Wide-Viewing Characteristics of Self-Formed Micro-Domains in a Liquid Crystal Display with Dielectric Surface Gratings

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Abstract

We demonstrate the wide-viewing characteristics of a twisted nematic liquid crystal display (LCD) with self-formed micro-domains through the topographical alignment and fringe field effects of dielectric surface gratings (DSG). The mutual optical compensation between micro-domains within each pixel eliminates the contrast inversion phenomenon of TN mode without complex surface treatments.

1. Introduction

The twisted nematic (TN) mode has been widely used for most liquid crystal displays (LCDs) in either passive or active matrix driving. The TN mode, however, has some serious problems in the viewing characteristics which is primarily due to the asymmetric nature of the liquid crystal (LC) alignment [1].

Various methods have been developed to overcome this problem. One of the techniques for obtaining the symmetric phase retardation is the multi-domain method in which the orthogonal alignment of multi-domains along more than two directions compensates the asymmetry of each pixel [2]. However, for obtaining such multi-domain structures, at least two surface anchoring directions should be formed in each pixel through the alignment layer treatment [3]. This alignment layer treatment often 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 creating symmetric elastic distortions of LC so that the wide viewing characteristics are achieved [4,5]. Since no complex surface treatment for LC alignment is involved, these methods are known to be simple and cost-effective. The electric potential distortions are produced by patterned electrodes [4] or a two-dimensional array of dielectric surface relief structure [5]. These distortions are generated by the electrode fringe field (EFF) and the grating fringe field (GFF), respectively. Although the GFF effect is expected to play an important role, the systematic study has not been carried out so far. Moreover, an attempt to combine the GFF effect with the topographical alignment of LC [6,7] has not been made yet. 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 GFF effect.

In this work, we propose a new concept of spontaneously forming periodic micro-domains within each pixel of the TN LCD. This micro-domain array is achieved through the novel phenomenon in the GFF effect of DSG, i.e., the spatial variation in the effective voltage in the LC layer. If this effect is combined with the topographical alignment effect of DSG, the micro-domain array greatly improves the gray scale stability of the TN mode without complex surface treatment.

2. Principles of Micro-Domain Array

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 [6,7]. 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, ξ, defined as the effective voltage per unit thickness across DSG, V_{DSG}/h, scaled by that across the LC layer, V_{LC}/l, where h and l are the thickness of the LC layer and the height of DSG on the substrate, respectively. Note that $h / l << 1$ for most practical applications.

We first derive an expression for ξ in terms of the effective dielectric constant of the LC layer (ε_{LC}) and that of DSG (ε_{DSG}). Consider that both h and l are periodic in x as shown in Fig. 1. Assuming that no polarization in LC appears on a macroscopic scale, the electric displacement has only the z-component, D_z, that is uniform. Under these circumstances, the effective voltages per unit thickness, V_{DSG}/h and V_{LC}/l, are simply proportional to D_z/ε_{DSG} and D_z/ε_{LC}, respectively. This directly leads to $\xi = \varepsilon_{LC}/\varepsilon_{DSG}$. Since the value of ξ is periodic with DSG along the x axis, the spatial average of ξ over x is physically meaningful. The dimensionless dielectric parameter ξ is then given by

$$\xi = \frac{\langle \varepsilon_{LC} \rangle}{\varepsilon_{DSG}} \quad . \qquad (1)$$

The bracket denotes the spatial average over x.

The parameter ξ can be used for describing the main features of the GFF effect created by a periodic array of DSG in the LC cell [8]. In fact, a subtle change in the GFF effect can be precisely controlled by the change in $\langle \varepsilon_{LC} \rangle$ to ε_{DSG}. For $\xi \approx 1$, no GFF effect will exist and only the topographical alignment of LC will appear as a function of the periodicity of DSG. However, for $\xi >> 1$, a strong GFF effect is produced while for $\xi << 1$, the effect resembling the non-planar electrode case or a pure EFF effect is expected. Note that for $\xi > 1$, 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 ξ =3.0 are shown in Fig. 1. 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.

