Wide-Viewing Liquid Crystal Displays with Periodic Surface Gratings

Sin-Doo Lee, Jae-Hong Park, Tae-Young Yoon, and Chang-Jae Yu
School of Electrical Engineering , Seoul National University, Kwanak P.O. Box 34, Seoul 151-742, Korea

Abstract

A new concept of forming self-aligned multidomains is used for fabricating wide-viewing liquid crystal displays (LCDs) with periodic surface gratings.An array of the periodic surface gratings is produced on substrates using a photosensitive polymer by the illumination of the UV light through a patterned photomask. A multidomain structure is naturally formed on the grating surface by the initial director distortions together with continuous variations of an external electric field. The LCD cells with periodic surface gratings are found to show excellent extinction in the off-state and wide-viewing property in the on-state.

1. Introduction

One of the most widely used liquid crystal displays (LCDs), the twisted nematic (TN) LCD, has suffered from poor viewing properties that originate intrinsically from the asymmetrical nature of the LC alignment irrespective of the driving scheme whether a passive multiplexing or an active matrix driving is employed. Various methods have been developed to solve the narrow viewing problem of LCDs. For example, multidomains are often used for compensating the optical asymmetry in each pixel [1]. For obtaining such multidomains in each pixel, at least two easy directions should be generated for the surface alignment of LC. However, the surface treatment usually involves complex processes such as multiple rubbing and photo-exposure.

Recently, in a vertically aligned LCD configuration, the distortions of the electric potential in the LC layer have been utilized for producing multidomains. In this case, an electrode fringe field (EFF) is used for creating symmetric elastic distortions of the LC [2,3], so that the wide viewing characteristics of the LCD are achieved. Since no complex surface treatment for the LC alignment is involved, this method is known to be simple and cost-effective. However, the fringe field is produced by means of only patterned or non-planar electrodes [2]. In another case, a two-dimensional array of surface relief structures is used for spontaneously producing four-domains in each pixel of a vertically aligned LCD under an applied voltage [3]. Therefore, it is important to explore the possibility of using an array of dielectric surface gratings (DSG) on a planar electrode to produce topographical alignment of LC as well as the grating fringe field (GFF) effect.

We propose a new concept of spontaneously forming periodic multidomains in each pixel of the LCD with periodic surface gratings that have three different categories: a two-dimensional array of surface relief structures, one-dimensional linear surface relief structures of the order of the pixel size, and one-dimensional dielectric surface gratings of a few microns. In the dielectric surface grating case, the GFF effect is combined with topographical alignment of the LC [4,5]. In such a self-forming micro-domain structure, the range of viewing in the LCD is expected to be greatly extended since mutual compensation of the optical retardation is naturally achieved in each pixel. Basically, the strengths of topographical and GFF effects are governed by both the geometrical factors and the dielectric property of the DSG. In the following sections, the main features of wide-viewing technologies in the three categories above will be described. Some concluding remarks will be made in the remaining section.

2. Two-dimensional Array of Surface Relief Structures

We first describe a wide-viewing LCD mode realized in an axially symmetric vertical alignment (ASVA) configuration. In order to obtain this configuration, a two-dimensional array of axially symmetric surface relief structures was formed using the UV curable photopolymer on a glass substrate. The UV curable optical adhesive (NOA60, Norland Products Inc.) was spin-coated on an indium-tin-oxide (ITO) glass substrate. The photopolymer layer was irradiated by the UV light through a chromium photomask. The mask has circular apertures of 100 μm in diameter which are arranged in a period of 200 μm. The coated photopolymer layer was subsequently illuminated without the photomask to cure the whole area. The fabrication process of the array of the axially symmetric surface relief structures is shown in Fig. 1.

