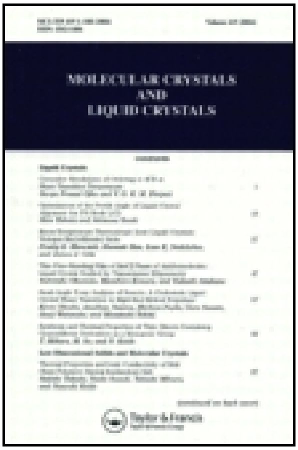

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MODELING AND SIMULATION OF PARASITIC CAPACITANCES FOR ACTIVE MATRIX LIQUID CRYSTAL DISPLAYS (AMLCDs)

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MODELING AND SIMULATION OF PARASITIC CAPACITANCES FOR ACTIVE MATRIX LIQUID CRYSTAL DISPLAYS (AMLCDs)

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In this paper, we present a compact approach for modeling a parasitic capacitance in active matrix liquid crystal displays (AMLCDs) as a function of voltage applied at pixel electrodes. The director distribution as well as the potential distribution is estimated from a three-dimensional finite element method (FEM), while the parasitic capacitance within a liquid crystal cell is calculated with an energy moment method. Furthermore, we applied our proposed approach on the VA (vertical alignment) mode LC cell with a chevron-type electrode structure in order to understand the dynamic behavior of the cell.

Keywords: energy method; finite element method; liquid crystal display; parasitic capacitance; simulation

INTRODUCTION

A device parameter such as a parasitic capacitance within a LC cell is an important factor for the estimation of the performance of an active matrix liquid crystal displays (AMLCD). In order to optimize a driving waveform

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for a good image quality, an accurate and robust analysis tool for parasitic capacitances is essentially required [1]. Since the dielectric constant of LC material has a property of anisotropy and furthermore the dielectric properties of LC material can be influenced by the disclination within LC cell, the conventional analytic method cannot be applied for an accurate estimation of dynamic behavior of LC cell. Moreover, it is very important to devise an elaborate numerical approach if we want to figure out how the molecules (directors) respond to the voltage applied at pixel electrode whose geometry is quite complicated such as IPS and MVA modes. In this paper, we propose a compact approach for the computation of a parasitic capacitance in an AMLCD cell with varying voltage applied at pixel electrode. The calculation procedure comprises a step of calculating the director and potential distributions, followed by a step of computing the parasitic capacitance in AMLCD cell

NUMERICAL MODEL

For the dynamic analysis of director distribution, the Euler-Lagrange equation of the Frank-Oseen free energy density should be formulated for the director distribution. In addition, the Laplace equation for the electric potential distribution should be formulated in response to the applied voltage [2–5]. The numerical procedure under consideration comprises a couple of iterative treatments for each time step. Firstly, we obtain a solution with respect to voltage from the Laplace equation, given a known director distribution. Then the Ericksen-Leslie equation is solved for the director deformation when the distribution of voltage is known. As a numerical approach, we employed a finite element method (FEM) [6].

Thereafter, the energy moment method is employed for extracting the parasitic capacitance within an LC cell [7]. The total electric field energy for a given conductor voltage configuration can be expressed by summing the energies stored in the parasitic capacitors.

$$W = \frac{1}{2}C\phi^2 = \frac{1}{2}\int \vec{E}\varepsilon\vec{E} \tag{1}$$

where C is capacitance, ϕ is the potential value, $\vec{E}$ is electric field, W is total energy in AMLCDs cell, and ε denotes the dielectric anisotropy of the liquid crystal is described by the uniaxial tensor,

$$\varepsilon = \varepsilon_{\perp}\delta_{ij} + (\varepsilon_{||} - \varepsilon_{\perp})n_i n_j \tag{2}$$

The energy has to be calculated for different conductor voltage configurations, the number of which is equal to the number of existing capacitances. The values of the parasitic capacitance are obtained by solving the linear system of equations.

$$\begin{bmatrix} U_{1,2}^{1} & U_{1,3}^{1} & \cdots & U_{8,9}^{1} \\ U_{1,2}^{2} & U_{1,3}^{2} & \cdots & U_{8,9}^{2} \\ \vdots & \vdots & \ddots & \vdots \\ U_{1,2}^{36} & U_{1,3}^{36} & \cdots & U_{8,9}^{36} \end{bmatrix} \cdot \begin{bmatrix} C_{1,2} \\ C_{1,3} \\ \vdots \\ C_{8,9} \end{bmatrix} = \begin{bmatrix} I^{1} \\ I^{2} \\ \vdots \\ I^{36} \end{bmatrix} \tag{3}$$

$$U_{i,j}^{k} = (\phi_i^k - \phi_j^k)^2 \tag{4}$$

where ϕ_i and ϕ_j are the potential values at the ith and the jth conductors, respectively. $C_{i,j}$ is the coupling capacitance between the ith and the jth conductors. The index k means kth voltage configuration. Therefore, I^k is the calculated electric field energy obtained from Eq. (2) for the kth voltage configuration.

