displays like computers, and large displays like projectors and televisions [2]. In addition to the display application, nematic LCs have various application areas such as optical switching, spatial light modulator, and holographic data storage as they are susceptible to external effects such as electric field, magnetic field, heat, and light.

MBBA (N-(4-methoxybenzyl-iden)-4-butylaniline) was the first liquid crystal to have a nematic phase at room temperature and was used in the production of liquid crystal displays (LCD). Because MBBA exhibits a nematic phase at room temperature, researchers in optoelectronic device technology are very attracted to it.

In addition, its low viscosity enables it to be utilized as a lubricant since the friction coefficient remains constant even when the isotropic-nematic phase transition temperature is surpassed [3]. MBBA hydrolyzes rapidly with increasing temperature. Therefore, any moisture can affect the alignment of MBBA molecules in the electric field, resulting in a slightly delayed response time.

Low chemical stability is its most significant problem [4]. It was an important step for Gray et al to discover mesogens (cyanobiphenyl (CB)) that are highly stable across a wide temperature range, are characterized by a high positive dielectric anisotropy and high birefringence and are nematic at room temperature [5]. Numerous experiments on the 4-n-alkyl-4-cyanobiphenyl (nCB) series have shown that adding methylene to the alkyl chain induces various mesophases [6]. 5CB (4-pentyl-4'-cyanobiphenyl), which belongs to the homologous series of nCB, has a nematic phase and a simple molecular structure at room temperature. Due to its weak absorption in the visible spectrum region, high stability, and high dielectric and optical anisotropy, it is one of the most investigated LC materials for its physical properties. 5CB is an important thermotropic LCs and is being utilized extensively in creating novel functional materials for contemporary devices such as optoelectronics, display, and battery technologies, among other applications [7].

In this study, the dielectric properties of 5CB and MBBA nematic liquid crystals with different dielectric anisotropy were investigated in detail. In addition, a structure with zero dielectric anisotropy was obtained with 5CB and MBBA. Finally, molecular orientations of 5CB, MBBA, and 5CB/MBBA structures under 0V and 20V voltages were investigated and reported.

2. Materials and Method

In this work, nematic liquid crystals N-(4-metoksi benziliden)-4-butilanilin (MBBA) with negative dielectric anisotropy ($25°C'de\ \Delta\varepsilon' = -0.54$) and 4-n-pentyl-4'-cyanobiphenyl (5CB) with positive dielectric anisotropy ($25°C'de\ \Delta\varepsilon' = +13.3$) at room temperature were used for experimental studies. Due to the methoxy group, MBBA is a well-known thermotropic mesomorphic material having a dipole moment in the transverse direction. Figure 1 shows the molecular structures of the nematic LCs MBBA and 5CB.

In the experiment, MBBA and 5CB liquid crystals were mixed at a weight ratio of 1:0.02. Three hours were spent keeping the mixture in an ultrasonic bath at 40°C. For the measurements, ITO (indium tin oxide)-coated liquid crystal cells with a surface resistance of 25Ω and a thickness of $14.6\mu m$ were used. The samples were injected into the cells by capillary action. Then, dielectric measurements were performed using a Novocontrol Alpha a Dielectric/Impedance Analyzer with a frequency range of 1 kHz-10 MHz and a voltage range of 0-20 V at room temperature. Measurement in the high frequency range has been limited to 10 MHz because of the dominating effect of finite resistance of ITO coating on glass plates of sample cell and lead inductance.

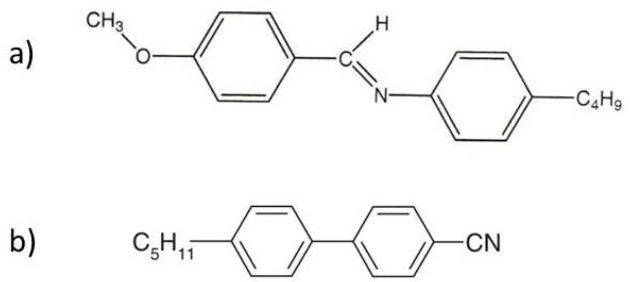

Figure 1. Moleculer structures of the a) MBBA b) 5CB nematic liquid crystals.