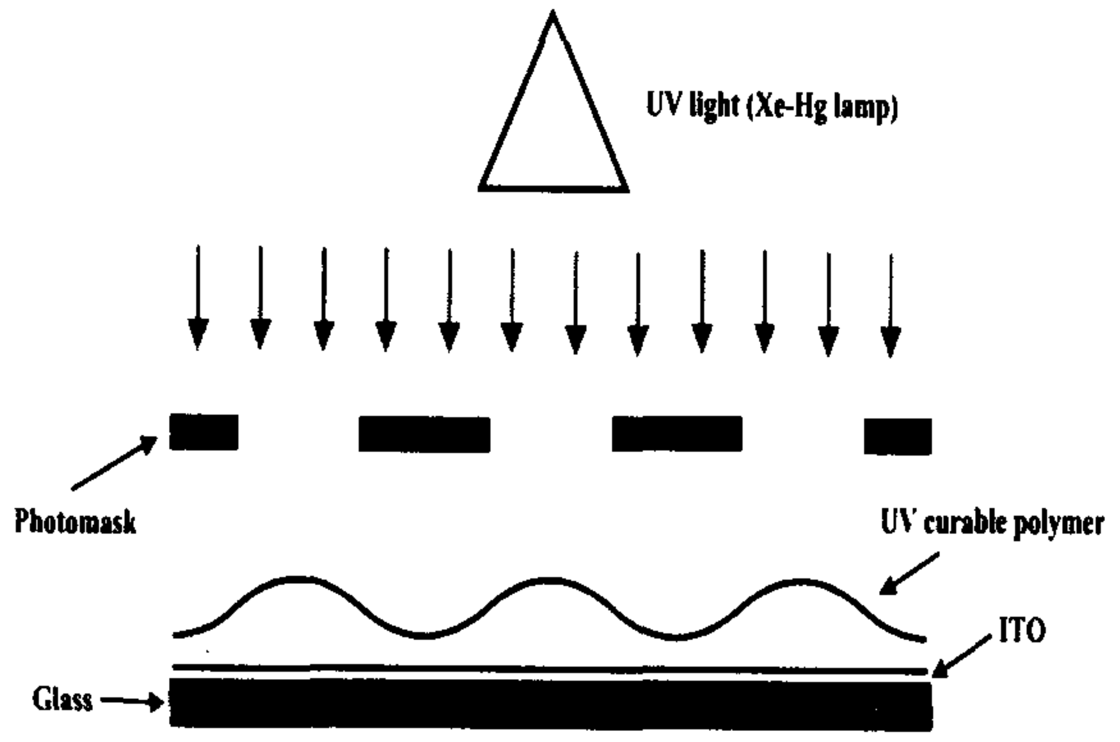


Figure 1: The fabrication process of surface relief structures with periodicity of 200 μm.

As for an example of fabricating the ASVA LC cell, the polyimide of JALS204 (Japan Synthetic Rubber) was spin-coated onto the surface relief layer surface for homeotropic alignment. The cell was assembled with the above prepared substrate and the other with only the layer of JALS204. We used 5 μm glass spacers to maintain the cell gap. The ASVA cell was filled with a nematic liquid crystal, EN40 (Chisso), which has negative dielectric anisotropy.

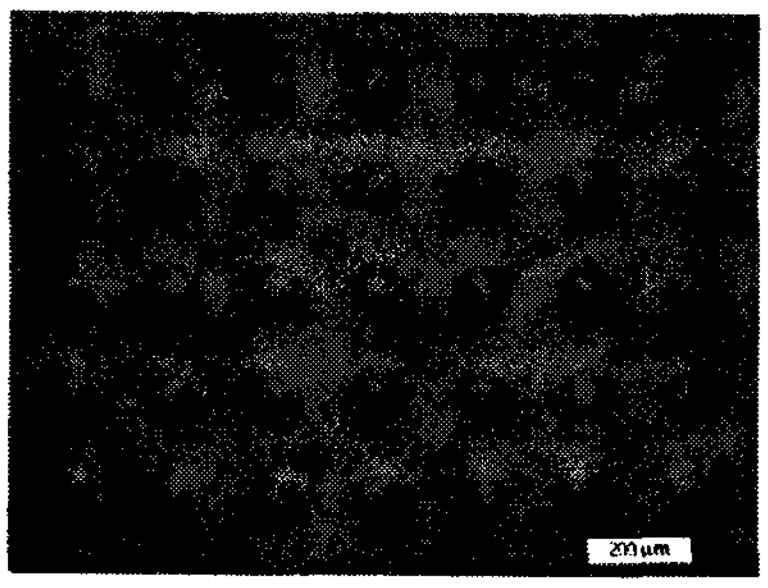
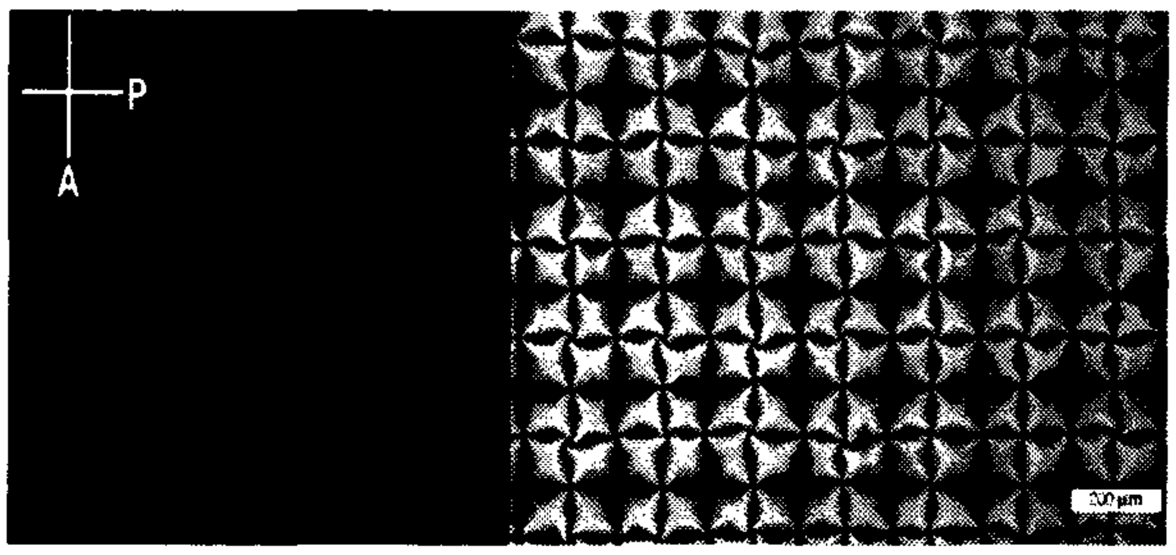


Figure 2: A two-dimensional array of surface relief structures formed using the UV curable polymer.