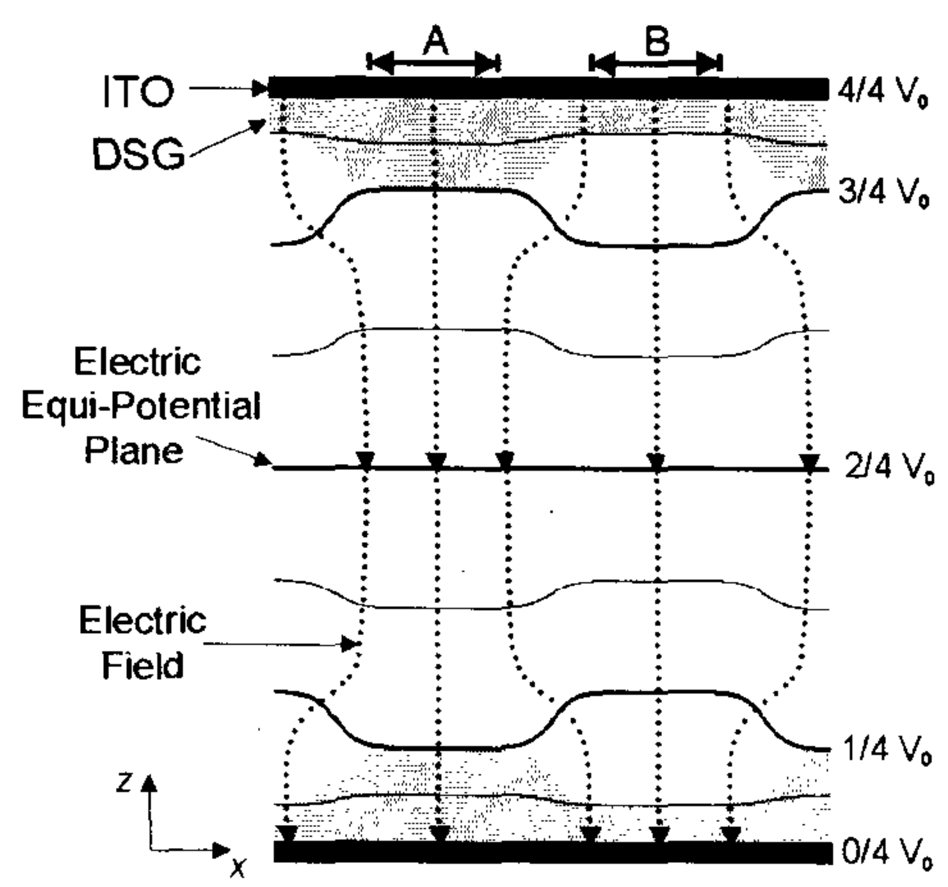

Figure 1. The cross-sectional view of spatial variations of VLC and the fringe field lines produced by the GFF effect of ξ =3.0 in the presence of high DSG in "A" and low DSG in "B".

We now examine the GFF effect on the Fredericks transition in the TN cells for two cases of $\xi > 1$and $\xi < 1$. For both cells, the DSG vectors on the substrates are perpendicular to each other. The cell parameters are assumed to be h_A = 0.5 μm, h_B = 0, and l_A = 5.5 μm, giving l_B = 6.5 μm which is the cell thickness. The dielectric constant of the DSG material, AZ-6612 of Clariant Co., is ε_{DSG} = 5.1. The periodicity of DSG is chosen as 6.0 μm.

