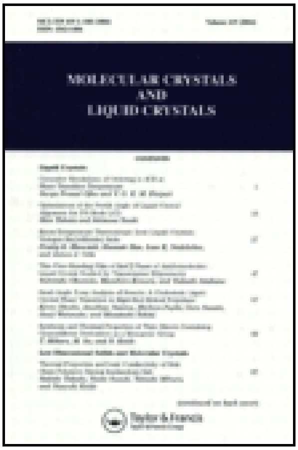

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Dielectric Behavior of Polyvinyl Alcohol (Pva) and its Influence on Lcds

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DIELECTRIC BEHAVIOR OF POLYVINYL ALCOHOL (PVA) AND ITS INFLUENCE ON LCDs

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This paper describes how the polyvinyl alcohol (PVA) used to anchor molecules in nematic liquid crystal cells (NLCs) presents the typical behavior of a disordered solid whose electric conductivity is frequency and temperature dependent ($\sigma'(\omega, \mathrm{T})$), in accordance with the hopping behavior. It has also been found, however, that PVA used as alignment layers in liquid crystal displays (LCDs) causes dielectric interfacial dispersion in these displays. This interfacial polarization can be modeled in the intermediary frequency range (10–10^3Hz), since neither liquid crystal nor PVA show, separately, a dielectric dispersion mechanism in this region. Thus, even though isolated PVA shows a hopping behavior, this behavior can be disregarded in the intermediate frequencies (10–10^3Hz) in the analysis of LCDs.

Keywords: nematic liquid crystal; dielectric properties; conductivity; interfacial polarization; displays

INTRODUCTION

The production of nematic liquid crystal (NLC) displays uses layers of polymers treated so as to promote anchoring of crystal liquid molecules in well-defined directions. The polymers most commonly employed are polyimides and polyvinyl alcohol (PVA).

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Studies of these polyimides have demonstrated that they influence the operational characteristics of the displays, causing strong dielectric dispersion because of the polarization of their interface with the liquid crystal. This interfacial polarization affects the molecular relaxation and the transition voltage of these displays and leads to the "crosstalk" effect [1–7]. This article reports on a study and characterization of the isolated dielectric behavior of PVA and its influence on NLC cells.

METHODOLOGY

Three liquid crystal cells were prepared in a 10 μm spaced twisted nematic configuration (TN) composed of PVA alignment layers with thickness of 1000 Å, 2500 Å and 4000 Å, filled with NLC-E7 (Merck Ltd., West Drayton, UK). A cell composed of a 200 μm PVA layer was also prepared.

All the cells were prepared with 1 mm soda-lime glass substrates, covered with circular gold electrodes with an area of 0.78 cm^2.

The complex permittivity was obtained by measuring the impedance in the newly prepared cells using a SOLARTRON (SI1260—0.1 Hz to 10 MHz) impedance bridge. The voltage was kept constant at 50 mV_{rms} in all the tests.

The boundary effects in the cell capacitors were corrected by means of an empirical method with a residual error or less than 1.1% [8]. The PVA cell was thermally analyzed in temperatures between 20–80 ± 1°C.

EXPERIMENTS AND RESULTS

Figure 1 illustrates the complex conductivity behavior ($\sigma'(\omega) - j\sigma''(\omega)$) in response to the frequency in the PVA.

An analysis of the experimental data for the PVA shown in Figure 1 reveals that the PVA is strongly dependent on the applied frequency. The real part (σ'_{DC}) of the conductivity ($\sigma'(\omega)$) tends toward a behavior that is independent of the frequency in the region below 10 Hz, while in the frequency region (>10 Hz) the conductivity (σ'_{AC}) is highly dependent on the frequency.

The PVA cell was studied under various temperatures in order to better understand its behavior. This analysis is illustrated in the graph in Figure 2.

The experimental data shown in the graph in Figure 2 clearly indicate that the conductivity is strongly temperature dependent in the lower frequency region (σ'_{DC}) and only slightly temperature dependent in the higher frequency region (σ'_{AC}). This behavior appears to be congruent with a mechanism whereby charged particles that are thermally activated move, i.e., by hopping.

