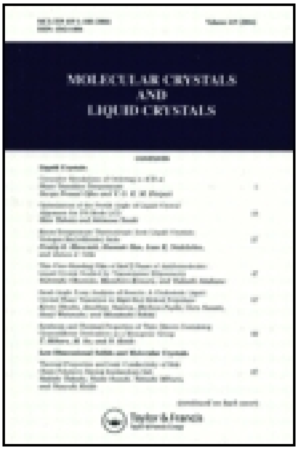

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Black Matrix in Liquid Crystal Display: High-Permittivity Dielectric or a Floating Metal for the BM?

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In this paper, we report our theoretical study on the influence of black matrix (BM) on the optical performance of liquid crystal cell as a light valve. For our numerical simulation, a couple of widely employed electrode patterns–PVA (Patterned Vertical Alignment) and the Super IPS (In-plane Switching) cells, were chosen for our theoretical investigation on the dependence of BM on the transmittance and capacitances. In addition, a careful comparative study was also undertaken between the case when high-permittivity dielectric is employed and the other case when a floating metal is used for BM. Our simulations revealed that the Super IPS mode is more sensitive to the insertion of BM than the PVA mode cell. It also turned out that the influence of parasitic capacitance is more appreciable in case when high-permittivity dielectric is chosen for BM than the case when a floating metal is employed for BM.

Keywords: black matrix; floating electrode; PVA; simulation; Super IPS

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I. INTRODUCTION

Preferably, the black matrix (will be cited as 'BM' for abbreviation) is inserted in the stack of LCD cell for the manufacture of LCD panels in an effort to block a leaky light in the peripheral data line as well as gate line around the cell region. However, the BM inevitably affects the electro-optical characteristics of liquid crystal cell. Furthermore, it seems like the species of the material used for the BM can be an important factor in the final electro-optical characteristics of the designed cell structure. In the LCD manufacturing industries, a couple of approaches were tried for the material choice for the BM. One is the high-permittivity dielectric and the other is a metal floated (i.e. metal layer without voltage applied). Figure 1 is a schematic diagram illustrating the electric potential distribution when either the dielectric BM or the metal BM is inserted in the stack of constituting layers. Referring to Figure 1, the electric characteristics for the above-mentioned two cases seem to be apparently similar to each other.

However, more careful investigation reveals that the degree of electric distortion for those two cases is quite different and that there is an appreciable variance in parasitic capacitances between those two cases. In other words, the electrical and optical performance of a certain type of LC cell is changed upon what kind of material is employed for the BM. Additional observation is that the above-mentioned material dependence effect seems to be altered by the structural change of LC cell. For instance, TN (Twisted Nematic) mode, which has a common electrode without pattern on CF (Color Filter)

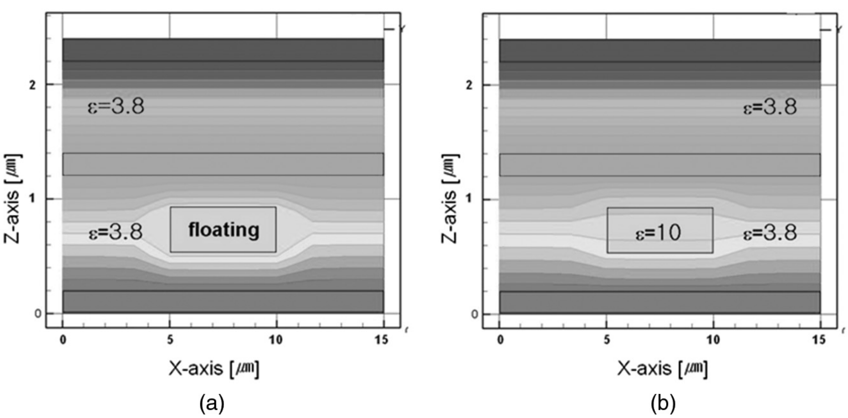

FIGURE 1 Electric potential distribution of a simple structure, (a) with the floating electrode (b) with the dielectric with high permittivity.

substrate, seems to be less influenced by the material species of the BM. This is because the common electrode functions as a kind of isolator between BM and the liquid crystal layer.