SIMULATION AND DISCUSSIONS

In order to verify the accuracy of the proposed method, the VA mode cell with chevron-type electrode structure, as depicted in Figure 1, was chosen as a test vehicle. Figure 1 shows the geometry of the electrode structure as well as the mesh generated for the exemplary VA cell. The exemplary LC cell is composed of a pixel electrode, a common electrode, a gate electrode, and a data electrode. The simulation region is 264 um × 88 um × 6.9 um except glass layer. The finite element mesh covers a total of 22,695 nodes and 123,168 tetrahedrons. The LC parameters are: $K_{11} = 16.7 \times 10^{-12}$, $K_{22} = 7.3 \times 10^{-12}$, $K_{33} = 18.1 \times 10^{-12}$, $\varepsilon_{||} = 3.6$, $\varepsilon_{\perp} = 7.8$, and $\gamma_1 = 0.1$ $Pa \cdot s$. We assumed pre-twist angle of $\Phi = 0°$ and pre-tilt of $\theta = 90°$.

We have performed calculation with voltage sweep for the pixel electrode from 0 V to 10 V. We have simulated for the potential distribution and the director distribution with strong anchoring condition. The common electrode, gate electrode, and data electrodes are tied to ground potential. Figure 2 shows the electric potential distribution and the director distribution when 10 volt is applied at the pixel electrode. Referring to Figure 2, it should be noted that almost all the directors are aligned in a perpendicular direction to the electric field since the liquid crystal demonstrates a negative type and has two domains, while the disclination occurs on the data line and the gate line and along the pattern of the pixel and common electrodes.

Referring to Figure 1(a), the exemplary structure includes a total of 4 electrodes comprising a pixel electrode, a gate line, a data line, and a common electrode. Therefore, there are 6 unknown capacitances in the VA cell.

