ELECTRICAL MODEL FOR THRESHOLDLESS ANTIFERROELECTRIC LIQUID CRYSTAL CELLS

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Abstract

The equivalent circuit for a thresholdless antiferroelectric liquid crystal (TLAFLC) cell has been derived using an electrical model. The model may be used to predict the TLAFLC dynamic behavior. The electrical response in the time domain of TLAFLC cells upon certain hypothesis has been obtained. Optical characteristics related to these electrical features have been derived as well.

The equivalent circuit model reasonably reproduces the voltage across the cell, switching currents and the optical hysteresis obtained by experimental methods. The procedure for determining the voltage-dependent capacitance due to induced spontaneous polarization is shown. On the basis of the proposed model, we also suggest a number of clues to optimize some electrical parameters of liquid crystal materials as well as driving schemes.

Keywords

Electrical model; antiferroelectric liquid crystal; V-shape switching; hysteresis.

I. INTRODUCTION

Electro-optic switching in surface-stabilized ferroelectric liquid crystals (SSFLCs) was discovered by Clark and Lagerwal in thin homogeneous cells [1].This switching is characterized by a single hysteresis (bistability) and fast response times (several orders of magnitude lower than nematics). However, FLCs are not suitable for display applications because they essentially lack continuous gray-scale capability [2].

Typical antiferroelectric liquid crystals (AFLCs) present double hysteresis (tristability) and analogue gray-scale thus being good candidates for obtaining high-quality displays. Both FLCs and AFLCs show voltage threshold but associated with different physical mechanisms.

On the other hand, thresholdless, hysteresis-free V-shaped switching was observed in AFLC mixtures [3].

In this paper, we will show an approach to obtain the electrical equivalent circuit of a TLAFLC cell by measuring its complex impedance at different switching states. The agreement between theoretical and experimental results of its electrooptical performance is fairly good.

II. EXPERIMENTAL

In the present study, we used an antiferroelectric mixture supplied from the Military University of Warsaw. This material was aligned inside a thin cell with a thickness of 1.7 μm under surface-stabilized conditions. The electrode area is 1 x 1 cm^2. An Impedance/Gain-Phase analyzer (HP 4194A) was used to perform the complex impedance measurements. This equipment was linked to a PC via GPIB bus. The PC runs a specific software (HP VEE) that controls the main parameters for data acquisition.

Impedance measurements corresponding to the discrete values on the four ramps of the optical hysteresis cycles were taken with this setup. These values are associated with different switching states of the TLAFLC mixture in the ferroelectric phase (when applied voltage is $\neq 0$ V) or in the antiferroelectric phase (when applied voltage is equal to 0 V).

The optical transmittance of the TLAFLC cell was measured under crossed polarizers, using a photomultiplier tube as detector, while applying a triangular wave voltage at different frequencies. We simultaneously measured the current response in order to study the electrooptical properties. A specific circuit formed by two sub-systems (analogue and digital) was built. In order to investigate the properties of TLAFLC cell in the quasi-equilibrium state, a triangular wave of sufficiently low frequency was applied.

III. ELECTRICAL MODEL OF TLAFLC CELLS

The first model of electric equivalent circuit proposed [4] for deformed helix ferroelectric liquid crystals (DHFLC) cells is shown in Figure 1.

Each element or combination of elements describes the different aspects related to the electrooptic response:

(i) The static capacitor C_{st} accounts for the nonferroelectric part of the dielectric response (due to instantaneous polarization) of the DHF configuration.

(ii) The series $R_{hx}C_{hx}$ combination covers the ferroelectric aspect of the dielectric response. Both elements take into account the dielectric relaxation (heat dissipation) and the slow orientation of dipole polarization, respectively.

(iii) The series R_sC_s combination reflects the influence of the cell parameters such as resistivity and capacity of ITO layers, insulating and aligning layers. Normally, C_s is very large compared to other capacitances of the circuit.

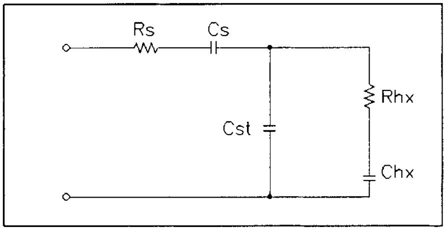

FIGURE 1. Electrical equivalent circuit of a DHFLC cell.

A model of electric equivalent circuit slightly modified was proposed for a TLAFLC cell [5]. In this case, a dependence of the parameters C_{hx} and R_{hx} on the voltage must be considered to describe the dynamic behavior. We will introduce the approach for determination of the equivalent circuit parameters.