3. Results

The unique dielectric characteristics of these structures are the primary reason LC materials are so widely used in display applications. For instance, by applying an electric field, the interaction between the LC molecules and the electric field causes the molecules to be reoriented. Electric dipoles are created due to the dielectric interaction between the LC molecules and the electric field. Therefore, molecular redirection is an essential phenomenon for applications. The dielectric behavior must be investigated in depth to evaluate the molecular response of liquid crystals. The complex dielectric constant (ε^*), which characterizes the distribution of electrical charges in a material, is a crucial parameter for defining the dielectric properties of LC materials and is represented by the following equation;

$$\varepsilon^* = \varepsilon' - i\varepsilon'' \quad (1)$$

where ε' is the real component of the complex dielectric constant, associated with the energy stored in the materials, and ε'' is the imaginary part, associated with the energy lost or dissipated in the materials. Figure 2.a and Figure 2.b shows the frequency-dependent variation of the real part of the dielectric constant for materials at 0V and 20V in the dark.

The $\varepsilon' - f$ plots show similar behavior for all materials at 0 V and 20 V. In the region of low-frequency, the value of ε' is almost constant. Nonetheless, the value of ε' decreases with increasing frequency. Relaxation occurs in this region, corresponding to the maximum of the $\varepsilon'' - f$ plot. The dipoles cannot follow the increasing frequency of the test signal and the molecules cannot be orientated in this region. Consequently, the polarization reduces in the high-frequency area, causing the ε' value to decrease [8], [9]. Evaluating the $\varepsilon' - f$ plots of nematic LCs at 0V and 20V, it was observed that the ε' value for 5CB and MBBA changes with the applied voltage. The fundamental cause for this behavior is the change of

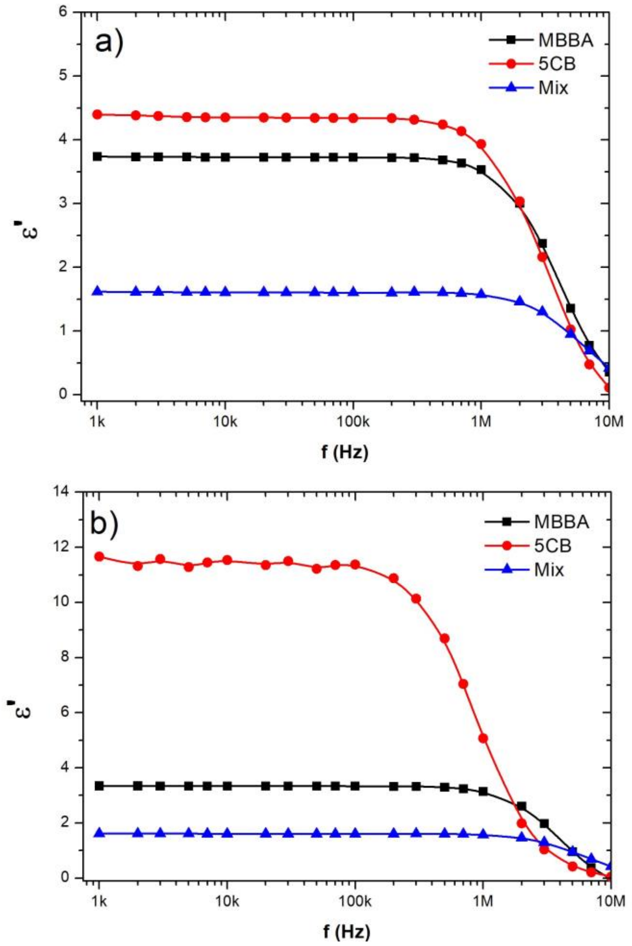

Figure 2. Frequency dependent ε' values of the samples at a) 0V b) 20V.