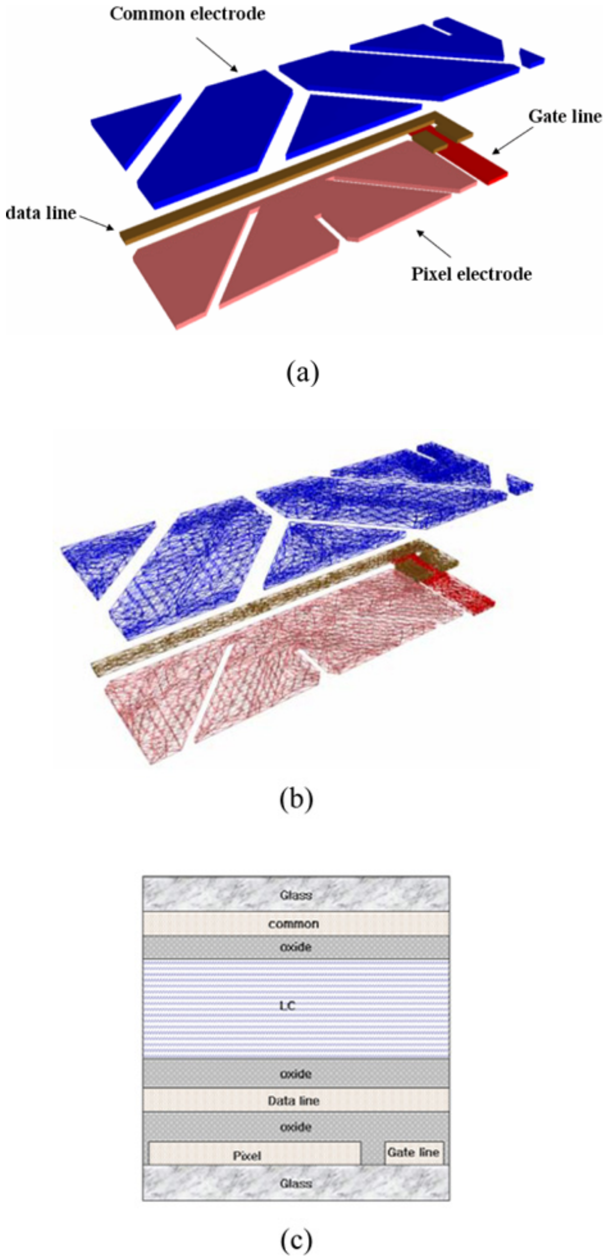


FIGURE 1 Schematic diagrams illustrating (a) electrode structure, (b) mesh, and (c) layer structure of exemplary cell used in this study. (See COLOR PLATE XXIV)

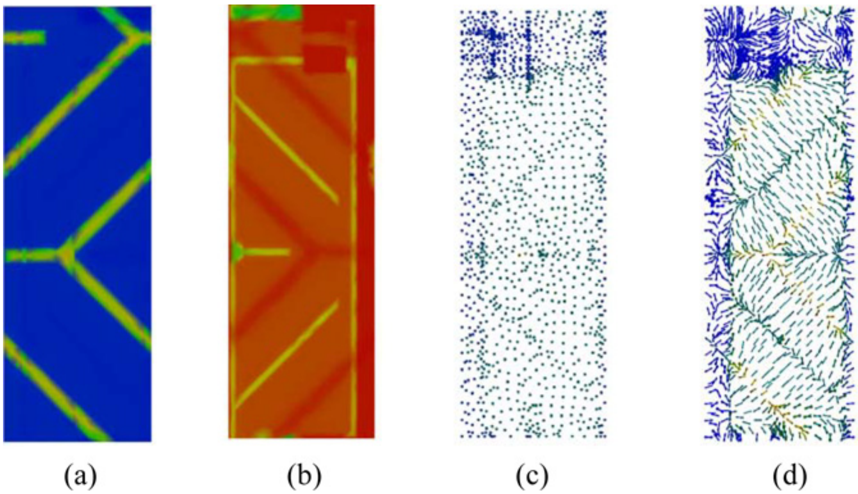
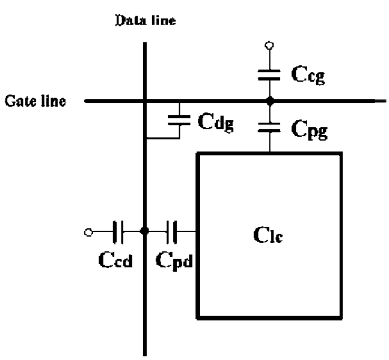


FIGURE 2 Plots illustrating the simulated electric potential and director distributions for the exemplary VA cell, the electric potential distribution (a) at top and (b) at bottom of the liquid crystal layer, and the director distribution (c) at off state, (d) at on state. (See COLOR PLATE XXV)

Figure 3 shows the equivalent circuit of the exemplary VA cell. Since there are 6 unknown capacitances, 6 different conductor voltage configurations are needed to calculate the unknown capacitances.

Figure 4 shows the calculated pixel capacitance as a function of pixel voltage. Referring to Figure 4, it should be noted that the critical voltage



(a)

Capacitance	Electrode
C_{lc}	pixel - common
C_{pd}	pixel - data line
C_{pg}	pixel - gate line
C_{cd}	common - data line
C_{cg}	common - gate line
C_{dg}	Data line - gate line

(b)

FIGURE 3 (a) Equivalent circuit of the exemplary cell used in the simulation and (b) index table for the parasitic capacitance.

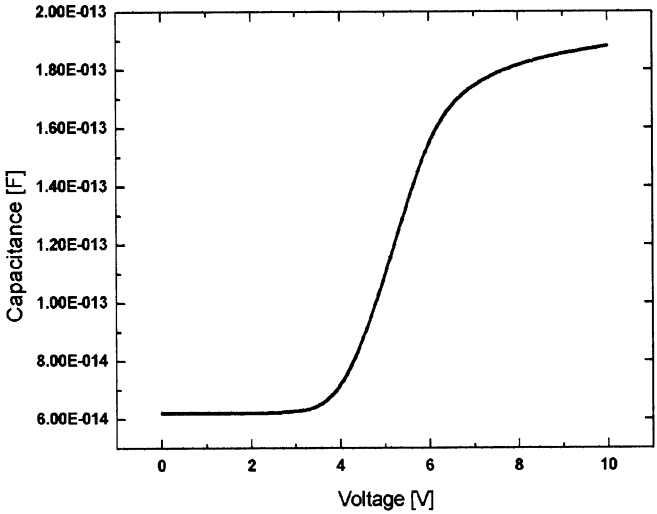


FIGURE 4 A plot showing the dependence of pixel capacitance on the voltage condition.