In this paper, we report our 3D-FEM study on the electro-optical characteristics of an LCD cell with respect to material species of the BM, for instance, dielectric and floating metal. As exemplary cell structure in our theoretical work, the PVA (Patterned Vertical Alignment) and the Super IPS (In-plane Switching) mode cells were chosen.

II. NUMERICAL MODEL

For the dynamic analysis of director distribution of LCD cell, 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 [1–4]. The numerical procedure under consideration comprises a couple of iterative treatments for each time step. Firstly, a solution is obtained with respect to voltage from the Laplace equation, given a known director distribution. Then the Ericksen–Leslie equation is solved for estimating the director deformation when the distribution of voltage is known. As a numerical approach, we employed a finite element method (FEM) [5]. In order to extract parasitic capacitances within LC cell, the energy moment method [6] is employed, which is useful and rigorous methods without structural limitation and the number of electrode. In addition, the extended Jones method [7–8] was used for the optical analysis of LC cell. It is also assumed that no charge is present in the metal.

III. SIMULATON RESULTS AND DISCUSSIONS

Figure 2 illustrates a schematic electrode structure as well as the BM for both PVA mode cell and Super IPS mode cell used in our study. For our comparison of those two cases, the simulation region as well as the number of electrode should be set the same. If we assume that the BM is a metal, the thickness of the BM layer is assumed to be 0.1 μm, which is electrically floated. In case when the BM is a dielectric material, the thickness is assumed to be 1.0 μm and the relative dielectric constant is 10. The applied voltages at the data line, gate line, and common electrode are assumed to be tied at zero volt.

Figure 3 shows the transmission characteristic for PVA mode cell when 6 V is applied at pixel electrode and Figure 4 shows the

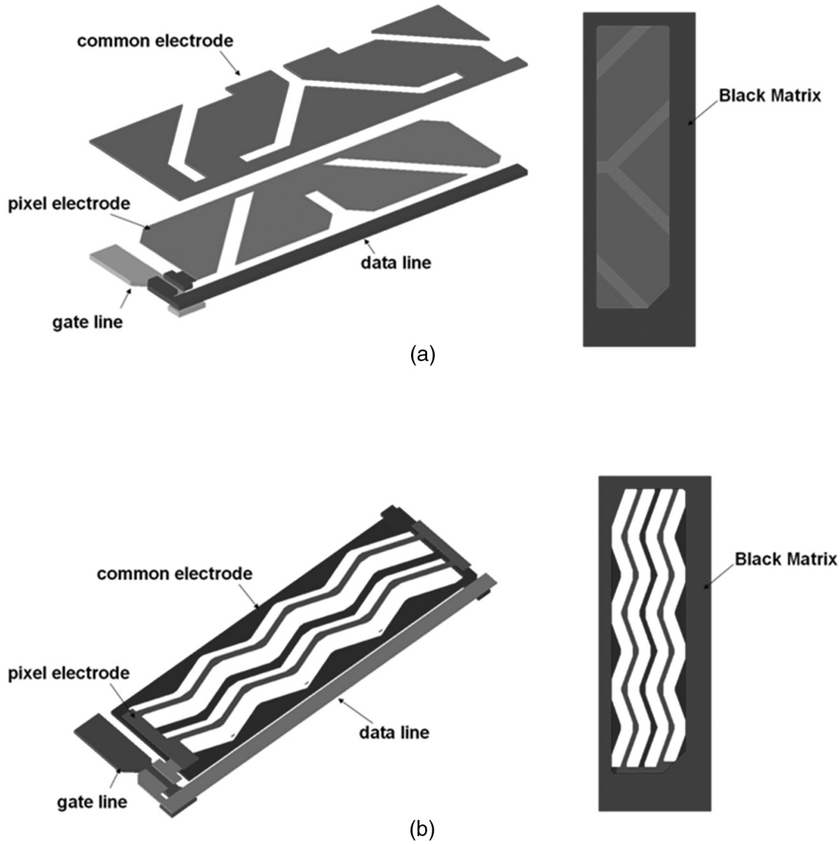

FIGURE 2 Structure of electrode and black matrix of exemplary cells, (a) PVA mode cell, (b) Super IPS mode cell.

simulated transmittance in PVA mode cell as a function of pixel voltage. Apparently, there seems no appreciable difference between the metal BM and the dielectric BM, which is confirmed by the fact that the BM does not affect the voltage distribution and movement of directors in PVA mode cell. Here, the reason is that the common electrode on the CF (Color Filter) substrate functions as a kind of isolator between liquid crystal layer and the BM.

