Dielecrtric and Voltage Holding Properties of the Half-V-shaped Switching Ferroelectric Liquid Crystal Mode Driven by Active Matrix

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For high quality displays, analog responding liquid crystals with spontaneous polarization (P_s) need to be coupled with active matrix driving schemes. We have characterized the half-V-shaped switching ferroelectric liquid crystal mode (half-V FLC mode) in terms of dielectiric and voltage holding properties. Research on these switching properties provided us with the technology for switching half-V FLC mode FLCs by using amorphous silicon TFTs.

Introduction

The development of new AM-LCDs has accelerated in recent years and their use has spread not only in notebook PCs, but also in desktop monitors. The next most important target for the application of AM-LCDs will be TV displays because of their enormous market size. One possible way to reach this goal is to apply ferroelectric liquid crystals (FLCs) or antiferroelectric liquid crystals (AFLCs), for example half-V-shaped switching ferroelectric liquid crystals (half-V FLCs) [1~3], as the liquid crystal materials. Among the ferroelectric liquid crystals, the half-V FLCs are particularly promising because they have an analog grayscale capability suitable for TFT LCDs. However, in case of TFT driving, pixel voltage fluctuations (drop) occur due to a spontaneous polarization (P_s) switching current.

In this paper, we reported the results of dielectric and voltage holding properties of half-V FLCs with active matrix driving schemes as a function of capacitance of FLC cell (C_{LC}), spontaneous polarization (P_s) and storage capacitance (C_{sto}).

Experimental

In this study, we constructed sample cells with 1.8um gap and 1cm^2 test electrodes. The liquid crystals used in this work were R-1811 (Clariant) with P_s of 2, 4, 6 and 10 nC/cm^2 respectively. The phase sequence of these materials is as follow; Isotropic - Cholesteric - Smectic C* - Crystal (Table 1). The alignment layers are polyimide (Nissan Chem.) having a low pretilt angle below 2 degrees. Liquid crystal was injected into an empty cell, whose inner surfaces of substrates were anti-parallel rubbed.

	Phase Sequence (℃)
R-1811	Iso 98~96 Ch 57~58 S^*_C -9 Cryst.

Table1. Phase sequence of R-1811 and R-1812

To obtain the uniform alignment with only one domain during cooling process from isotropic to

Smectic* C (Sm^*C), an electric field of a low DC voltages should be applied only near the phase transition temperature from Ch to Sm^*C.

Dielectric measurements were performed using LCR meter (Hewlett-Packard, 4284A) in the frequency range between 10 Hz and 1MHz. The measuring oscillation voltage was 0.1 V_{pp}. In voltage holding measurement, the gate pulse width and the frame time were fixed at 21us and 16.7 ms, respectively. The parameters for the measurements were spontaneous polarization (P_s) and built-in storage capacitance (C_{sto}).

Dielectric Properties of half-V FLCD

Fig. 1 shows the equivalent circuit for Half-V FLCDs, which was derived for DHF-LCDs. [4,5] We adopt this circuit because a half-V FLCD is also known as an analog responding LC with spontaneous polarization. The static capacitor C_{static} is the nonferroelectric part of the dielectric response, which is the result of the instantaneous polarization. The C_{hx} is the ferroelectric part of the dielectric response, which is caused by slow orientation of dipole polarization. A dissipative element R_{hx} must be included in the part of the circuit to describe the dielectric relaxation, which will be associated with the viscosity of the LC director.

The capacitance of the half-V FLCD cell C_{cell} was measured as a function of the bias voltage for several frequencies, shown in Fig. 2. In general, LCs with spontaneous polarization (DHF LCDs , TLAF-LCDs and so on) show that the capacitance C_{cell} is dependent on the bias voltage as well as the frequency when the bias voltage is small than V_{sat}.