molecular order due to increasing voltage. 5CB has a higher ε' at 20V (11.66) than at 0V (4.40), while MBBA has a smaller ε' at 20V (3.34) than at 0V (3.74). It is seen that the value of the 5CB/MBBA mixture remains unchanged (1.62). This result is a consequence of the fact that nematic liquid crystals exhibit different dielectric anisotropy. The response of molecules to an applied electric field is determined by the dielectric anisotropy ($\Delta\varepsilon'$) of the LC molecules. Dielectric anisotropy is expressed the following equation;

$$\Delta\varepsilon' = \varepsilon'_{\parallel} - \varepsilon'_{\perp} \tag{2}$$

where $\varepsilon'_{\parallel}$ represents the parallel component of the real part of the complex dielectric constant, $\varepsilon'_{\perp}$ represents the perpendicular component.

When the $\Delta\varepsilon'$ is positive ($\varepsilon'_{\parallel} > \varepsilon'_{\perp}$), the LC molecules align in the direction of the applied electric field (Figure 3.a). In the situation of positive dielectric anisotropy, the polarizability of LC molecules is greater along their long axis; hence, the molecules are aligned along the direction of the electric field. When the $\Delta\varepsilon'$ is negative ($\varepsilon'_{\parallel} < \varepsilon'_{\perp}$), however, the molecules are oriented perpendicular to the electric field direction (Figure 3.b). In this situation, the polarizability of the LC molecules will be perpendicular to the electric field's direction [10]. When the $\Delta\varepsilon'$ is zero, it is impossible to orient LC molecules (Figure 3.c.). Equation 3 demonstrates this situation clearly. Equation 3 represents the threshold voltage (V_{th}), which is the voltage at which liquid crystal molecules begin to orient [11];

$$V_{th} = \pi\sqrt{\frac{K}{\varepsilon_0 \Delta\varepsilon'}} \tag{3}$$

where K represents the elastic constant and ε_0 ($\varepsilon_0 = 8.85 \times 10^{-14} Fcm^{-1}$) represents the dielectric constant of the free space charge. According to Equation 3, the fact that $\Delta\varepsilon' = 0$ indicates $V_{th} \to \infty$. This explains why molecules with zero dielectric anisotropy are not aligned [12]. ε' values were calculated at a frequency of 1 kHz using Equation 2 for all samples. There was a value of 7.16 for 5CB, -0.39 for MBBA, and 0 for a mixture of 5CB and MBBA. The results are consistent with the scientific literature. Figures 4.a and 4.b show the frequency-dependent variation of the imaginary part of the dielectric constant at 0V and 20V. The $\varepsilon'' - f$ graph provides information on the behavior of molecular relaxation. Examining the plots, it can be observed that the ε'' value for the samples increases with frequency firstly but then decreases after a specific frequency value. This frequency is the relaxation frequency (f_R), which provides information on the dynamics of polar groups and the molecular motion of the examined systems [13]. At frequencies below the f_R, the dipoles adapt to the electric field; polarization is entirely achieved and ε'' is proportional to frequency. Nevertheless, the variance of the electric field is higher above the f_R, therefore orientation polarization is eliminated and the dipoles cannot follow the test signal. As a result, both ε' and ε'' decrease with frequency. The relaxation frequency is shown by the maximum of the $\varepsilon'' - f$ plot. For 0V and 20V, the f_R values for 5CB and MBBA are determined.

The relaxation frequency for 5CB at 0V and 20V was determined to be 2.91 MHz and 794 kHz, and 3.58 MHz and 3.42 MHz for MBBA. When voltage is applied to nematic liquid crystals, the relaxation frequencies decrease. The reduction in f_R values with increasing voltage can be explained by the influence of the electric field on the molecular orientation and, consequently, the presence of low anchor force.

The dielectric relaxation behavior of LCs can be investigated using the Cole-Cole model and Cole-Cole equation expressed the following equation;

$$\varepsilon^* = \varepsilon'_{\infty} + \frac{\varepsilon'_s - \varepsilon'_{\infty}}{1 + (i\omega\tau)^{1-\alpha}} \tag{4}$$

where ε'_s and ε'_{∞} are the low- and high-frequency limiting values of the ε', respectively, ω is the angular frequency, τ is relaxation time, α is a distribution parameter. When α equals zero, the Cole–Cole model is reduced to the Debye model. In the investigated frequency range, the Cole-Cole plot forms a semicircle in materials that correspond to the Debye model [14].

