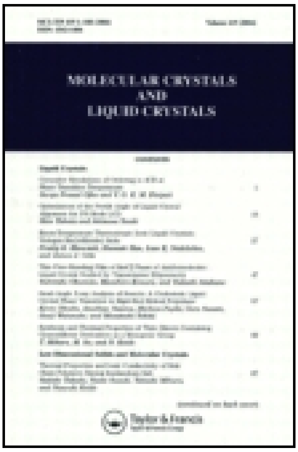

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Self-Induced Array of Micro-Domains in a Twisted Nematic Structure on a Surface Geometric Grating

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Self-Induced Array of Micro-Domains in a Twisted Nematic Structure on a Surface Geometric Grating

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We studied the intrinsic alignment of liquid crystals (LCs) together with the distorted electric potential (DEP) effect on a substrate with one dimensional surface geometric grating (SGG). It was found that in the presence of such SGG, a periodic array of micro-domain structures arises naturally from the DEP effect. The formation of the regular micro-domains in a twisted nematic structure is explored. The micro-domain structure was found to significantly improve the gray scale stability of a LC display.

Keywords: liquid crystal displays; twisted nematic; gray scale stability; wide viewing; mutli-domain

INTRODUCTION

The twisted nematic (TN) mode has attracted much interest for low power consumption applications such as active matrix addressed liquid crystal displays (LCDs). The overall performance of the active matrix addressed LCDs are currently suitable for desktop monitor applications. However, one of serious problems to replace the cathode ray tubes by LCDs is the poor viewing property. In the TN case, this is primarily due to the asymmetrical nature of the LC alignment [1].

Various methods have been studied to overcome this problem. The most widely adopted is to use an optical retardation film attached on a LCD panel. The role of the optical film is to compensate the phase retardation of the LC film along directions of the viewing-angles of interest [1]. However, a well-designed optical film does not still provide sufficient optical compensation in all directions. Therefore, the poor viewing characteristics in certain angles are inevitable. In principle, one of techniques for obtaining the symmetric phase retardation is the self-compensation of the asymmetry among sub-domains oriented in two orthogonal directions in each pixel [2]. For obtaining such multi-domain structures, at least two surface anchoring directions should be used in each pixel to produce several sub-domains through the alignment layer treatment [3]. This alignment layer treatment often involves an additional rubbing process along another direction.

Recently, a novel concept of producing a multi-domain structure has been reported in a vertically aligned mode [4,5]. This approach is based on the distorted electric potential (DEP) effect on a substrate with surface geometrical grating (SGG). The fringe field due to the DEP effect induces symmetric elastic distortions of LC. In contrast to the alignment layer treatment, the formation of sub-domains in each pixel naturally occurs. The DEP effect is produced through patterned electrodes [4] or the periodic thickness variations in the surface layer in terms of surface SGG [5].

One of the interesting features of SGG is that when the dielectric constant of SGG is small compared to that of the spatially averaged LC, the role of SGG is to produce periodic spatial variations of the effective voltage across the LC layer through the DEP effect [6]. As expected in a multi-domain structure, in this case, the gray scale stability of the TN mode would be significantly improved [6]. Another is that the intrinsic alignment of LC by SGG could be realized simultaneously with the DEP effect. However, such complimentary effect has not been fully studied yet from practical as well as fundamental viewpoints. In this work, we present numerical results for the alignment effect of LC together the gray scale stability of the LCD in the presence of SGG in a simplified model.

THEORETICAL ANALYSIS

Consider a micro-domain structure produced by one-dimensional SGGs. The DEP effect due to the presence of SGG is determined not by SGG alone but by the interrelation between LC molecules and SGG. This means that the material parameters of LC and SGG as well as the LC alignment state influence the DEP effect. To a first approximation, this interrelated phenomenon can be described in terms of a physical quantity, $\langle\alpha\rangle$, defined as the spatially-averaged electric potential difference per unit thickness in the LC layer scaled by that in SGG [6]. In order to enlarge the DEP effect, $\langle\alpha\rangle$ should significantly differ from the unity. In both limits of $\langle\alpha\rangle >> 1$ and $\langle\alpha\rangle << 1$, the DEP effect creates the strong fringe field. Especially, in the case of $\langle\alpha\rangle < 1$, the effective voltage across the LC layer (V_{LC}) spatially varies with the height of SGG. Figure 1 shows this spatial variation in V_{LC} in the case of $\langle\alpha\rangle < 1$.

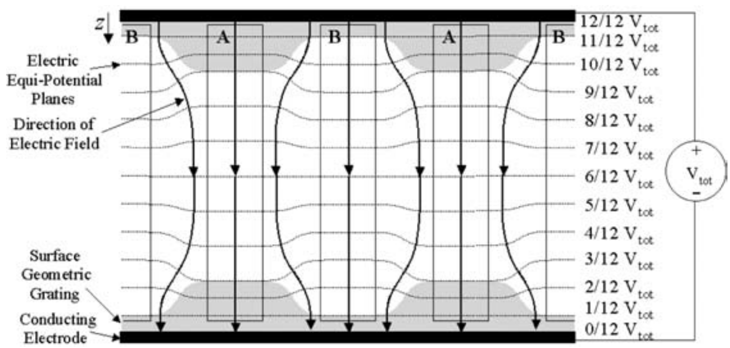


FIGURE 1. The DEP effect in the presence of SGG when $\langle\alpha\rangle < 1$.