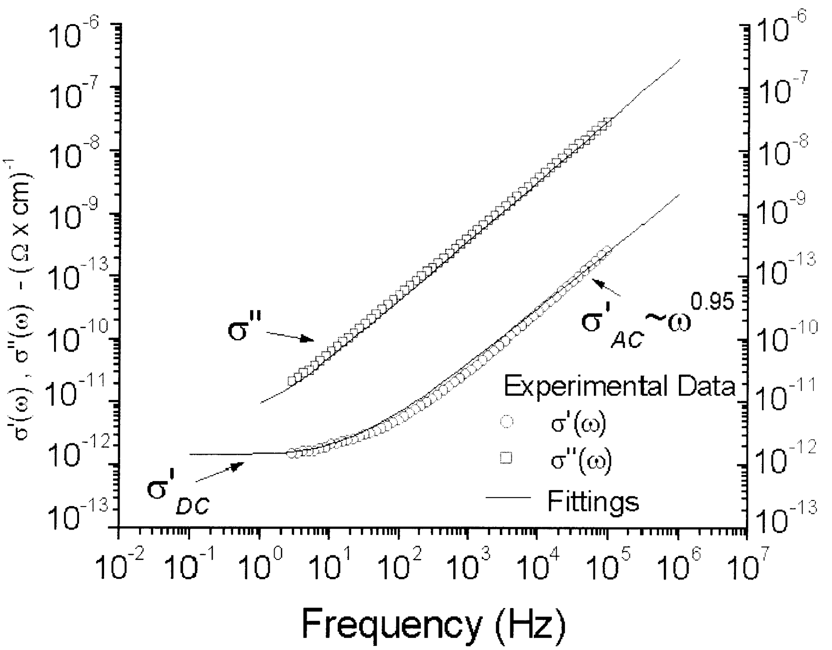


FIGURE 1 Experimental and calculated curves of the complex conductivity $\{\sigma^{*} = \sigma'(\omega) - j\sigma''(\omega)\}$ for the PVA at 20°C as a function of frequency. The PVA studied here a 98% degree of hydrolysis.

To clarify this PVA behavior, we have attempted to adjust a hopping model to the graphs of Figures 1 and 2, in which the hopping conductivity typical of disordered solids is given by Equation (1) in the complex form [9, 10]:

$$\sigma^{*}(\omega) = \sigma'_{DC}\left[1 + \frac{j\omega\tau}{\ln(1 + j\omega\tau)}\right], \tag{1}$$

where σ'_{DC} is the DC conductivity and τ is the time constant.

Separating the real and imaginary parts in Equation (1), one has

$$\sigma'(\omega) = \sigma'_{DC}\left[1 + \frac{\arctan(\omega\tau)\omega\tau}{\{\ln[1 + (\omega\tau)^2]^{1/2}\}^2 + [\arctan(\omega\tau)]^2}\right], \tag{2}$$

$$\sigma''(\omega) = \sigma'_{DC}\left[\frac{\ln[1 + (\omega\tau)^2]^{1/2}\omega\tau}{\{\ln[1 + (\omega\tau)^2]^{1/2}\}^2 + [\arctan(\omega\tau)]^2}\right]. \tag{3}$$

Adjusting Equations (2) and (3) to the experimental data of Figure 1 and Equation (2) to the experimental data of Figure 2 leads to a good

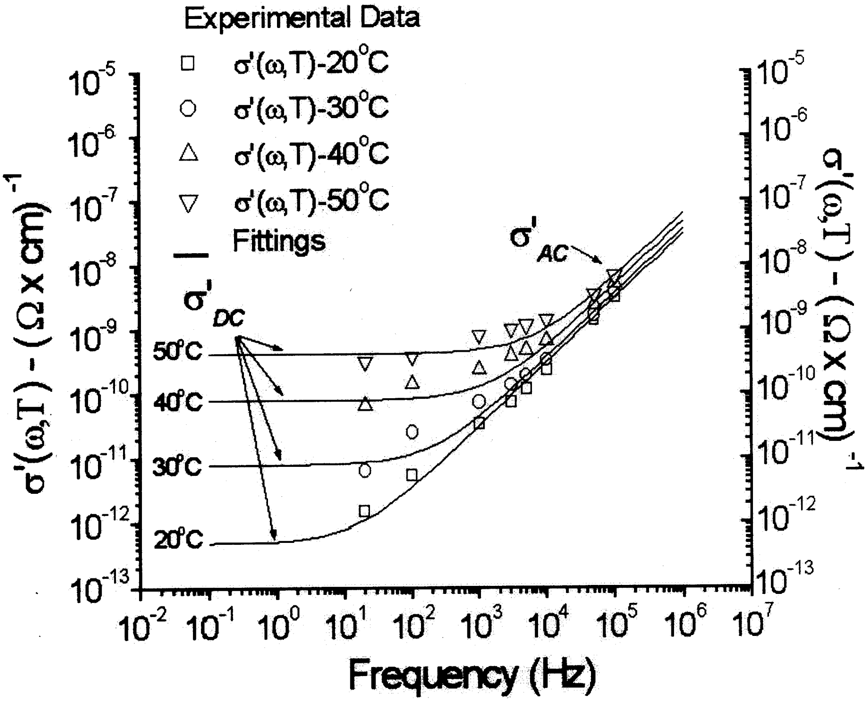


FIGURE 2 Experimental and calculated curves of the real conductivity of PVA versus frequency for temperatures of 20°C to 50°C.