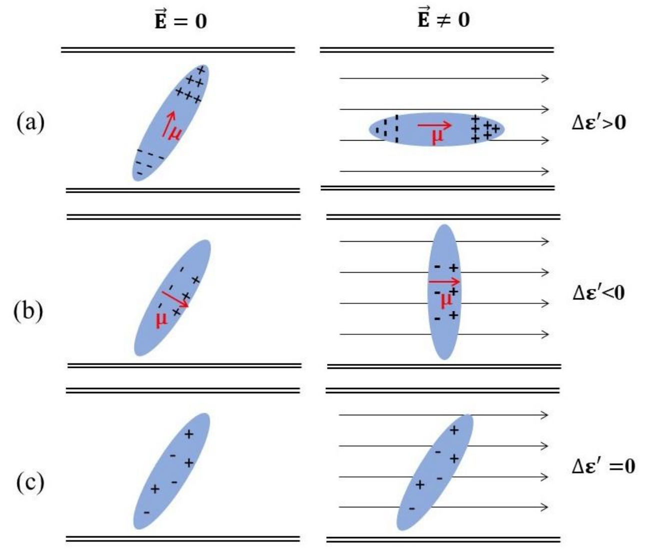

Figure 3. Orientation of the liquid crystal's molecules with a) positive b) negative c) zero dielectric anisotropy

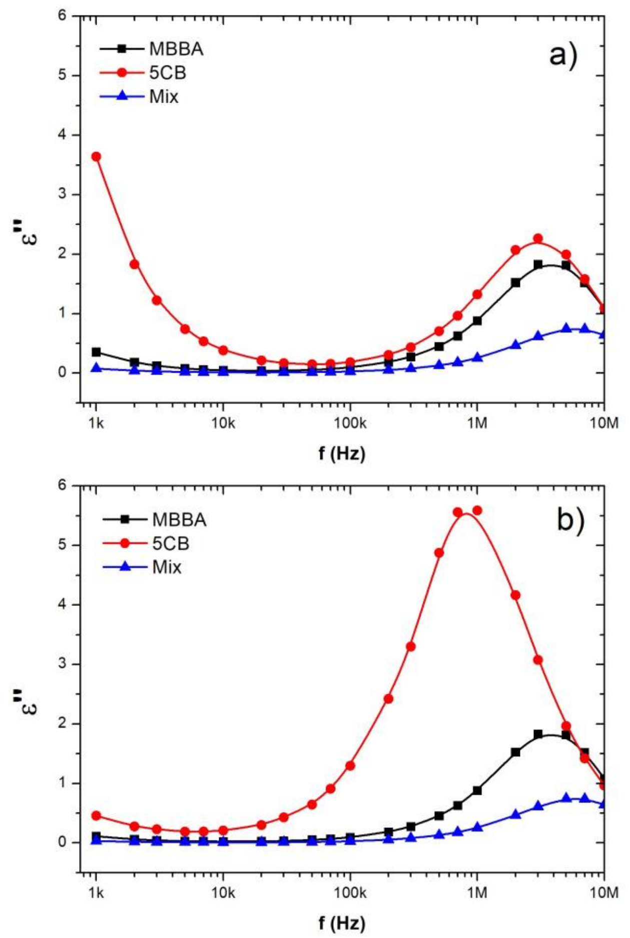

Figure 4. Frequency dependent ε'' values of the samples at a) 0V b) 20V.

Figure 5.a and Figure 5.b show the Cole–Cole plots of the samples for 0V and 20V. According to the plots, all sample exhibits a nearly Debye-type relaxing behavior. In addition, the Cole–Cole equation was used to determine the relaxation time of the samples. The relaxation time for 5CB at 0V and 20V was $0.05\mu s$ $0.17\mu s$, while for MBBA it was $0.04\mu s$ and $0.05\mu s$. The main cause for this phenomenon is that the molecules require more time to return to their initial state with increasing voltage [15].