In fact, $\langle\alpha\rangle$ is given

$$\langle\alpha\rangle = \frac{\varepsilon_{SGG}}{\langle\varepsilon_{LC}\rangle} \quad (1).$$

Here, ε_{SGG} = dielectric constant of SGG and $<\varepsilon_{LC}>$ = spatial average of the dielectric constant of LC. This tells us that the decrease in ε_{SGG} in relative to $<\varepsilon_{LC}>$ results in the increase in the spatial variations of V_{LC}.

Interestingly, the spatial variations of V_{LC} lead to considerable spatial variations of the mid-plane tilt (θ) of the LC layer. This implies that under the same applied voltage, V_{tot}, a micro-domain structure with different values of θ can be naturally produced when the DEP effect of $\langle\alpha\rangle < 1$ is used. Such micro-domain structure in the TN mode is expected to improve the gray scale stability because the gray scale instability in a conventional TN LCD mainly arises from the uniformity in θ. The uniform distribution of θ along a certain direction causes the gray scale inversion [1]. However, in the above micro-domain structure, micro-domains have different tilt directions of θ that result in the compensation of the optical retardation between different θs.

In the light of the above ideas, the improvement in the gray scale stability of the TN mode was experimentally achieved. The desired $\langle\alpha\rangle$ was obtained under the following condition that $\varepsilon_{SGG} = 5.1$, $\varepsilon_{LC,||} = 37.7$, and $\varepsilon_{LC,\perp} = 7.9$. The nominal cell thickness was 5.14μm. Figure 2 shows the electro-optic (EO) transmission through the TN cell whose gray scale stability was improved by the micro-domain structure. The EO curves at various voltages did not intersect with each other up to the range of the vertical viewing angle of 60° in which the gray scale stability is much improved compared to a conventional TN cell [1].

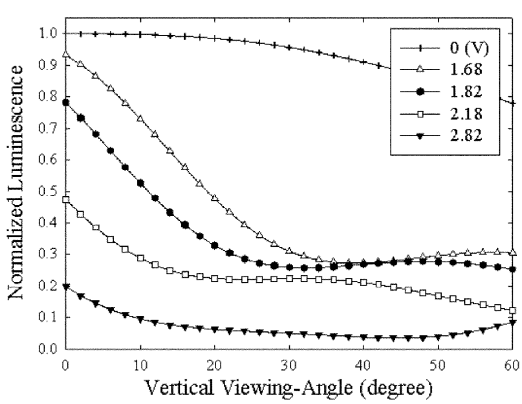
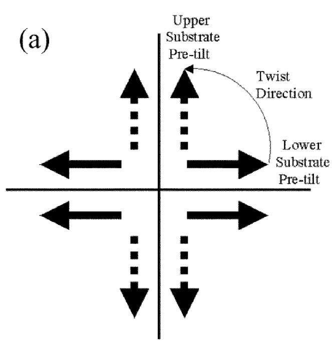


FIGURE 2 The EO transmittance through a TN cell with the micro-domain structure.

It is known that one-dimensional SGG tends to align LC perpendicular to the grating vector due to the minimization of elastic distortions of LC induced by one-dimensional SGG [7]. This intrinsic alignment effect is essentially determined by the periodicity of SGG, which is independent of $\langle\alpha\rangle$. Thus, SGG with small periodicity and $\langle\alpha\rangle < 1$ produces a non-negligible DEP effect together with the alignment effect. This means that when such SGG is prepared for the alignment purpose, the micro-domain structure discussed above is naturally produced. Therefore, when the 4-domain structure is obtained from the alignment effect of SGG, if $\langle\alpha\rangle < 1$, then the micro-domain structure, arising from the DEP effect, is obtained in each sub-domains without any additional process. This combination of the 4-domain TN structure and the micro-domain structure is expected to improve the viewing angle characteristics.

The 4-domain TN structure used in our study is shown in Figure 3(a). In this case, alternative pretilt directions are produced on each alignment layer and they are perpendicular to each other [3]. If $\langle\alpha\rangle < 1$, in every sub-domain of Figure 3(a), the micro-domain structure as shown in Figure 3(b) is produced through the DEP effect in the presence of SGG. The different values of θ are produced in micro-domains of "A", "B", and "C" due to the spatial variation in V_{LC}.

(a)



(b)

	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

FIGURE 3 Two multi-domain structures studied: (a) The 4-domain TN structure and (b) the micro-domain structure produced in the sub-domain of (a).