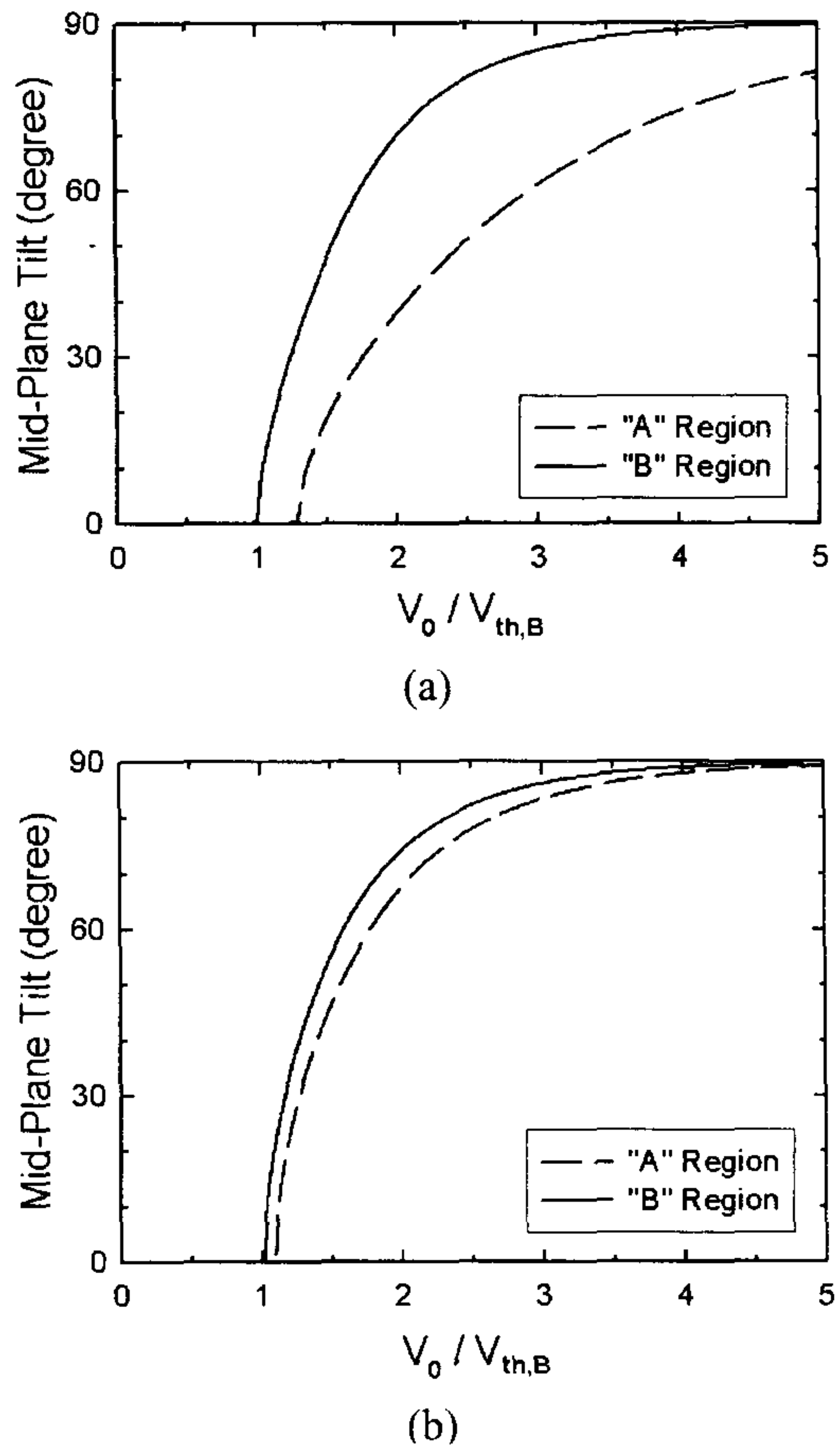

Figure 2. The mid-plane tilt angle in "A" and that in "B" as a function of the applied voltage V_0 scaled by the Fredericks threshold $V_{th,B}$ in "B" for (a) $\xi > 1$ and (b) $\xi < 1$. The self-formed micro-domains are expected in (a).

For the cell of $\xi > 1$, material parameters of a commercial LC (ZLI-4900-100 of Merck Co.) are used: the dielectric constants $(\varepsilon_\perp, \varepsilon_{//})$ = (7.9, 37.7) at 1 kHz and the elastic constants (K_1, K_2, K_3) = (16.3, 9.5, 23.3) in unit of 10^{-7} dynes. The value of ε_{LC} increases with V_{LC} from 7.9 to 37.7, giving $1.55 < \xi < 7.39$. For the cell of $\xi < 1$, the same material parameters other than the dielectric constants $(\varepsilon_{\perp}, \varepsilon_{//}) = (2.1, 5.1)$ at 1 kHz are used. This means that ξ varies from 0.42 to 1.00 with increasing V_{LC}. Using the above parameters, we carried out numerical simulations to study the GFF effect on the Fredericks transition in the TN cells with DSGs of two different ξ's [9].