III.1 Electrical Behavior

The results obtained for the complex impedance Z_{exp} (modulus and phase) measured of the TLAFLC cell at different switching states (in ferro/antiferroelectic phases) applying discrete DC voltages across of it, are shown in Figure 2. By using a minimization process for the difference function:

$$Z_{dif} = Z_{exp} - Z_{mod} \quad (1)$$

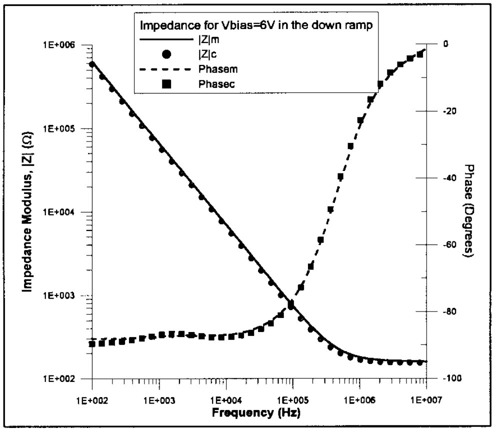

FIGURE 2. Modulus and Phase of Z_{exp} and Z_{mod} for a TLAFLC cell in the down ramp of the optical hysteresis.

where Z_{mod} is the impedance associated to the electric circuit proposed, we found that the parameters that optimize such Z_{dif} function are the following ones: Cs=14nF; Rs=153.5 Ω ; Cst=2.95nF. These values are not depending on the applied voltage (V_i).

However, C_{hx} and R_{hx} must depend on the voltage to describe the electrooptic properties of a TLAFLC cell. In the equilibrium state, the following relationship from the circuit can be derived:

$$\frac{dVcs}{dVi} = \frac{Cst + Chx(Vi)}{Cst + Chx(Vi) + Cs} \quad (2)$$

where V_{cs} is the voltage of the capacitance C_s, and V_i is the triangular signal of low frequency applied across the cell. As above mentioned, the current response (I_{exp}) can be easily measured. Taking into account the following equation,

$$V_{cs} = Q_{cs}/C_s = (1/C_s)\int I_{exp}\, dt \quad (3)$$

and assuming a piecewise linear approximation for V_{cs}, the variation of C_{hx} and R_{hx} with the voltage can be obtained, as shown in Figure 3.

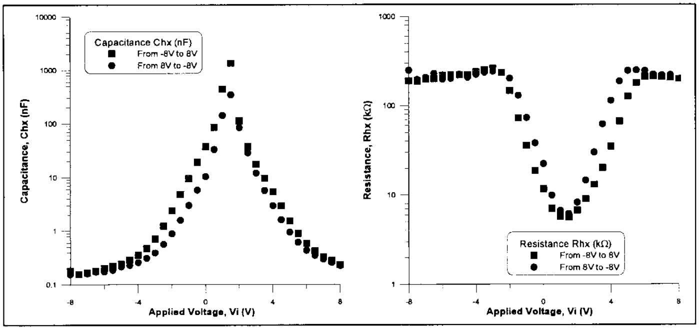

FIGURE 3. Variation obtained for C_{hx} and R_{hx} as a function of V_i.

III.2 Electrooptic Behavior

W-shape switching was observed applying two low frequencies of the triangular wave, as shown in Figure 4. The transmittance of a TLAFLC cell between crossed polarizers can be written as:

$$T = T_0 \sin^2(2\theta) \qquad (4)$$

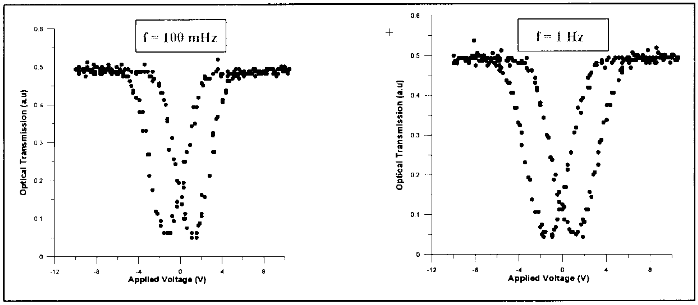

FIGURE 4. Optical hysteresis measured for the TLAFLC cell applying two different frequencies of the triangular signal.

where T_0 is the maximum transmittance and θ is the apparent tilt angle. The appearance of W-shape switching in AFLC mixtures under different conditions of alignment and thickness of the cell was investigated [6]. The mechanism associated with the W-shape switching occurrence may be due to several factors such as the conductivity of the alignment layers, cell thickness, the frequency of applied voltage, temperature, among others.

IV. CONCLUSIONS

A procedure to obtain all parameters of the proposed electrical equivalent circuit for a TLAFLC cell was demonstrated. It was found that constant parameters of the circuit can be derived by using a simple mathematical method of minimization for the Z_{dif} function.

The variation of the capacitance C_{hx} and resistance R_{hx} with the applied voltage was obtained by studying the electrical circuit in the equilibrium state. In this case, a simple relationship between V_{cs} (voltage of the capacitance C_s) and V_i can be derived.

This model permits to predict the electrooptic response of TLAFLC cells and also describe their static and dynamic behavior. In this way, standard simulators such as SPICE, SIMULINK, etc. could be used to optimize the performance of this kind of AFLC materials by using new active-matrix addressing schemes.

V. ACKNOWLEDGEMENTS

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