When the photopolymer is illuminated through the photomask, the photopolymerized process begins at positions corresponding to the apertures. Then, the difference in density between the illuminated and unilluminated areas causes the contraction (or dilation) effect to make the polymer move into the illuminated region to join the polymerization process. Fig. 2 shows A two-dimensional array of surface relief structures formed using the UV curable polymer. The regions inside the circular patterns in Fig. 2 correspond to the areas that were illuminated by the UV light. The average height of the surface relief structures depends on the illuminated UV intensity and irradiation time to some extent.

The microscopic textures of the ASVA cell under crossed polarizers were shown in Fig. 3. Under no applied voltage, the LC molecules are aligned perpendicular to the substrate so that a dark state similar to a normal VA state is obtained as shown in Fig. 3(a). Upon the application of the voltage above the Fredericks threshold [6], the axially symmetric structure can be observed on the surface relief surface with two-dimensional periodic hemispherical structures.



(a) (b)

Figure 3: Microscopic textures of the ASVA cell at two different applied voltages; (a) 0 V and (b) 13.6 V.

The dark region under an applied voltage in Fig. 3(b) represents the hill of the grating surface of the photopolymer layer. Around the hill of the grating surface, the actual voltage drop is larger than in the valley region. The important issue on the fabrication process is that the average height of the hemispherical relief structures should be optimized. When the height is large, the LC director tends to follow the relief structure very strongly and then the whirl of the director on the surface can occur. In our case, the tangential angle of the grating surface is about 0.3° enough to prevent this phenomenon.

We now discuss the viewing characteristics of the ASVA cell from the measure iso-contrast map. As shown in Fig. 4, the viewing angles are far extended and symmetrical when compared to a typical TN case. Moreover, the iso-contrast map has the 4-fold symmetry as expected from the microscopic texture in the on-state shown in Fig. 3(b).

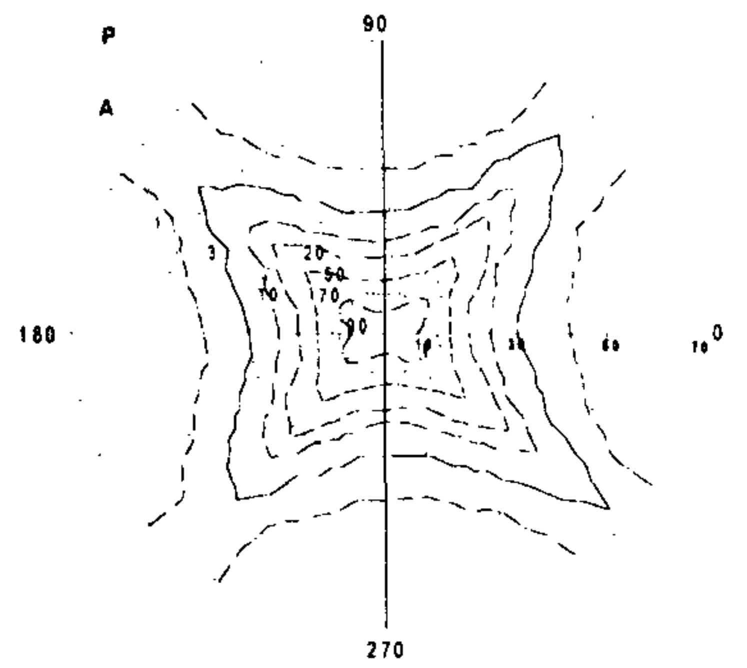


Figure 4: The iso-contrast map of the ASVA LC cell.

Note that the domain sizes in each pixel can be easily varied and no defects are involved during operation of the ASVA LCD cell.

3. One-dimensional Periodic Surface Relief Structures

Instead of using two-dimensional array of hemispherical surface relief structures, we now use two linear arrays of photo-polymer gratings, arranged orthogonal to each other, to obtain another type of the four. In this configuration, in the-off state, the LC molecules align perpendicular to cell surface, and under an applied voltage, they are reoriented by the distorted electric field at the grating surfaces to make four different domains. Similar to the ASVA case, the twisted VA (TVA) cell with surface gratings shows nearly complete extinction in the off-state and wide-viewing property in the on-state. The schematic diagram of the TVA was shown in Fig. 5. In the off-state, the LC molecules align perpendicular to cell surface, and under an applied voltage, they are reoriented by the distorted electric field at the grating surfaces to make four different domains.