NUMERICAL ANALYSIS

Numerical analysis is carried out in the 4-domain TN structure shown in Figure 3(a) with or without the micro-domains in Figure 3(b). Since the optical interference effect is absent, the overall transmission can be obtained from the average of the EO transmission through sub-domains.

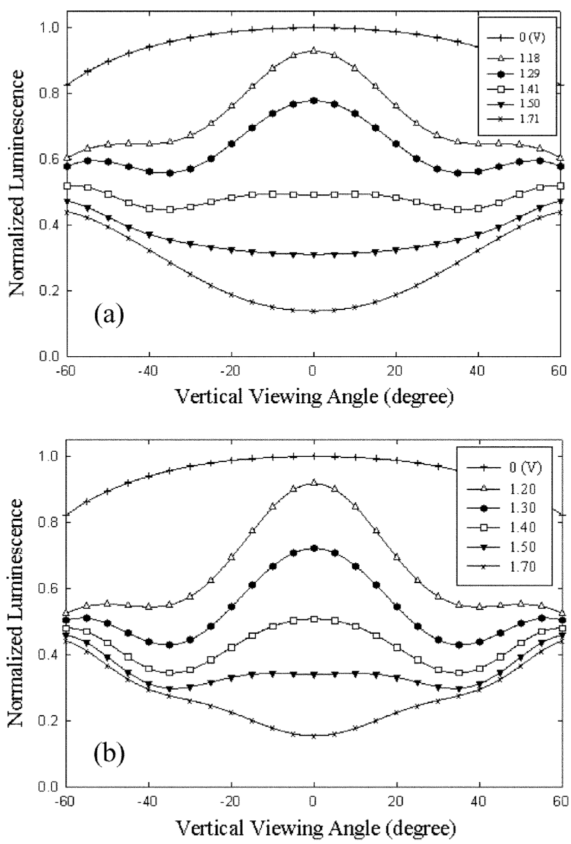


FIGURE 4 Numerical results for the EO transmission through the 4-domain TN (a) with a micro-domain structure, (b) without a micro-domain structure. For a direct comparison, we present the EO transmission as a function of the mean value of V_{LC} in Figure 4(a).

We first consider the compensation effect due to the micro-domain structure. The spatial variations of V_{LC} in the micro-domains were analyzed by the equation, $V_{LC} = V_{tot} \cdot [1+(C_{LC}/C_{SGG})]^{-1}$ where V_{tot} = the applied voltage, C_{LC} = the capacitance of LC, and C_{SGG} = the capacitance of SGG. First, we found the relation between C_{LC} and V_{LC} [8], then we inserted this pair into the above equation to obtain V_{tot} as a function of V_{LC}. From the inverse of this relation, we found V_{LC} as function of V_{tot}, then the distribution of LC director and the EO transmission were found for micro-domains. The average of the EO transmission gives the EO transmission of one sub-domain in the 4-domain TN structure.

The average over the sub-domains is related to the mutual compensation effect in the 4-domain TN structure. This is considered by assigning the appropriate molecular orientation to each sub-domain. Then, the micro-domains in Figure 3(b) have the same orientations as those of sub-domains. The validity of this approach will be presented elsewhere [6] together with the experiment results.

For numerical simulations, the same physical parameters as in Figure 2(a) were used. Figure 4(a) is the EO transmission through the 4-domain TN with a micro-domain structure produced in every sub-domain, while Figure 4(b) shows that of the 4-domain TN without a micro-domain structure. It can be seen from Figure 4(a) and 4(b) that the micro-domain structure plays a critical role in flattening the EO transmission curves at various operating voltages. As a consequence, the gray scale stability is increased. The optimization of the geometric and dielectric parameters of SGG will further enhance the gray scale stability of the LCD.

CONCLUSION

We studied the intrinsic alignment of LC together with the distorted electric potential (DEP) effect on a substrate with one dimensional SGG. It was found that in the presence of such SGG, a periodic array of micro-domain structures arises naturally from the DEP effect. The micro-domain structure was found to significantly improve the gray scale stability of the TN mode. When the dielectric constant of SGG is small compared to that of LC ($\langle\alpha\rangle < 1$), which is spatially averaged, the SGG produces the distortions of the effective voltage across LCs in the LC layer. As a consequence, a micro-domain structure is obtained within which micro-domains have different mid-plane tilts of LC. The optical compensation between micro-domains improves the gray scale stability.

One interesting point is that the DEP effect can be achieved simultaneously with the alignment effect of SGG. Because the periodicity of SGG, governing the alignment effect, is independent of $\langle\alpha\rangle$, SGG with small periodicity and $\langle\alpha\rangle < 1$ has both the alignment effect and the DEP effect. Therefore, when a multi-domain structure is obtained through the alignment effect of such SGG, the micro-domain structure arising from the DEP effect is naturally induced in every sub-domain of the multi-domain structure.

Finally, the micro-domain in sub-domains in the TN mode plays a critical role in flattening the EO transmission curves at various voltages, which increases the gray scale stability. Further studies on various interesting surface effects arising from the geometric and dielectric properties of SGG remain to be explored.

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