12.6: A Novel Fast-Switching LCD with Dual-Domain Bend Mode

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Abstract

A novel fast-switching LCD with dual-domain bend (DDB) mode is described. DDB alignment is achieved using antiparallel-rubbed cell filled with chiral-doped LC. Initial alignment is mono-domain 180-degree twist. Tilt direction is controlled by oblique electric field to be counter direction in each domain. Twist-to-DDB deformation occurs continuously so that DDB mode does not require high-voltage initialization which is inevitable in Optically Compensated Bend (OCB) mode. DDB gives wide and symmetric viewing angle in contrast to mono-domain bend formed from 180-degree twist showing strong asymmetry.

1. Introduction

Fast-switching LCD is required to improve motion-picture quality of TV and multimedia monitor applications. Overdrive techniques accelerate the response of conventional LCDs [1-6], however, the response time is not short enough for either impulse-type driving [7,8] or field-sequential driving [9,10]. Bend alignment used in OCB mode exhibits fast response time less than 10ms in all gray-scale transitions [11-14]. However, high voltage and/or some built-in transition nuclei are required to obtain bend alignment from initial splay alignment [15-17]. In contrast, chiral-doped OCB (C-OCB), an initial alignment of which is 180-degree twist, does not require above special initializations [18]. However, C-OCB exhibits strong asymmetric viewing angle due to the LC-molecule tilt in the mid-layer of the LC cell. In this paper, we describe novel fast-switching LCD with dual-domain bend (DDB) mode. DDB mode does not require the initialization to obtain the bend alignment and has wide and symmetric viewing angle properties.

2. Operation Principle

Figure 1 shows schematic diagram of DDB alignment. In DDB mode, antiparallel-rubbed cell is filled with chiral-doped LC. By adjusting the chiral pitch p to satisfy the following relation with the cell gap d, 180-degree twist alignment is obtained as an initial state.

$$0.25 < d/p < 0.75 \qquad (1)$$

LC molecules begin to tilt up around the threshold voltage (Vth). Since DDB cell is antiparallel-rubbed, tilt direction of LC molecules cannot be determined by pretilt direction. Oblique electric field, which is induced by electrode slit and/or protrusion (not shown in Fig. 1), controls the tilt direction to divide the pixel area in two domains. One domain has splay deformation layer at the top, while the other has that at the bottom. Deformation to bend-like alignment occurs continuously with increasing voltage. At lower voltage, LC directors at the mid-layer in two domains tilt counter directions each other. Therefore, DDB mode diminishes asymmetric viewing-angle properties observed in mono-domain C-OCB mode.

With optical films to compensate the residual retardation of the LC layer, DDB cell can change its transmittance between dark state and bright state.