For fabricating the one-dimensional periodic surface relief gratings, we used a chromium photomask with 200 µm striped apertures which were arranged in a period of 400 µm. The TVA LC cell was assembled with two grating surfaces whose grating vectors were orthogonal to each other. The cell thickness was maintained using glass spacers of 5 µm thick and filled with the LC of EN37 (Chisso Petrochemical Co.) which has negative dielectric anisotropy

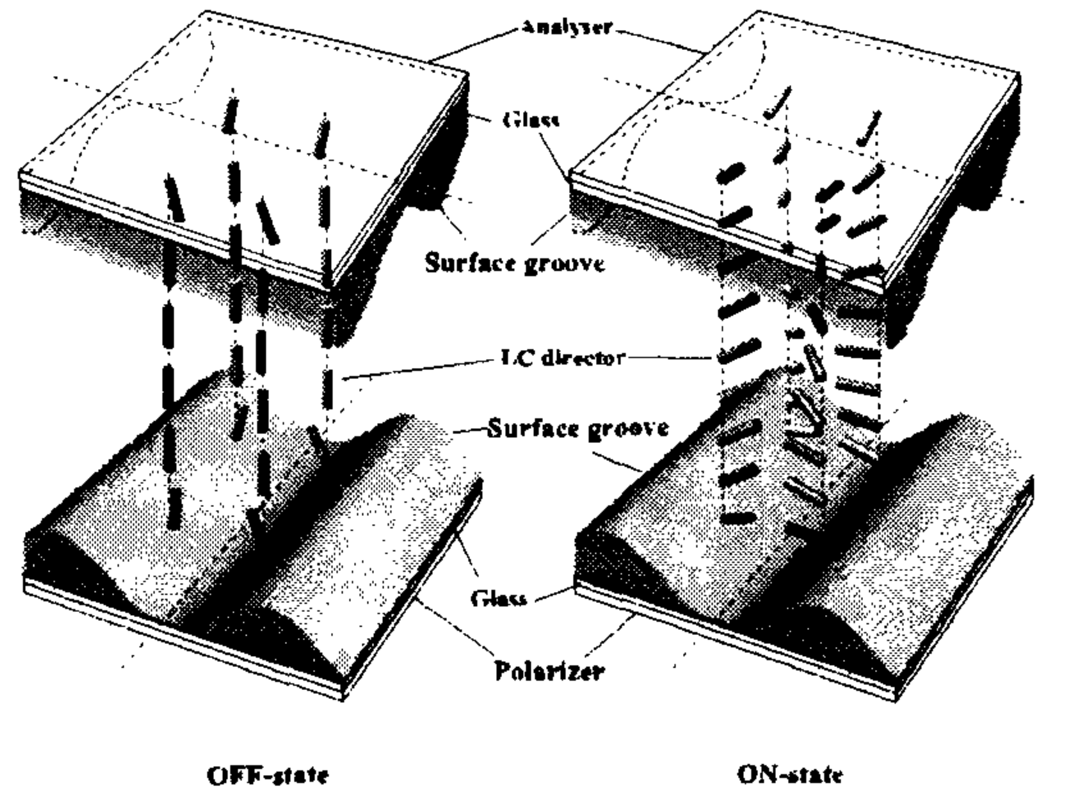


Figure 5: The TVA with surface gratings

As shown in Fig. 5, under no applied voltage, the LC molecules are vertically aligned so that a dark state similar to a normal VA mode is obtained in the TVA cell. When the voltage is applied, the distorted electric field will produce the director distribution with four-fold symmetry in each unit domain since two surface grating vectors of the cell are orthogonal to each other.