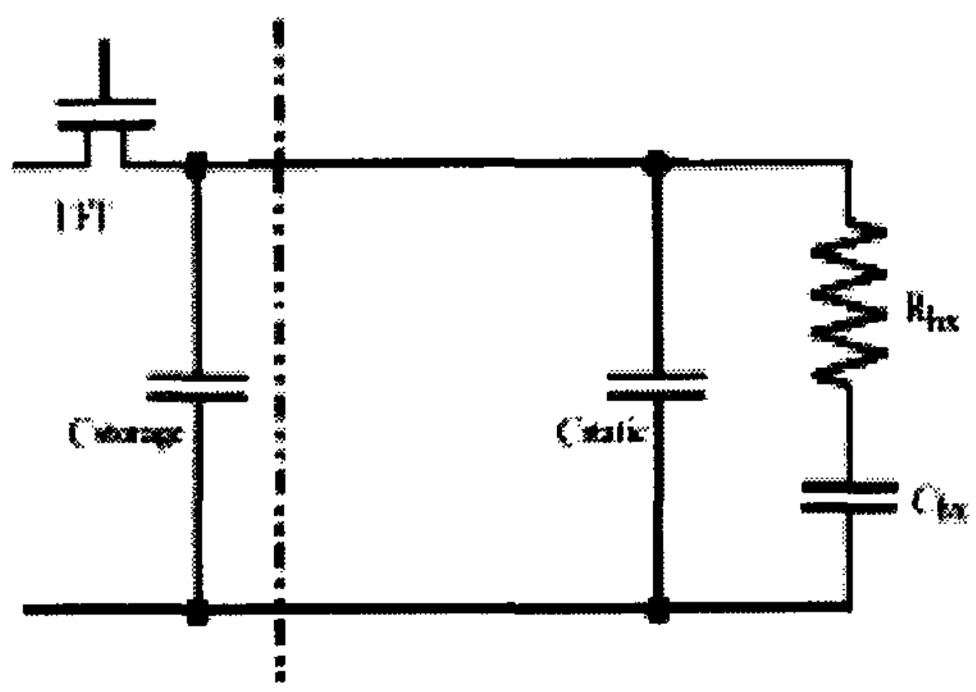

Fig. 1. Electronic equivalent circuit of a half-V FLCD [4, 5]

However, the capacitance of the half-V FLCD cell C_{cell} is almost constant regardless of the frequency and the bias voltage. We conclude that the molecular electric susceptibility perpendicular to the substrate will change negligibly when the molecules rotate on the cone with a small angle due to the initial alignment process that makes uniform LC directors.