In Fig. 2, the mid-plane tilt angle in the "A" region, θ_A, and that in the "B" region, θ_B, are plotted as a function of the applied voltage V_0 scaled by the Fredericks threshold $V_{th,B}$ in the "B" region. For the cell of $\xi > 1$ (ZLI-4900-100), the actual value of V_{th} is found to be 1.00 V in "A" and 0.78 V in "B". For the cell of $\xi < 1$, it is given as 2.67 V in "A" and 2.48 V in "B". It should be emphasized that the difference in the mid-plane tilt angle between "A" and "B", $\Delta\theta$, increases with V_0, reaches a maximum, and eventually vanishes in the high voltage limit. Moreover, $\Delta\theta$ for $\xi > 1$ is always larger than that for $\xi < 1$ because of the enhanced spatial variations of V_{LC}. As will be discussed later in Fig. 3, self-formed micro-domains will be observed only for $\xi > 1$.

3. Experiment

Based on the above ideas, we fabricated our TN cell having DSG of $\xi > 1$. The periodicity of DSG was 6.0 μm. The widths of hill and valley of DSG were 2 μm and 4 μm, respectively. The measured parameters were h_A = 0.79 μm m, 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.

Figure 3 shows a photograph of the TN cell taken under crossed polarizers at V_0 = 2.1 V (ξ = 3.8). Clearly, an array of self-formed micro-domains within each pixel can be seen and the transmitted light intensity through the cell varies periodically with DSG. As shown in Fig. 3, each unit cell consists of four bright domains in the corners ("D"), one dark domain in the center ("N"), and four gray domains ("S") in the sides. The brightness depends on the net thickness of the LC layer which varies with the position of DSG. The DSGs in "D", "S", and "N" are in two-side occupied, one-side occupied, and not occupied configurations, respectively. In other TN cells having DSG with the periodicity longer than 10 μm, no micro-domains were observed under an applied voltage. This is consistent with the fact that DSG with long periodicity is not capable of aligning LC by the topographical effect [7].

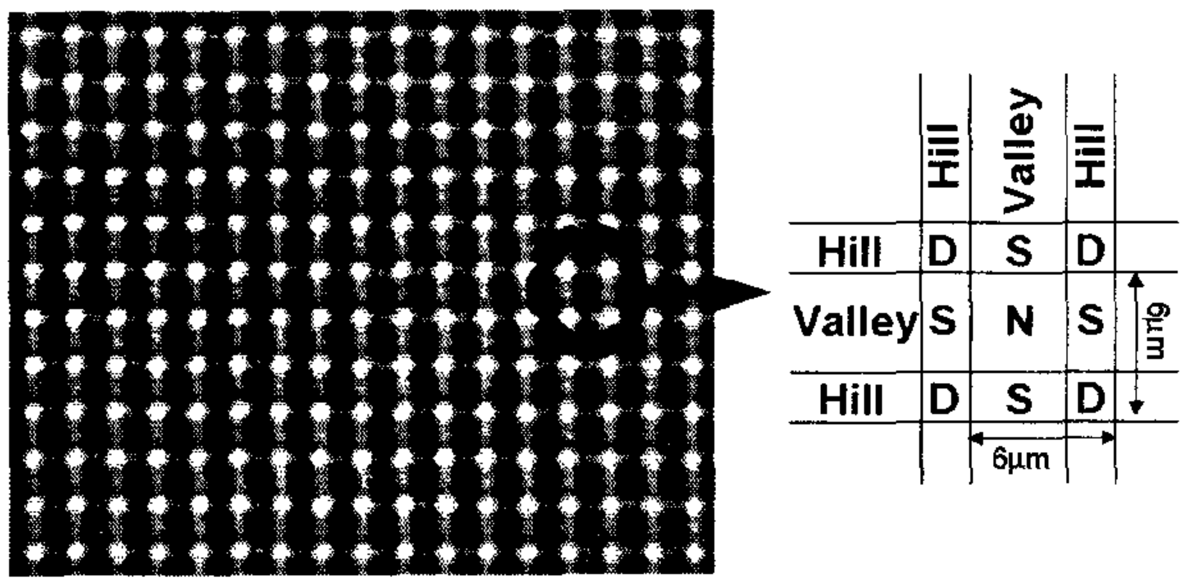

Figure 3. The photograph of our fabricated TN cell with periodic self-formed micro-domains taken under crossed polarizers at V_0 = 2.1 V (ξ = 3.8).