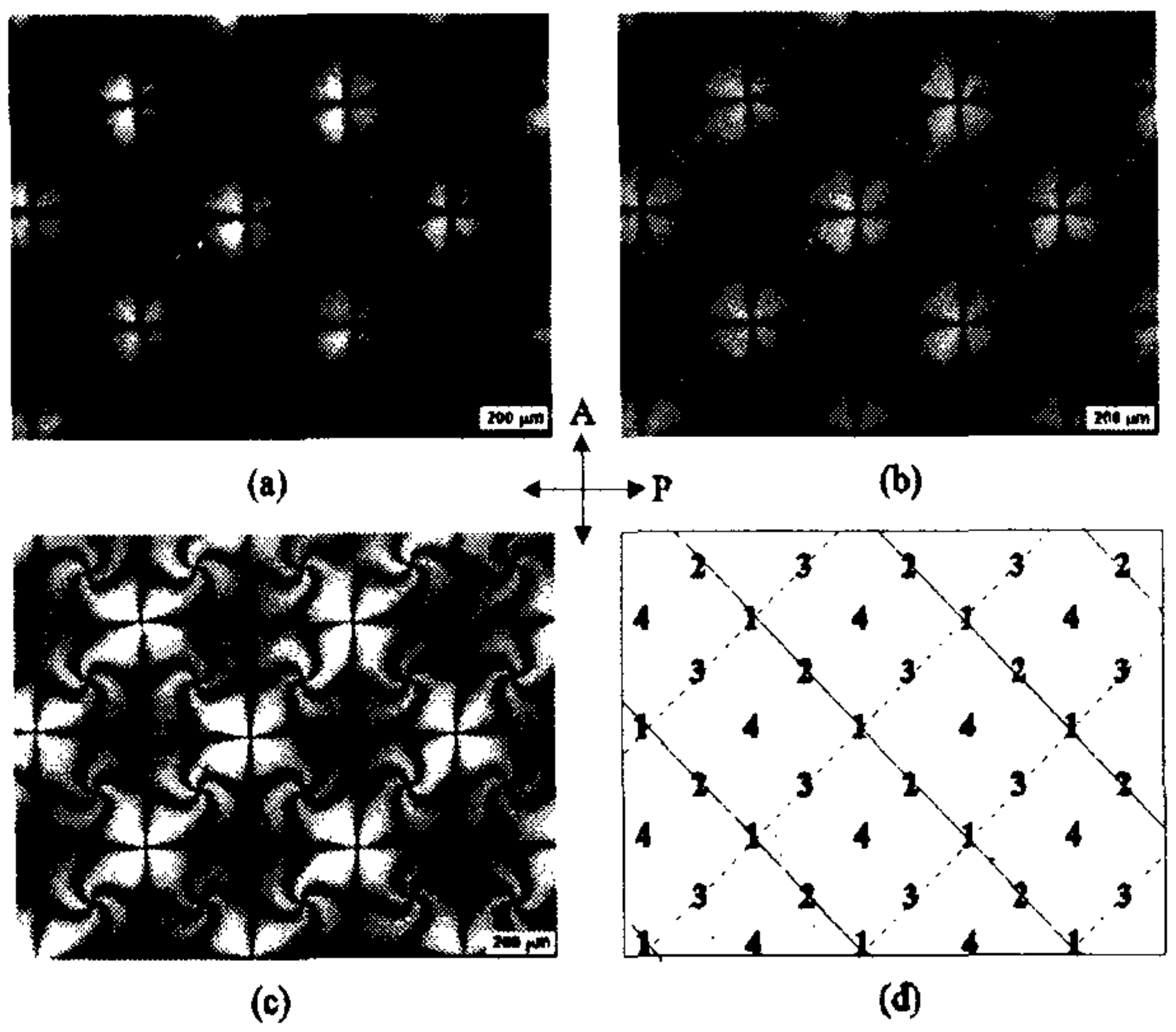


Figure 6: Microscopic textures of the VA cell with linear surface gratings at different applied voltages; (a) 3.59 V, (b) 3.79 V, and (c) 4.09. The effective voltages in the four regions ($V_1 > V_2 = V_3 > V_4$) are in (d).

We observed microscopic textures of the TVA cell under crossed polarizers as a function of the applied voltage of a bipolar square waveform at the frequency of 1 kHz. Fig. 6 shows three different textures at three different voltages and the distribution of the effective voltages. Note that the 4-fold symmetry, which is somewhat different from the ASVA cell, is clearly seen in Fig. 6. This comes from mainly the distorted electric field in the presence of the two periodic dielectric surface gratings whose grating vectors are perpendicular to each other.

For measuring the viewing property of the TVA cell with surface gratings, the LCD characterizing system (DMS, Autronics Co.) was used. Fig. 7 shows the viewing angle dependence of luminance. The luminance shows a high symmetry property, meaning that almost no directional dependence of the viewing property exists. This is due to the natural formation of the multidomain structure in the TVA cell.

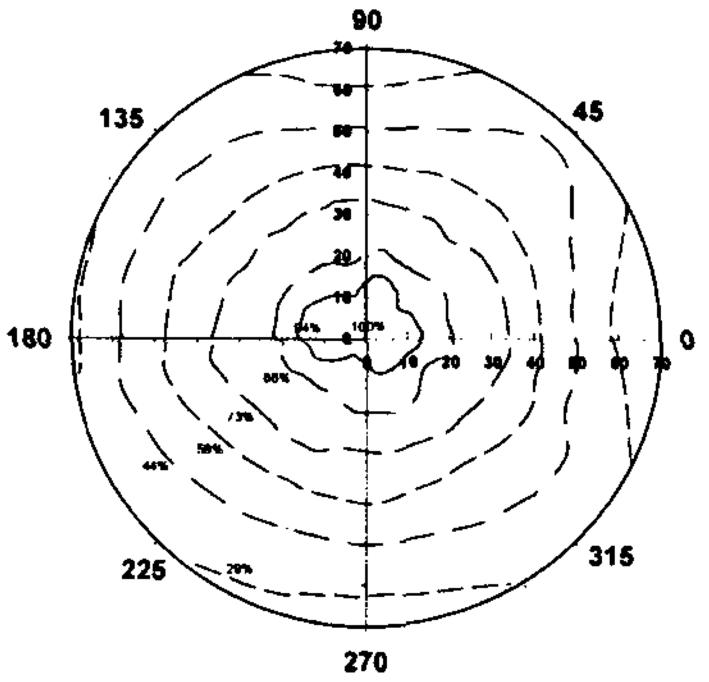


Figure 7: The luminance map of the TVA cell with two periodic surface gratings at 6.23 V (the luminance at normal direction is assumed as 100%).

4. Dielectric Surface Micrograting Structure

We now discuss the self-formation of micro-domains by the topographical and fringe field effects in a twisted nematic (TN) LCD with dielectric surface gratings (DSG). A regular array of the DSG produces periodically aligned micro-domains in each pixel because of the topographical alignment of LC [4,5] and the spatial variations of the effective voltage across the LC layer. The mutual optical compensation within each pixel is naturally achieved and thus the range of the viewing in the LCD is significantly extended without complex surface treatment.

Basically, the strengths of topographical and GFF effects are governed by both the geometrical factors and the dielectric property of DSG. The periodicity of DSG should be on the order of 1 μm to produce uniform alignment of LC by the topographical effect. Since the GFF effect depends on the dielectric properties of DSG relative to LC, the GFF effect may be described in terms of a scaled quantity, χ, defined as the effective voltage per unit thickness across DSG, scaled by that across the LC layer.