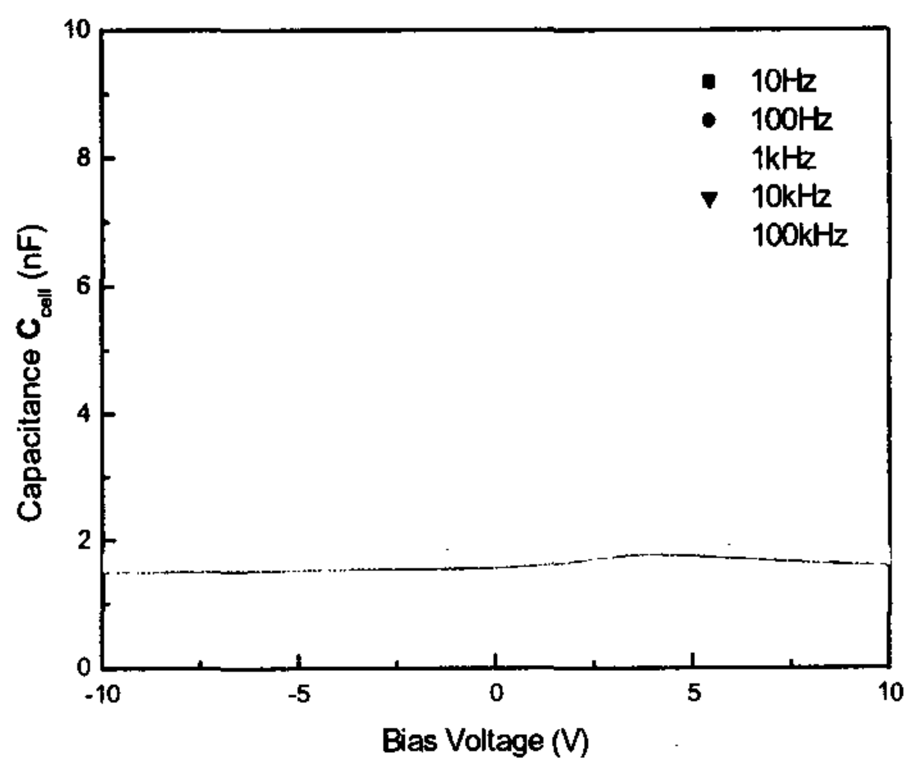

Fig. 2. The capacitance of a half-V FLCD cell as a function of the bias voltage

Voltage Holding Properties of half-V FLCD

Fig. 3 shows a model of FLCs with active matrix driving system. [5,6] The P_s switching of FLCs hardly occurs if the gata on time is short. At gate off, the FLCs respond while consuming the charge saved in the cell (Q_{total}) by the Ps switching. Therefore, voltage holding ratio (VHR) is constant when gate on time is short (~30us). At gate off, the VHR decreases because the P_s switching consumes the cell charge. The consumption of the cell charge by complete P_s switching is thought to be $2P_s$.

Yoshihara et al previously described the supposition that the consumption of the total cell charge (Q_{total}) at gate off as $2P_s$ when gate on time is short. Thus, VHR is represented by the following formula. [7]

$$VHR=(Q_{total} - 2P_s \times A)/Q_{total} \times 100\ (\%)$$

$$Q_{total} = C_{total} \times V_{ex}$$

A is the electrode area of cell and C_{total} consists of two parts: $C_{total}=C_{LC} + C_{sto}$, where C_{LC} is determined by the geometry of the cell and the high frequency dielectric constant of the LC material and C_{sto} by the built-in storage capacitor.

From the above equation, we have characterized the half-V FLC mode) mixture in terms of voltage holding properties as a function of spontaneous polarization (P_s) and storage capacitance (C_{sto}).