for the exemplary VA cell is 4 V. Furthermore, when 9 V is applied at the pixel electrode, the curve of the pixel capacitance exhibits saturation, while the pixel capacitance still increases. The reason for the fact that C_{lc} is not perfectly saturated is that the director still rotates at a disclination region along the pattern of the pixel and the common electrode.

Figure 5 shows a plot demonstrating the simulated transient response of the parasitic capacitances within the exemplary cell for the several voltage

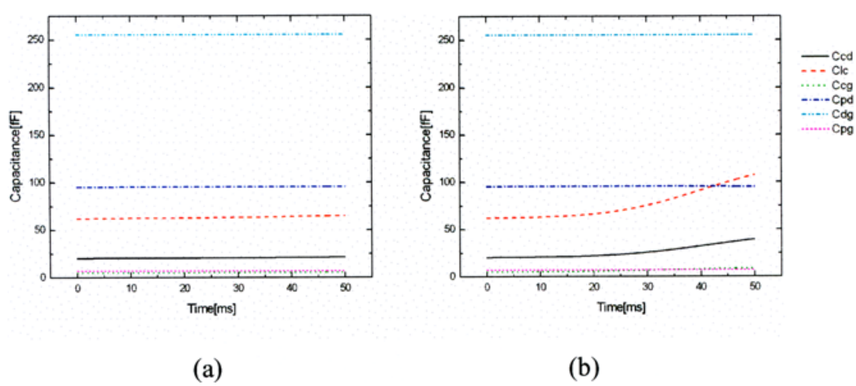


FIGURE 5 Plots demonstrating the simulated parasitic capacitances in exemplary cell as a function of time for each applied voltage, (a) 3 V, (b) 4 V, (c) 5 V, (d) 6 V, (e) 7 V, (f) 8 V, (g) 9 V, and (h) 10 V. (See COLOR PLATE XXVI)