The parameter χ can be used for describing the main features of the GFF effect created by a periodic array of DSG in the LC cell. In fact, a subtle change in the GFF effect can be precisely controlled by the change in ε_{LC} to ε_{DSG}. For $\chi \sim 1$, no GFF effect will exist and only the topographical alignment of LC will appear as a function of the periodicity of DSG. However, for $\chi >> 1$, a strong GFF effect is produced while for $\chi << 1$, the effect resembling the non-planar electrode case or a pure EFF effect is expected. Note that for $\chi > 1$, the spatial variations of V_{LC} are enhanced by the GFF effect. A typical example of spatial variations of V_{LC} and the resultant fringe field lines in the LC cell with DSG of $\chi = 3.0$ are shown in Fig. 8. The dimensionless height of the "A" region and that of the "B" region, scaled by the cell thickness, are 1/8 and 1/20, respectively.

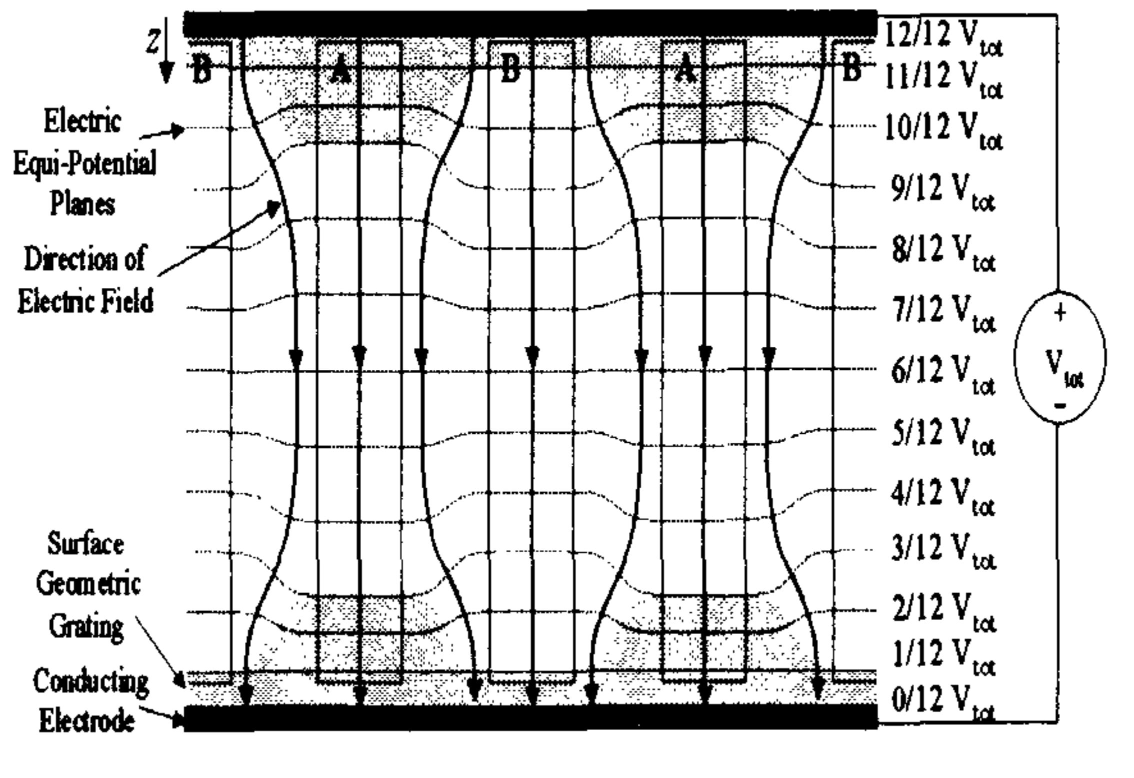
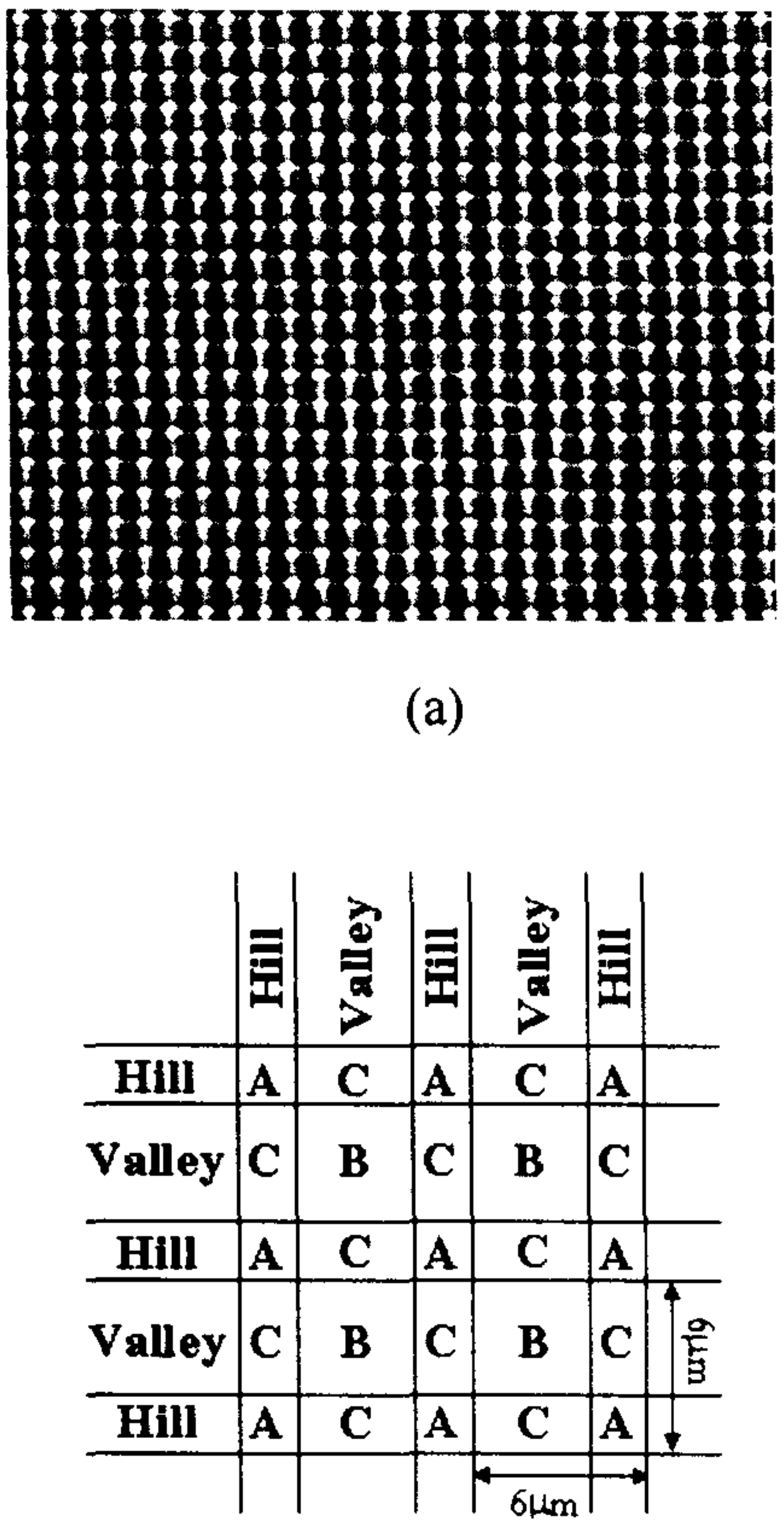