Figure 5 is a schematic diagram illustrating the C_{LC}, capacitance between pixel and common electrode. Apart from the previous optical characteristics, C_{LC} of the PVA cell with dielectric BM is greater by about 4.8% than that of metal BM. The reason for this is that the area of PVA cell with dielectric BM has increased and that therefore the

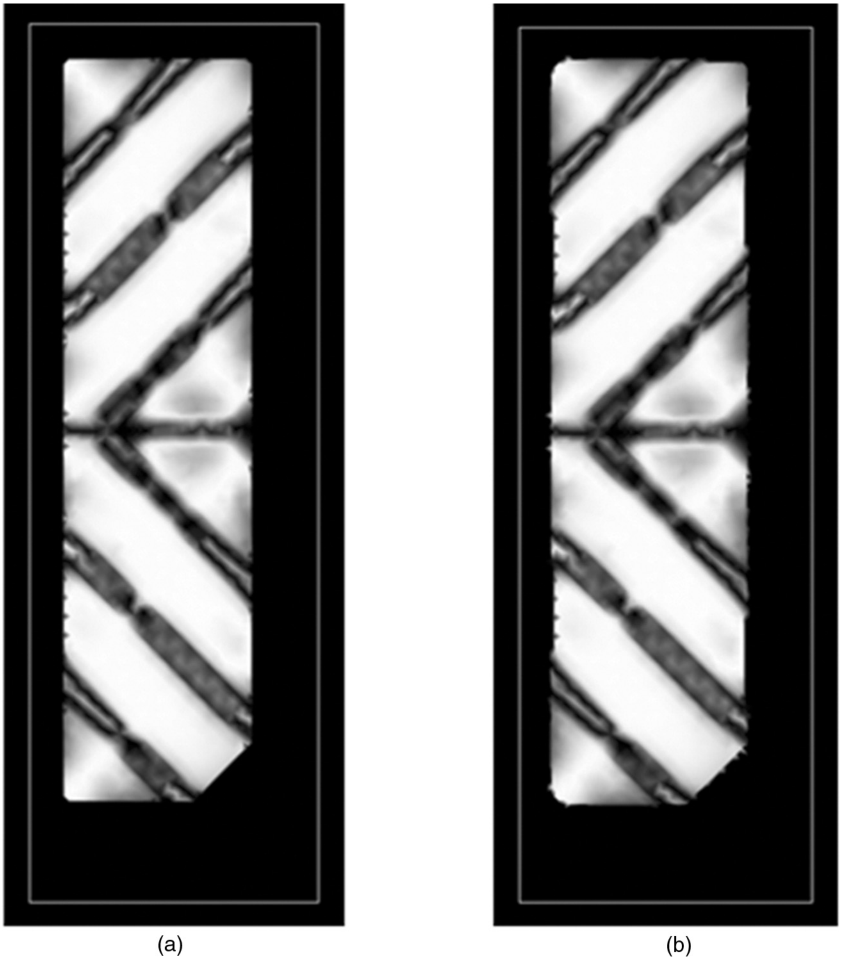

FIGURE 3 Transmission for PVA mode cell when 6 V is applied at pixel electrode.

amount of stored energy is also enhanced, independent of the director distribution.

Figure 6 illustrates the calculated transmission for Super IPS cell when 6 V is applied at the pixel electrode. As can be seen in the figure, a noticeable difference cannot be observed in comparison with the PVA mode. However, it should be noted from the Figure 7 that the transmittance of the Super IPS cell with dielectric BM is more appreciable than that with metal BM. That is, the material species for the BM affects more profoundly in the case of the Super IPS cell.