The criteria for self-forming micro-domains are given in terms of the periodicity of DSG and the magnitude of ξ in Fig. 4. In order to obtain both topographical alignment of LC and the GFF effect, the periodicity should be on the order of 1 μm and the dielectric parameter should be $\xi > 1$. The periodic micro-domains will be spontaneously formed only in this case. As shown in Fig. 4, a bare EFF effect occurs for $\xi < 1$, and topographical alignment effect disappears with increasing the periodicity above 10 μm. The criteria presented here should provide a basis for tailoring the electro-optic performances of LCDs by adjusting the geometrical factors and dielectric parameters of DSG.

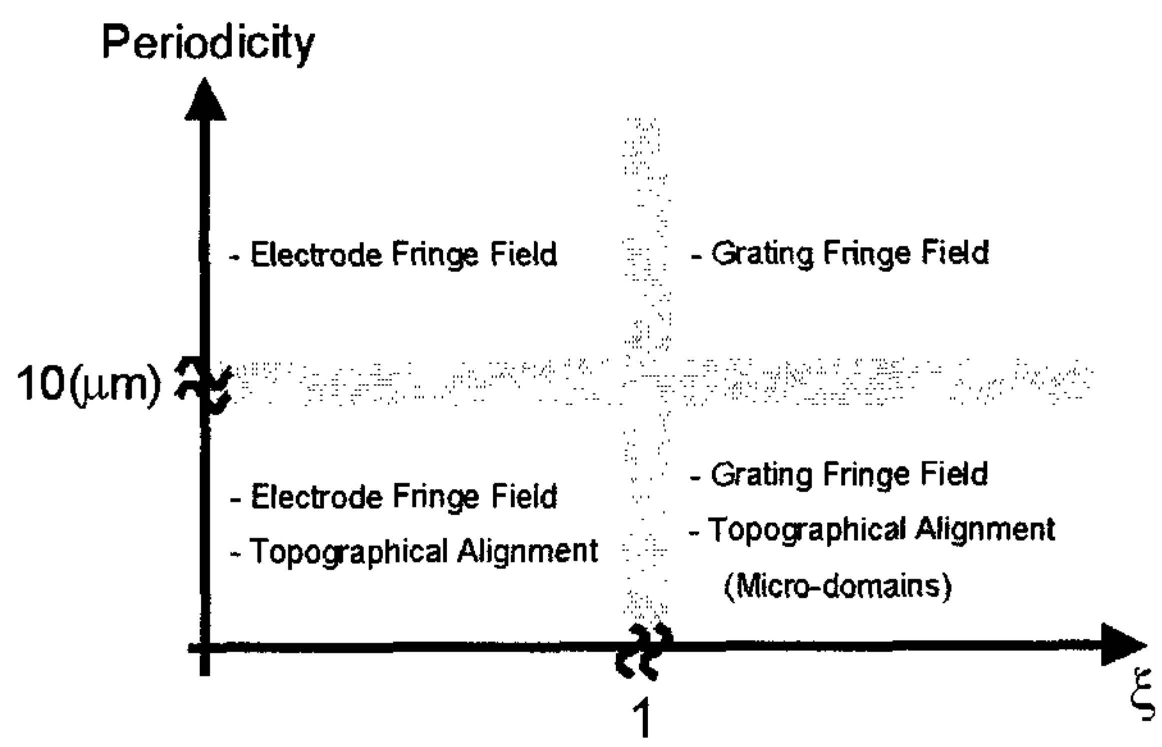

Figure 4. The criteria for self-forming micro-domains by the topographical alignment and grating fringe field effects of DSG.

4. Results and Discussions

In Fig. 5, the gray scale representation of iso-luminance maps of a conventional TN cell (cell I) and our fabricated TN cell with DSG (cell II) are shown along the positive vertical viewing direction [1] which is denoted by *s*. The thickness of cell I is 6.3 μm. The luminance of cell II at V_0 = 2.1 V (ξ = 3.8) is about 45 % in the normally white mode. For cell I, the same luminance is obtained at V_0 = 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 N region, respectively.