Figure 8: The cross-sectional view of voltage variations and the fringe field lines due to dielectric surface gratings.

Based on the above ideas, we fabricated the TN cell having DSG of $\chi > 1$. The periodicity of DSG was 6.0 μm. The widths of hill and valley of DSG were 2.0 μm and 4.0 μm, respectively. The measured parameters were $h_A = 0.79$ μm, $h_B = 0.28$ μm, and $l_A =$

5.22 µm, giving l_B = 6.24 µm . Materials being used for LC and DSG were ZLI-4900-100 and AZ-6612. Note that the AZ-6612 layer in "B" was not completely etched out during the etching process so that practically, h_B is not zero. Fig. 9 shows a photograph of the TN cell taken under crossed polarizers at 2.1 V (χ = 3.8). Clearly, an array of self-formed micro-domains in each pixel can be seen and the transmitted light intensity through the cell varies periodically with the DSG.

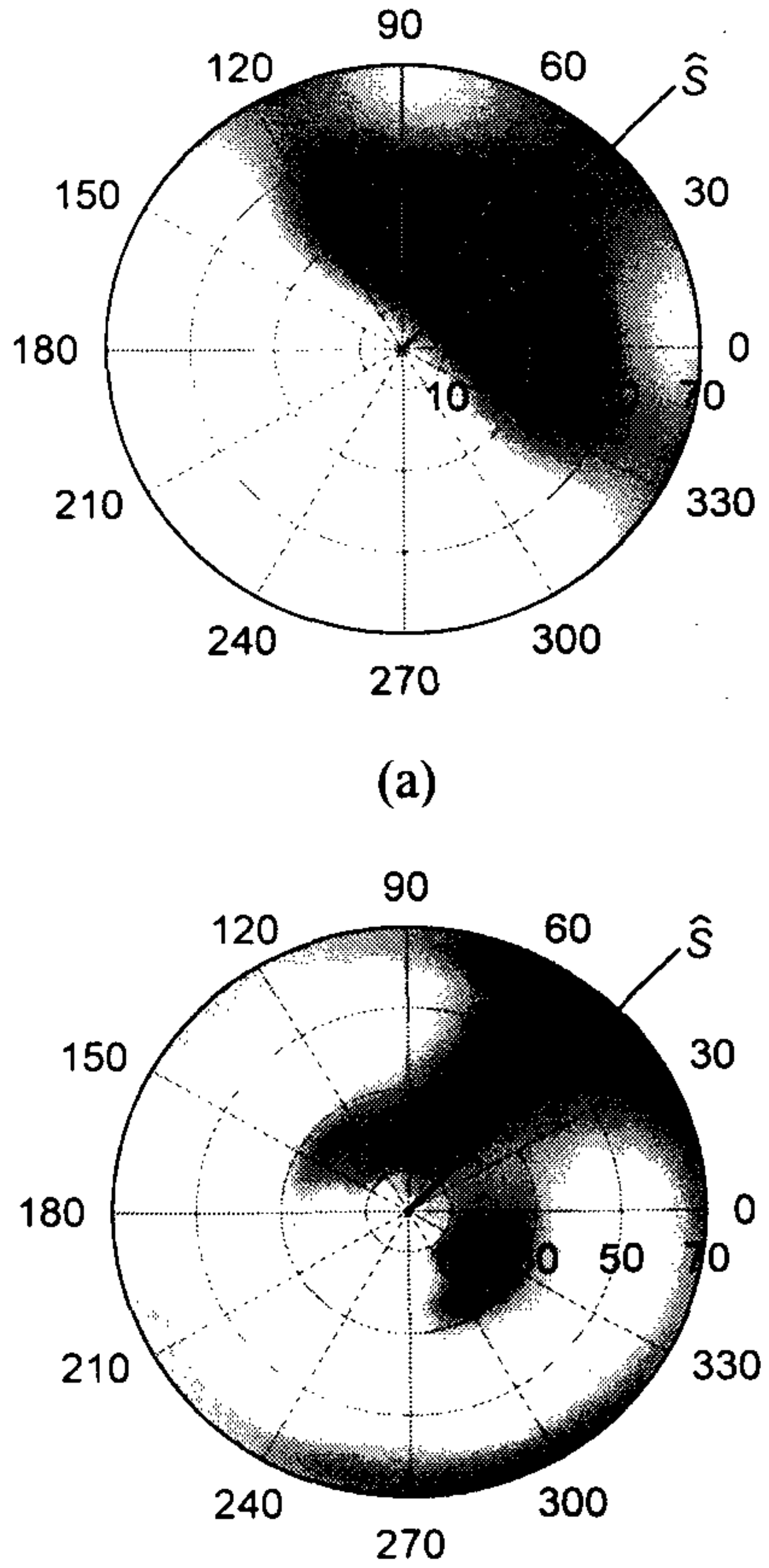

(a)

	Hill	Valley	Hill	Valley	Hill
Hill	A	C	A	C	A
Valley	C	B	C	B	C
Hill	A	C	A	C	A
Valley	C	B	C	B	C
Hill	A	C	A	C	A

(b)

Figure 9: Periodically self-formed micro-domains; (a) microscopic texture of the TN with dielectric surface gratings and (b) the arrangement of the dielectric surface gratings with the periodicity of 6 µm.

As shown in Fig. 9, each unit cell consists of four bright domains in the corners ("A"), one dark domain in the center ("B"), and four gray domains ("C") in the sides. The brightness depends on the net thickness of the LC layer which varies with the position of the DSG. The DSG configurations in "A", "C", and "B" are two-sides occupied, one-side occupied, and not occupied, respectively. In other TN cells having the DSG with the periodicity longer than 10 µm, no micro-domains were observed under an applied voltage. This is consistent with the fact that the DSG with long periodicity is not capable of aligning the LC by the topographical effect.



(a)

(b)

Figure 10: The gray scale representation of iso-luminance maps of (a) a conventional TN and (b) the TN with self-formed micro-domains due to dielctric surface gratings.