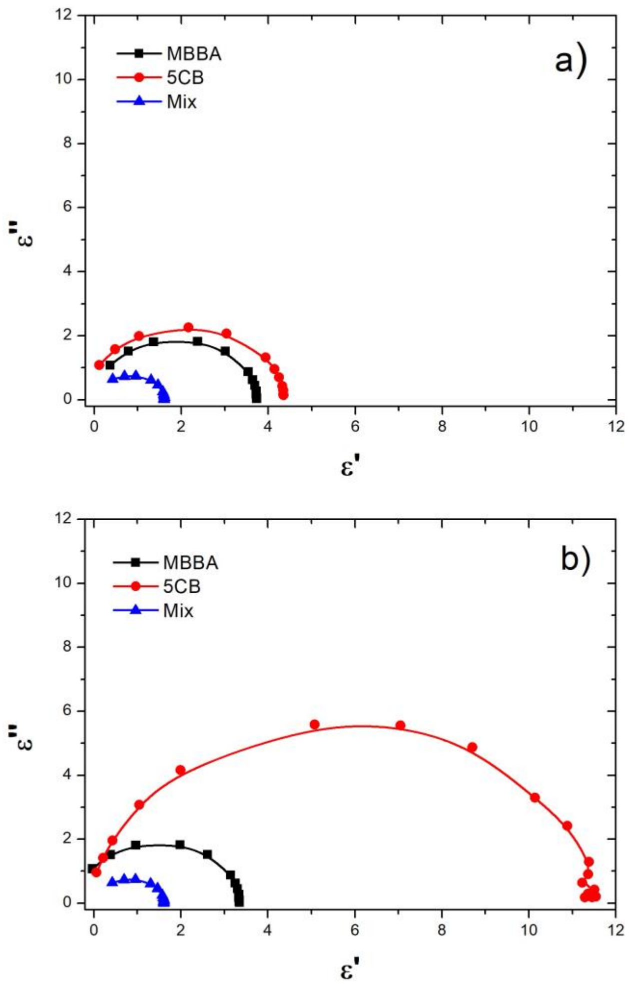

Figure 5. Cole-Cole plots of the samples at a) 0V b) 20V.

4. Conclusion

This work investigated the dielectric characteristics of nematic liquid crystals with negative (MBBA) and positive (5CB) dielectric anisotropy. In addition, the findings of obtaining a structure with zero dielectric anisotropy using MBBA and 5CB liquid crystals are presented. Under 0V and 20V voltages, the dielectric characteristics of the samples were investigated, and the orientations of the molecules were interpreted. The results indicate that the value of ε' increases for 5CB at 20V compared to 0V, however it lowers lightly for MBBA. In the structure formed using 5CB/MBBA, the ε' value is seen to be almost unchanged. These findings relate to $\Delta\varepsilon'$, which referes to the orientation of molecules influenced by an electric field. Because the parallel component of the ε' is higher than the perpendicular component for 5CB, and molecules align in the direction of the applied electric field; however, it is smaller than the perpendicular component for MBBA, and molecules are oriented perpendicular to the electric field direction. Despite this, the molecules are not oriented with an electric field in the 5CB/MBBA composites; this means the parallel and perpendicular component of the ε' is equal. Positive dielectric anisotropy liquid crystals are easier to orient at low frequency, whereas negative dielectric anisotropy liquid crystals are easier to orient at high frequency. In addition, relaxation frequency and relaxation time, two essential dielectric property parameters, were measured at 0V and 20V for samples. The relaxation frequency corresponding to the frequency with the maximum energy loss decreased for 5CB and MBBA at 20V voltage value. The relaxation time ($\tau = \frac{1}{2\pi f_R}$), which is inversely proportional to the relaxation frequency, increased for 5CB and MBBA at 20V voltage value. The results demonstrated that liquid crystal structures exhibit superior dielectric characteristics. Thus, these properties presented in the study open a way for using different nematic LCs in device applications. Consequently, it is thought that the study will contribute considerably to LC-based device applications.

5. References

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