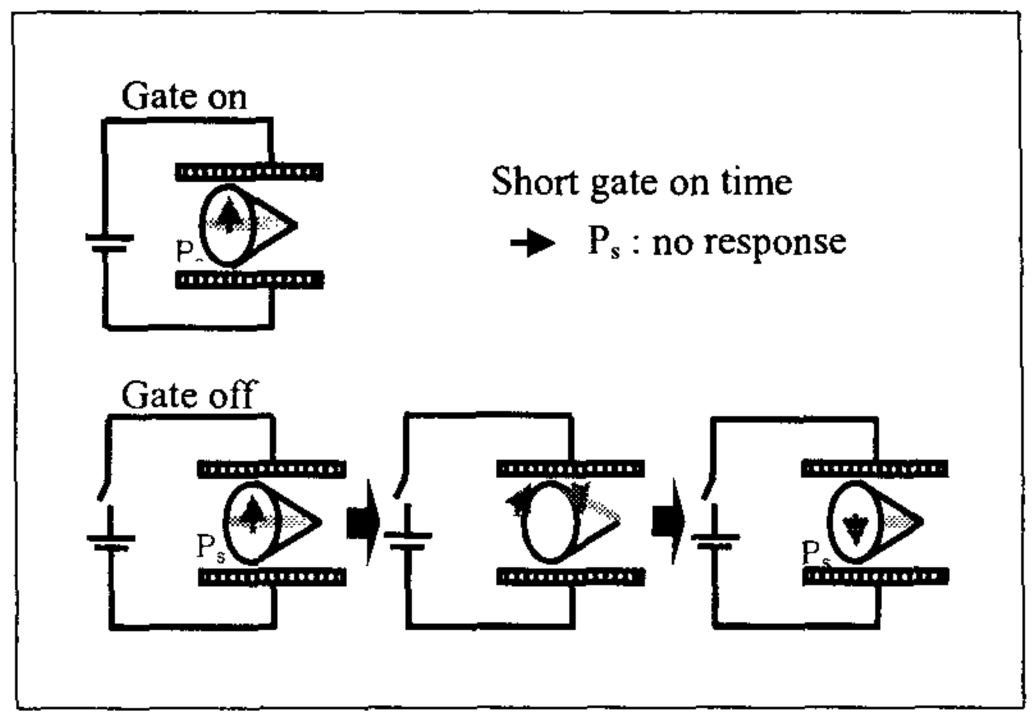

Fig. 3. Driving model of FLCs with active matrix system [7]

Fig.4 shows the measured results of spontaneous polarization (P_s) dependence of voltage holding ratio (VHR) – gate on time (tg) characteristics in R-1811 FLC materials. For a gate on time (tg) in the range of short tg (~30us), the voltage holding ratio (VHR) is constant because the P_s switching hardly occurs if the gata on time is short. As shown in Fig.4, larger spontaneous polarization (P_s) induces larger voltage drop. From these results, small spontaneous polarization (P_s) of materials can increase the holding ratio.

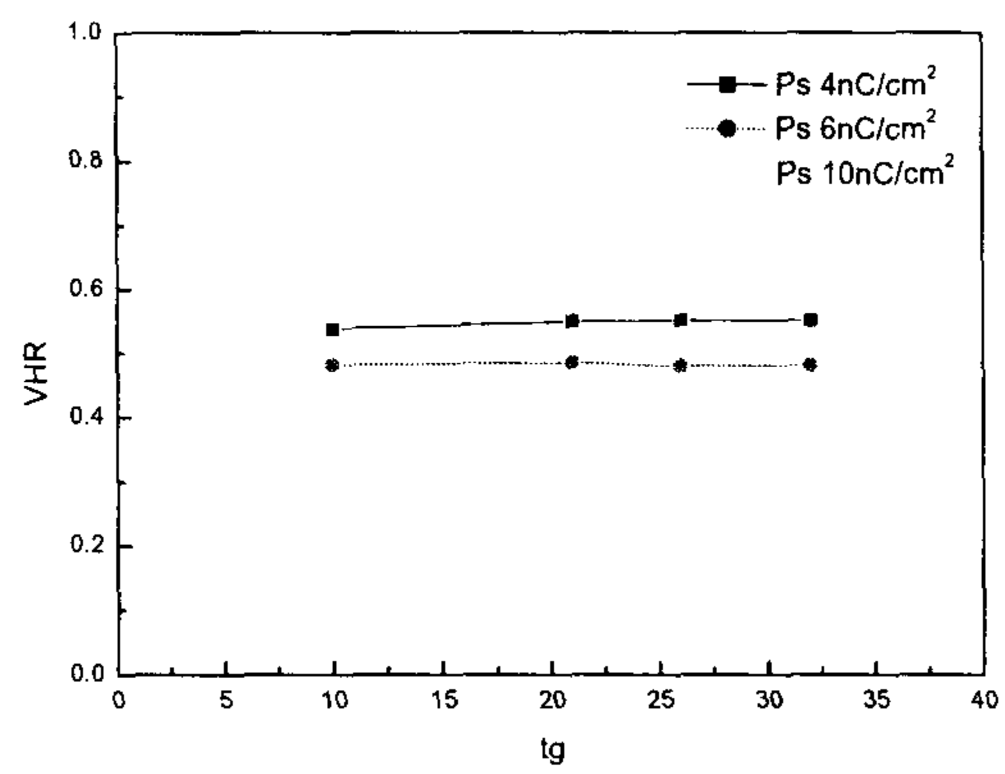

Fig. 4. Spontaneous polarization (P_s) dependence of voltage holding ratio (VHR) – gate on time (tg) characteristics in FLC materials (R-1811, Applied voltage: 5V, C_{sto}=0)

The voltage holding ratio (VHR) on different conditions of storage capacitance is shown in Fig.5. Larger storage capacitance compensates for the voltage drop. However, larger built-in storage capacitor reduces the aperture ratio, so optimizing the built-in storage capacitor is very critical issue point to design panels using materials with spontaneous polarization (P_s).