In order to obtain both topographical alignment of the LC and the GFF effect, the periodicity should be on the order of 1 µm and the dielectric parameter should be χ>1. The periodic micro-domains will be spontaneously formed only in this case. This criterion should provide a basis for tailoring the electro-optic performances of LCDs by adjusting the geometrical factors and dielectric parameters of the DSG.

In Fig. 10, the gray scale representation of iso-luminance maps of a conventional TN cell (cell I) and our fabricated TN cell with the DSG (cell II) are shown along the positive vertical viewing direction [7] which is denoted by *s*. The thickness of cell I is 6.3 μm. The luminance of cell II at 2.1 V ($\chi = 3.8$) is about 45 % in the normally white mode. For cell I, the same luminance is obtained at 1.5 V. The Fredericks thresholds for cell I and cell II are found to be about 0.79 V and 0.86 V in the "C" region, respectively. For the cell I shown in Fig. 10(a), a dark region is found to be as wide as ±80° with respect to *s* and two bright islands exist near 0° and 90° when viewed along *s*. For cell II shown in Fig. 10(b), however, the bright region is far extended and the dark region is as narrow as ±25° with respect to *s*. This agrees well with our numerical simulations. It is then concluded that the self-formed micro-domains in each pixel play a critical role on extending the range of viewing in LCDs.

In summary, various types of the DSG presented here will provide a physical insight to form self-aligned periodic multidomains in each pixel of the LCD that extend significantly the viewing range and produce the symmetrical viewing property. The physical behavior of the multidomain structure is predominantly governed by the geometrical factors of the DSG and the dielectric parameters of both the LC and the DSG. The main concept of the formation of the self-aligned domain structure is expected to play a crucial role in devising wide-viewing LCDs.

5. Acknowledgements

This work was supported in part by the Ministry of Information and Communication of Korea through Advanced Backbone IT Technology Development Project. We are indebted to M.O. Jin of Merck, Korea for providing us with the LC materials and technical help.

6. References

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