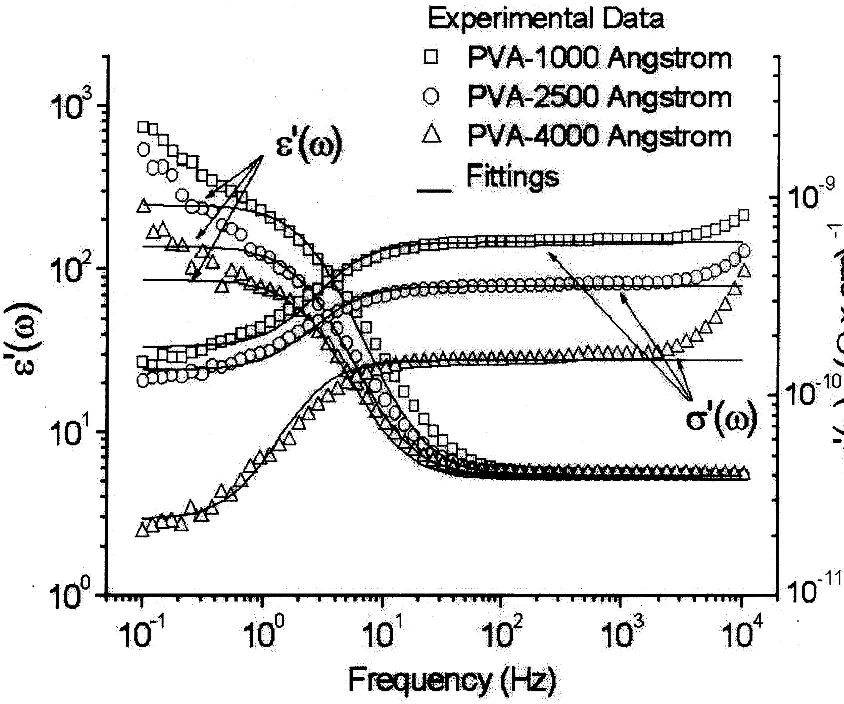
congruence, confirming that the PVA shows a hopping behavior. The results of these fittings are summarized in Table I.

Now, to verify whether this influence of the PVA is significant in the dielectric behavior of a LCD, the NLC-E7 cells were tested with PVA thickness of 1000 Å, 2500 Å, and 4000 Å. The results of these tests are illustrated in Figure 3a.

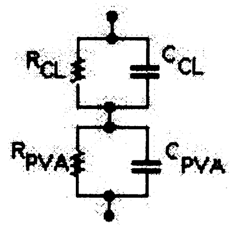
An analysis of the experimental data of Figure 3a clearly shows a strong dependence of permittivity and conductivity on the thickness of the PVA

TABLE I Estimated PVA Conductivity (σ'_{DC}) in the Temperature of 20°C, 30°C, 40°C, and 50°C

Temperature (°C)	$\sigma'_{DC} - (\Omega \times cm)^{-1}$
20°C	5×10^{-13}
30°C	9×10^{-12}
40°C	9×10^{-10}
50°C	4×10^{-10}



(a)



(b)

FIGURE 3(a) Permittivity and conductivity of the cells composed of CLN-E7 and PVA alignment layers with thickness of 1000 Å, and 4000 Å at 30°C. (**b**) Maxwell-Wagner equivalent electric circuit.

alignment layers for frequencies below 10^2 Hz, implying a behavior that is characteristic for an interfacial polarization mechanism.

To investigate this interfacial polarization of the LCD, we will consider a simple Maxwell-Wagner model for a capacitor with two dielectric layers, in which one layer represents the liquid crystal and the other the PVA, as indicated in Figure 3b [11]. By adopting this model, we disregard the nonlinear behavior (hopping) discussed above for PVA. In this two-layer parallel RC circuit, the permittivity and conductivity are obtained by Equations (4) and (5).

$$\varepsilon'(\omega) = \left\{ \frac{\frac{C_{CL}}{R_{PVA}^2} + \frac{C_{PVA}}{R_{CL}^2} + \omega^2 C_{PVA} C_{CL}(C_{PVA} + C_{CL})}{\left[\left(\frac{1}{R_{PVA}} + \frac{1}{R_{CL}}\right)^2 + \omega^2 (C_{PVA} + C_{CL})^2\right] C_0} \right\}, \tag{4}$$

$$\varepsilon''(\omega) = \left\{ \frac{\frac{1}{R_{PVA} R_{CL}}\left(\frac{1}{R_{PVA}} + \frac{1}{R_{CL}}\right) + \omega^2 \left(\frac{C_{PVA}^2}{R_{CL}} + \frac{C_{CL}^2}{R_{PVA}}\right)}{\left[\left(\frac{1}{R_{PVA}} + \frac{1}{R_{CL}}\right)^2 + \omega^2 (C_{PVA} + C_{CL})^2\right] \omega C_0} \right\}, \tag{5}$$

where C_0 is the cell capacitance in the vacuum, $C_0 = \varepsilon_0 A/d$, ε_0 is the vacuum dielectric permittivity, d is the thickness of the cell, $d = d_{PVA} + d_{CL}$, A is the cell surface area, and $\sigma'(\omega) = \varepsilon^{11}(\omega)\varepsilon_0\omega$.