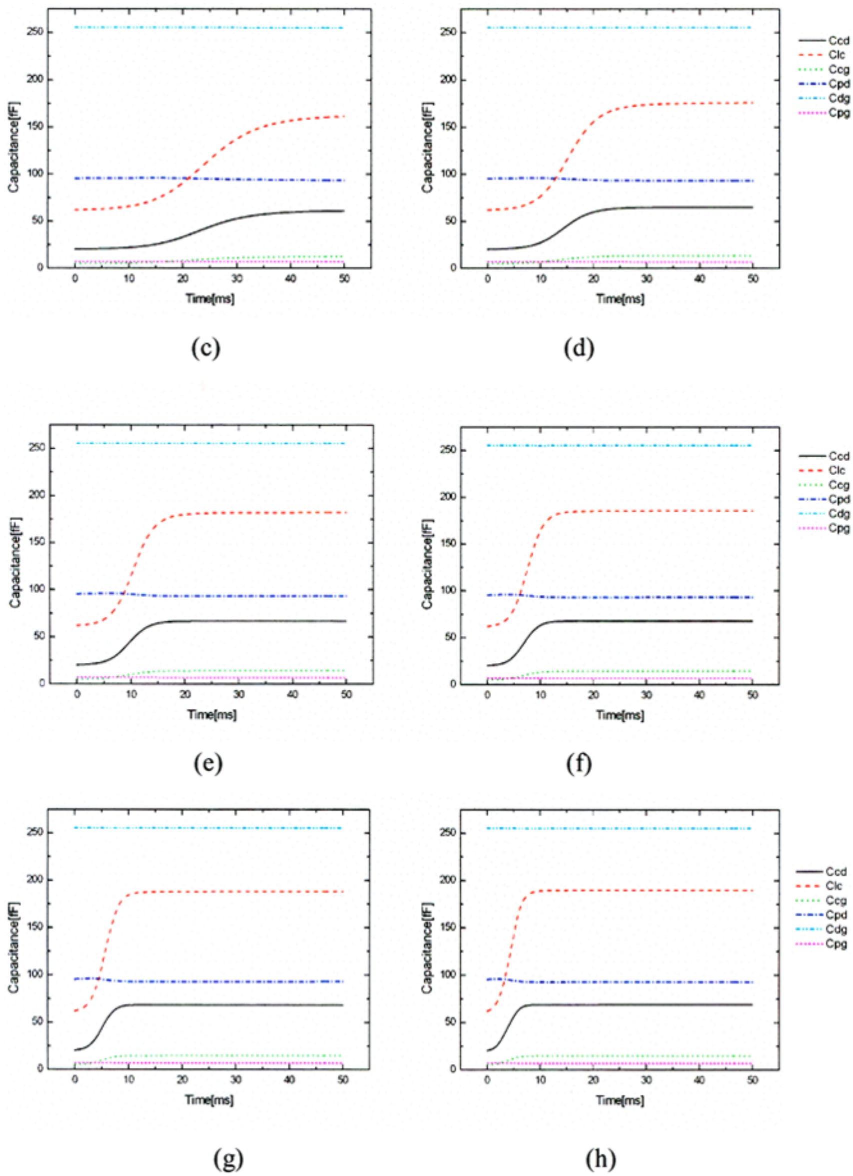


FIGURE 5 (Continued).

conditions. In Figure 5(a), when director does not respond to the electric field, the value of C_{dg} becomes a maximum, although the overlapped region between the data line and the gate line is small since the gap is very narrow.

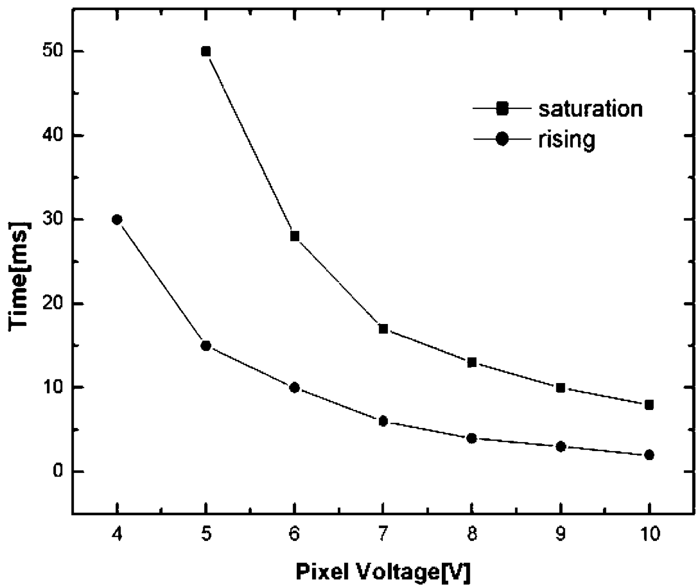


FIGURE 6 A plot showing the dependence of rising time as well as time for saturation as a function of applied pixel voltage.

Furthermore, since the isotropic material occupies the region between the data line and the gate line, the C_{dg} should be constant.

The C_{cd} demonstrates quite a similar characteristics to C_{lc}. This implies that C_{cd} is sensitive to the director distribution, while other parasitic capacitances except C_{lc} and C_{cd} are less sensitive to the dynamic behavior of directors. In the exemplary VA cell, the electric field is aligned in a vertical direction. Namely, since the magnitude of both Ex and Ey components of the electric field is much smaller than that of Ez, the parasitic capacitances related to the electrodes in the same plane, such as pixel electrode, data line, and gate line tend to be insensitive for director behavior. The capacitances C_{pd} and C_{pg}, however, operated by the fringing field such as for IPS mode or for FFS mode, will be altered like C_{lc} in Figure 5.

In addition, it should be noted that C_{lc} of the exemplary cell has a maximum value about 170 [fF] and the time for saturation as well as the rising time for each voltage condition can be extracted by referring to Figure 6.

CONCLUSION

The pixel capacitance and parasitic capacitances have been efficiently extracted from the energy method for understanding the dynamic behavior of LC cell. The potential and the director distribution of the exemplary cell can be obtained with three-dimensional FEM simulation. Transient characteristics for parasitic capacitances within the exemplary cell were derived and characteristics for saturation time as well as rising time were calculated. Using the energy method, the capacitances of LC cell having a complicated electrode structure such as in-plane switching (IPS) and multi-domain vertical alignment (MVA) can be calculated for optimal cell design of AMLCDs.

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