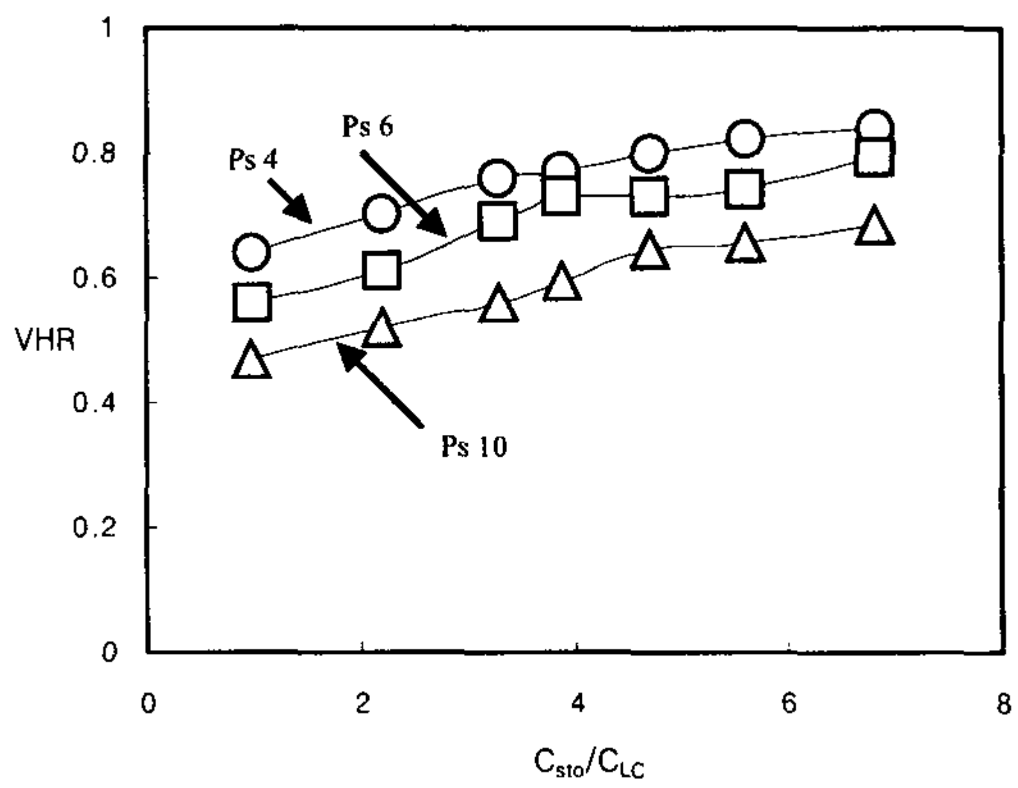

Fig. 5. The voltage holding ratio (VHR) vs. built-in C_{sto} characteristics in FLC materials (R-1811, Applied voltage: 5V)

Conclusions

We have investigated the dielectric and voltage holding properties of the half-V-shaped switching ferroelectric liquid crystal mode (half-V FLC mode) for application in TFT LCD. The equivalent circuit model for half-V FLCDs was discussed on the basis of the capacitance measurements. In addition, the model proposed in this work represents the voltage holding properties of FLCs. Experimental results indicate that the small spontaneous polarization (P_s) of materials or large built-in storage capacitance can increase the holding ratio.

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