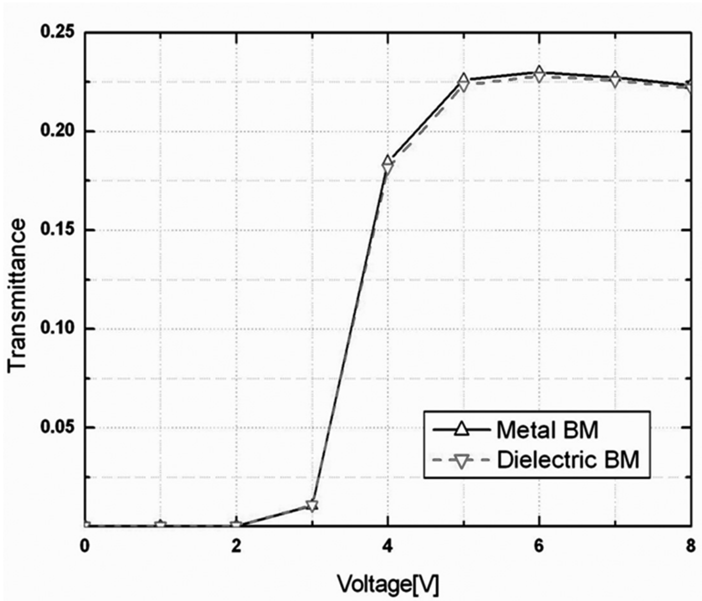

FIGURE 4 Transmittance as a function of voltage, for metal BM and dielectric BM in PVA cell, respectively, (a) Metal BM and (b) Dielectric BM.

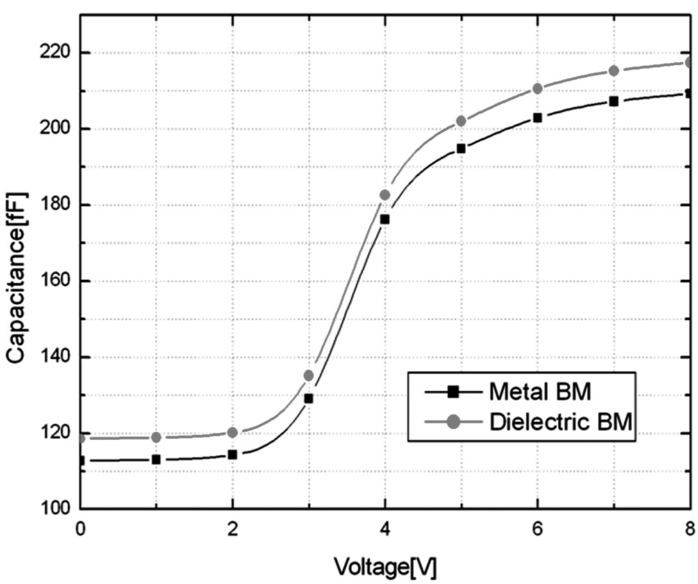

FIGURE 5 A plot demonstrating the simulated C_{LC} in PVA mode cell as a function of pixel voltage.