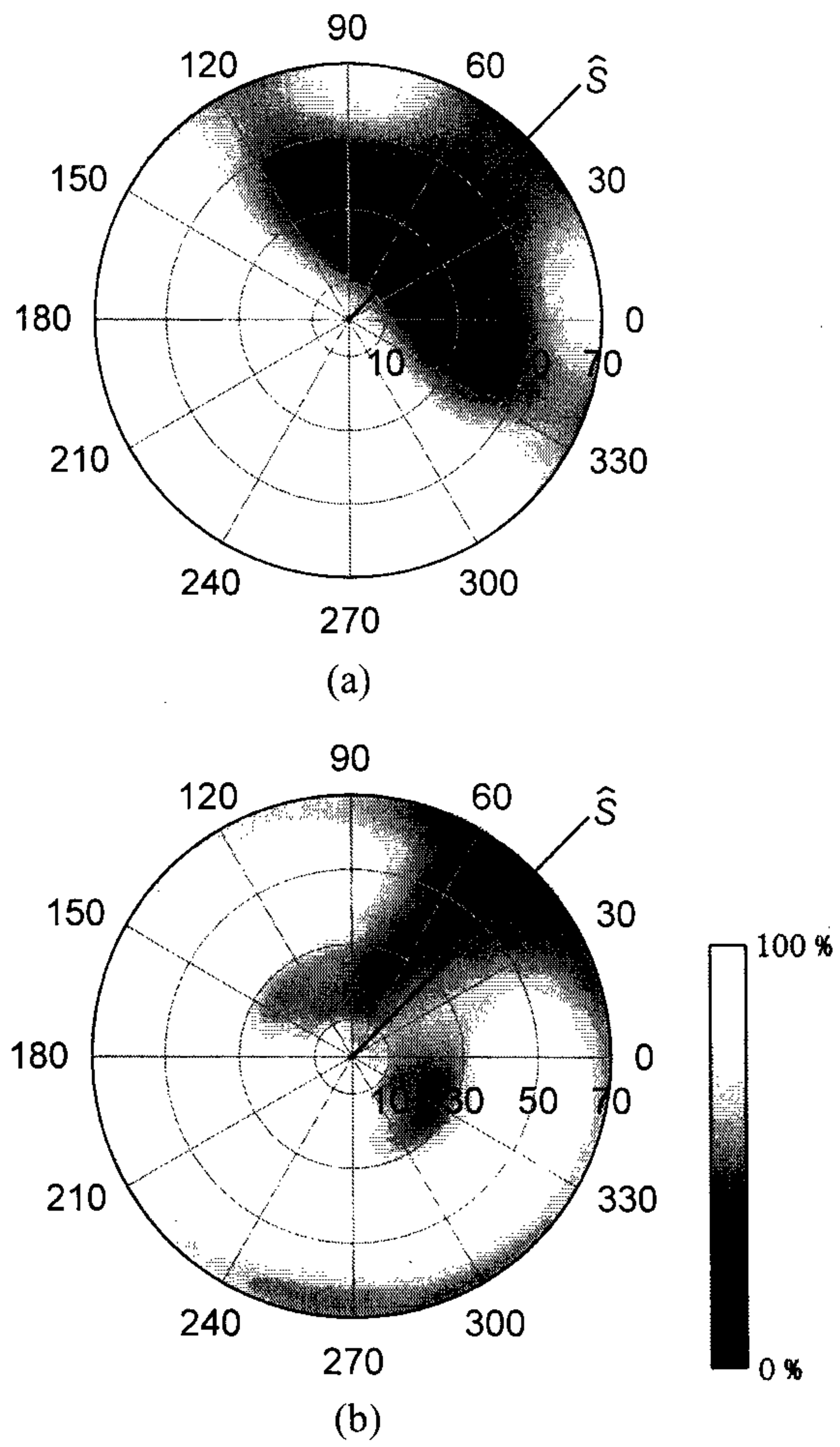

Figure 5. The gray scale representation of iso-luminance maps of (a) a conventional TN cell at V_0 = 1.5 V and (b) our fabricated TN cell with DSG of ξ = 3.8 at V_0 = 2.1 for given luminance of about 45 % in the normally white mode. The self-formed micro-domains are present in (b).

For the cell I shown in Fig. 5(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. 5(b), however, the bright region is far extended and the dark region is as narrow as 25° with respect to *s*. 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 conclusion, we demonstrated that self-formation of periodic micro-domains is predominantly governed by the geometrical factors of DSG and the dielectric parameters of both LC and DSG. The self-formed micro-domains in each pixel of the TN cell with DSG should be useful for eliminating the contrast inversion along certain viewing directions.

6. Acknowledgements

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7. References

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