The perpendicular permittivity and conductivity for the NLC-E7 are, respectively, $\varepsilon'_{\perp} = 5.4$ and $\sigma'_{\perp} = 2.6 \times 10^{-10}\,(\Omega \times \text{cm})^{-1}$ in the frequency range of $10 - 10^4$ Hz and 20°C [12]. Based on these values, Equations (4) and (5) were numerically adjusted to the graph in Figure 3a to estimate the PVA permittivity and conductivity in the different cells. These adjustments are illustrated in the graph of Figure 3a, and their results summarized in Table II.

The agreement between the calculated and experimental curves in frequencies between 1 Hz and 10^3 Hz shows that the two-layer model adopted here is adequate to explain the LCD behavior. This result indicates that the PVA nonlinearity caused by the hopping effect has a small influence on the LCD behavior and could be disregarded in adopting the two-layer dielectric linear capacitor model.

At frequencies below 1 Hz, the two-layer model is inappropriate to explain the behavior observed in the LCD, in view of the strong dielectric dispersion caused by the movement of ionic impurities in the NLC-E7 [12]. On the other hand, at frequencies over 10^3 Hz, one must take in account the dipolar relaxation mechanism of the NLC-E7 [12, 13] together with the hopping effect in the PVA.

Thickness (PVA)	ε'_{PVA}	σ'_{PVA} $(\Omega \times cm)^{-1}$
1000 Å	4.90	9.5×10^{-12}
2500 Å	6.67	8.8×10^{-12}
4000 Å	5.92	1.5×10^{-12}

Table II also shows that the conductivity estimated for the PVA (σ'_{PVA}) depends on its thickness. This behavior may be associated with charges originating from the electrodes and injected into the PVA. This injection of charges is assumed to occur up to a critical thickness, where the charges are no longer able to penetrate the PVA.

CONCLUSION

This paper presents a study on the electric conductivity $\sigma'(\omega, \mathrm{T})$ of PVA used to anchor the molecules in nematic liquid crystal cells (NLCs), showing its strong dependency on frequency and temperature, typical of a hopping mechanism.

It was also found that LCDs produced with PVA alignment layers suffer interfacial dispersion, which can be modeled by a two-layer parallel RC circuit in frequencies between 10 Hz and 10^3 Hz. Our analysis also revealed that, although PVA alone shows a hopping behavior, this behavior can be disregarded when analyzing LCDs in the same range of frequencies.

REFERENCES

[1] Edwards, H. O., Kedrgejewski, K. P., Laming, R. I., & Payne, D. (1989). *Appl. Opt.*, *28*, 1977–1979.
[2] Mada, H., & Nishikawa, A. (1993). *Jpn. J. Appl. Phys.*, Part 2, *32*(7B), L1009–L1010.
[3] Jacob, T., Klement, D., Schuler, B., Tarumi, K., & Sawada, A. (1998). *Displays and Vacuum Electronics*, *ITG Conference*, Germany, April 29–30, pp. 41–46.
[4] Jadzyn, J. & Czechowski, G., (1999). *Liquid Crystals, 26*, 453–456.
[5] Welford, K. R., Miners F., & Sambles, J. R. (1988). *J. Phys. D: Appl. Phys*, *21*, 1320–1325.
[6] Kim, T. H., Jung, S. S., Park, J. W., Choi, J. S., & Yun, Y. J. (2001). *J. Korean Phys. Soc.*, *39*, 67–71.
[7] Sawada, M., Higuchi, M., Kondo, S., & Saka, H. (2001). *Jpn. J. of Appl. Phys.*, Part 1, *40(5A)*, 3332–3336.
[8] Schaumburg, G. (1997). *Dielectrics Newsletter*, 05–10.
[9] Dyre, J. C. (1988). *J. Appl. Phys.*, *64(5)*, 2456–2468.
[10] Dyre, J. C. (1985). *Physics Letters*, *108A, 17(9)*, 457–461.
[11] Daniel, V. V. (1967). *Dielectric Relaxation*, London and New York, Academic Press.
[12] Costa, M. R., Altafim, R. A. C., & Mammana, A. P. (2001). *Liquid Crystals*, *28*(12), 1779–1783.
[13] Coffey, W. T., Crothers, D. S. F., Kalmykov, Yu. P., & Waldron, J. T. (1995). *Phys. A*, *213*(4), 551–575.