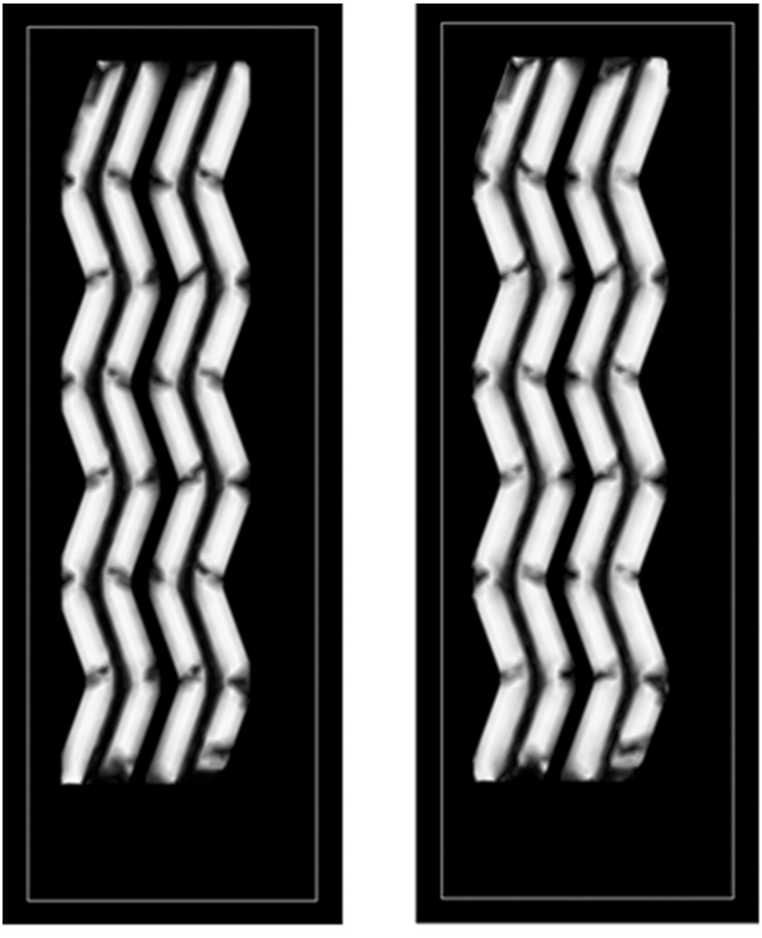

FIGURE 6 Transmission for Super IPS cell when 6 V is applied at pixel electrode, (a) Metal BM and (b) Dielectric BM.

Figure 8 shows C_{LC}, capacitance between pixel and common electrode in Super IPS cell. Like PVA cell, C_{LC} of the Super IPS cell with dielectric BM increases by an amount of about 5.7% than the case for metal BM.

Tables 1 and 2 illustrates parasitic capacitances for metal BM and dielectric BM within PVA cell and Super IPS cell, respectably, as well as the rate between those two cases, when 8 V is applied at pixel electrode. As depicted in the tables, the difference rate is under 5% for all

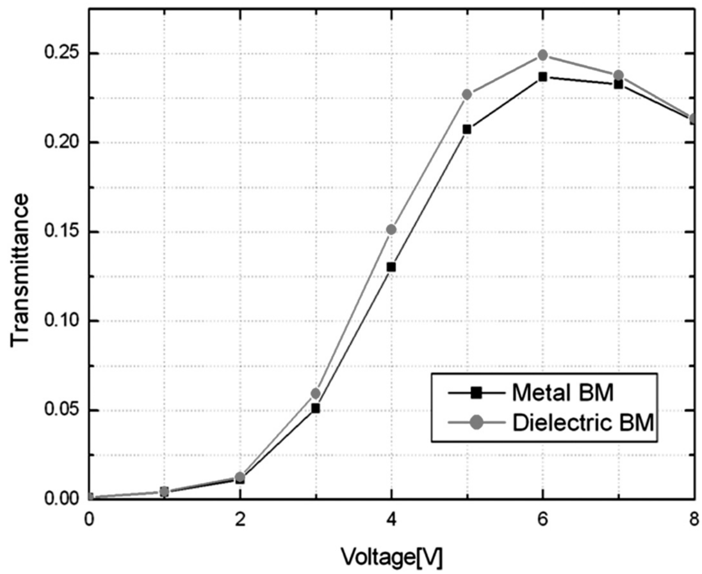

FIGURE 7 A plot demonstrating the simulated transmittances in Super IPS mode cell as a function of pixel voltage.

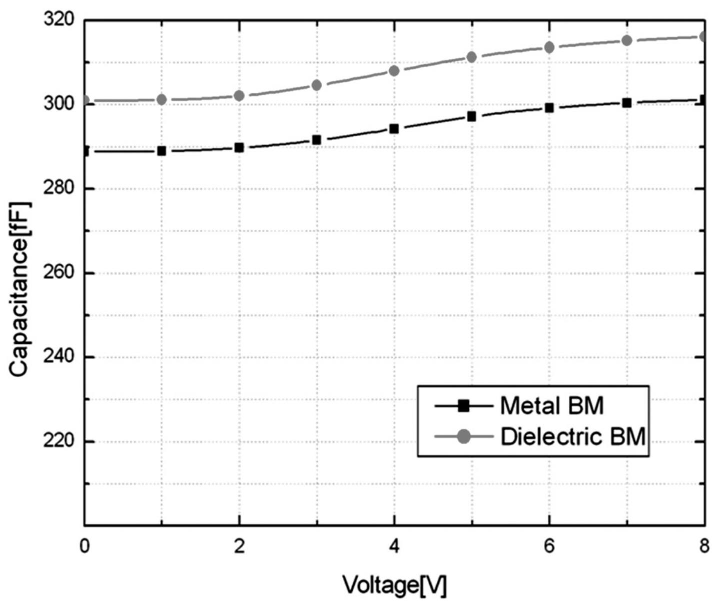

FIGURE 8 A plot demonstrating the simulated C_{LC} in Super IPS mode cell as a function of pixel voltage.

TABLE 1 Parasitic Capacitances for Metal BM and Dielectric BM and Variation Rate when 8 V Applied at Pixel Electrode in PVA Mode Cell

Parasitic capacitances	Metal BM	Dielectric BM	Rate%
pixel – common	209.246 [fF]	217.462 [fF]	4.8
pixel – data line	72.8564 [fF]	72.9580 [fF]	0.2
pixel – gate line	11.6862 [fF]	11.6921 [fF]	0.1
Common – data line	31.4445 [fF]	32.4400 [fF]	3.1
Common – gate line	10.3366 [fF]	10.4094 [fF]	0.7

TABLE 2 Parasitic Capacitances for Metal BM and Dielectric BM and Variation Rate when 8 V Applied at Pixel Electrode in Super IPS Mode Cell

Parasitic capacitances	Metal BM	Dielectric BM	Rate%
pixel – common	301.192 [fF]	316.094 [fF]	5.7
pixel – data line	42.3610 [fF]	48.0692 [fF]	12
pixel – gate line	1.84322 [fF]	1.983522 [fF]	8
Common – data line	226.009 [fF]	240.944 [fF]	6.2
Common – gate line	32.5179 [fF]	35.3109 [fF]	8

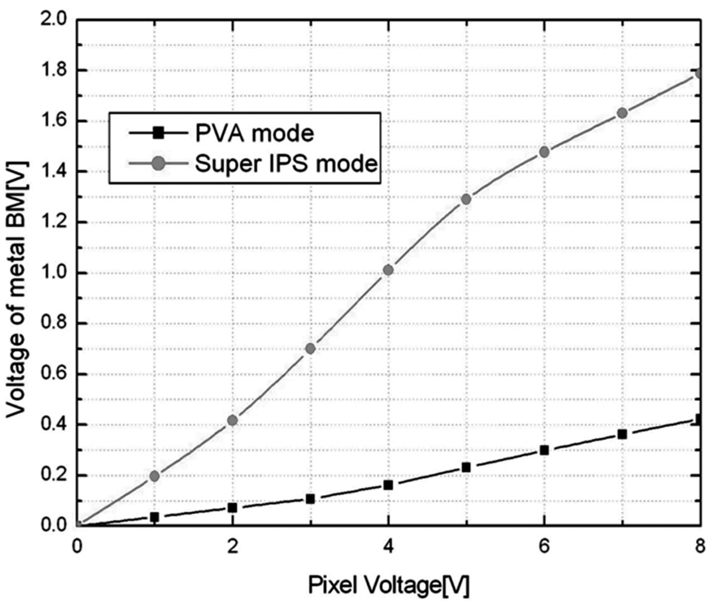

FIGURE 9 Induced voltage at floating metal BM as a function of pixel voltage.

capacitances in PVA cell due to the common electrode. In Super IPS cell, however, the difference rate is more than 5%. Therefore, our simulation implies that Super IPS mode is more affected than PVA mode by BM. Additionally, it seems that capacitances are more appreciable in the case of dielectric BM than in the case of metal BM. In the case of metal BM, there exist capacitive components between the BM, data line, gate line, pixel, and common electrode exist additionally, though.

Figure 9 shows voltage induced at the floating metal, which is represented as a function of pixel voltage. Both modes increase linearly for pixel voltage and the slope is calculated to be 0.053 for PVA cell and 0.224 for Super IPS cell, respectively. That is, 5.3% for PVA cell and 22.4% for Super IPS cell off voltage applied at pixel electrode are induced at floating metal BM, respectively.

IV. CONCLUSION

In this paper, we report our numerical study on the dependence of the electro-optical characteristics on the material species of the BM as well as the species of mode operation. A through investigation was made for the analysis of transmittance and parasitic capacitances in terms of cell structures as well as species of BM materials. The 3D-FEM simulation revealed that the Super IPS mode is more sensitive to BM layer species than the PVA mode. Furthermore, it turned out that parasitic capacitances are more appreciable in the case of dielectric BM than in the case of metal BM. Moreover, the voltage induced at floating metal for BM is obtained quantitatively from 3D-FEM analysis and we found that approximately 5.3% and 22.4% of the voltage applied at the pixel is induced at the floating metal for PVA cell and Super IPS cell, respectively.

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