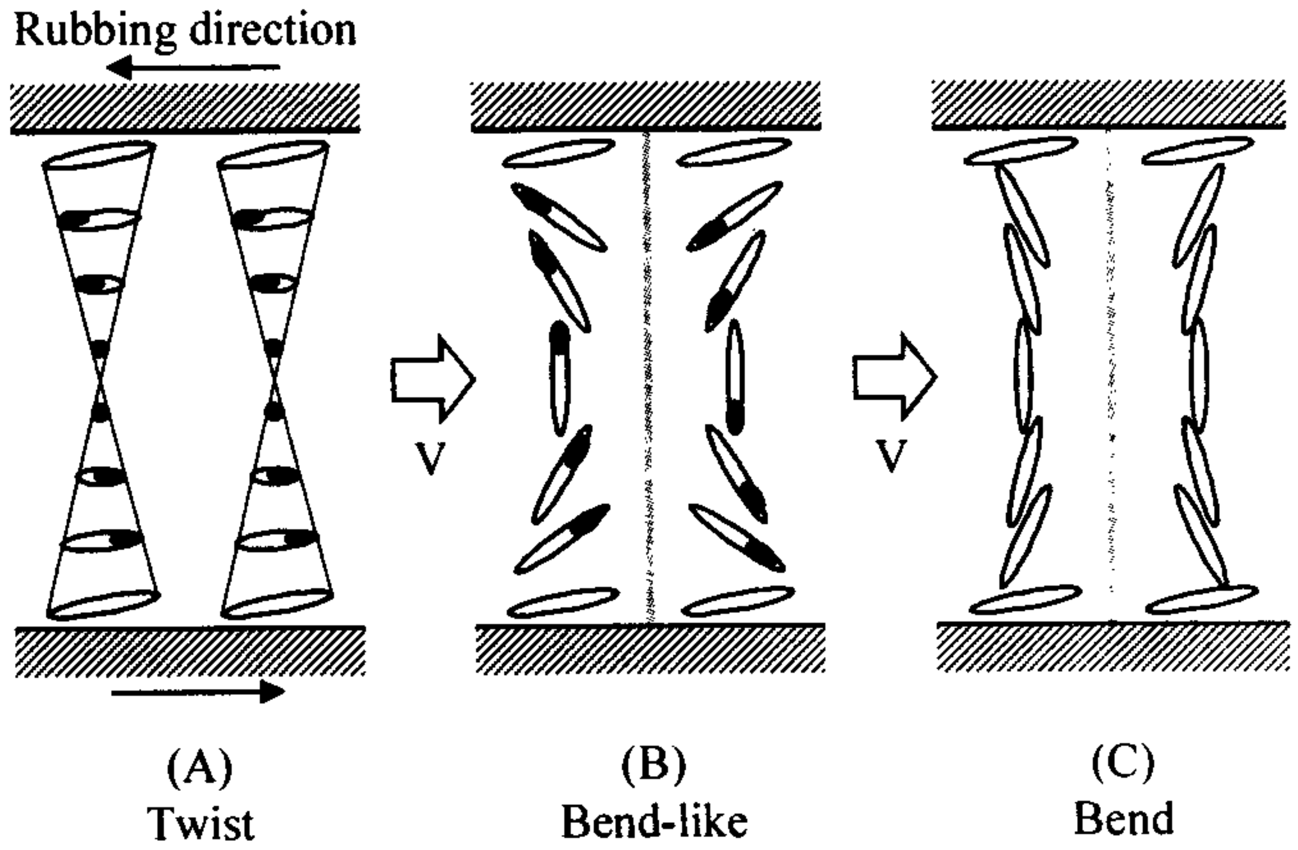

Figure 1 Operation principle of DDB mode; Marked-out edge tilts near side

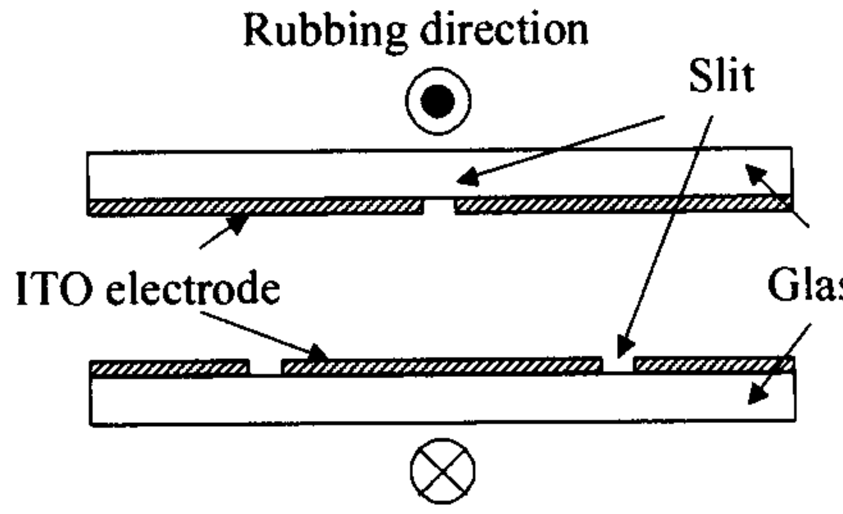

Figure 2 Cross-sectional structure of DDB cell

3. Experimental

3.1 DDB Alignment

An LC cell equipped with electrode slits on both substrates was used for the alignment observation. Figure 2 shows the cross-sectional structure of the cell. The slits of 10μm width were made with 100μm interval onto ITO electrodes. Polyimide alignment layers were spin-coated on both substrates. Antiparallel rubbing was made along the slits. The cell gap was 7μm. The cell was filled with chiral-doped LC material, physical properties of which are summarized in Table 1.

Table 1 Physical properties of LC used.

Item	Value	Measurement condition
Birefringence (Δn)	0.14	589nm
Dielectric anisotropy ($\Delta\varepsilon$)	+8.0	1kHz
Chiral pitch (p)	20 μm (d/p = 0.35)	

Initial 180-degree twist alignment was proved since there was no extinction angle under crossed polarizers. Figure 3(a) shows the microscopic image when 1.7V was applied to the cell. In order to check out the tilt direction, the cell was obliquely observed under crossed polarizers with the right side of the cell lifted from the stage. The tilt directions of two adjacent domains were counter directions since interference colors were different. The director profiles of the domains are schematically described in Fig. 3(b). DDB alignment was achieved by use of oblique electric field generated by electrode slits.

(a)

(b)

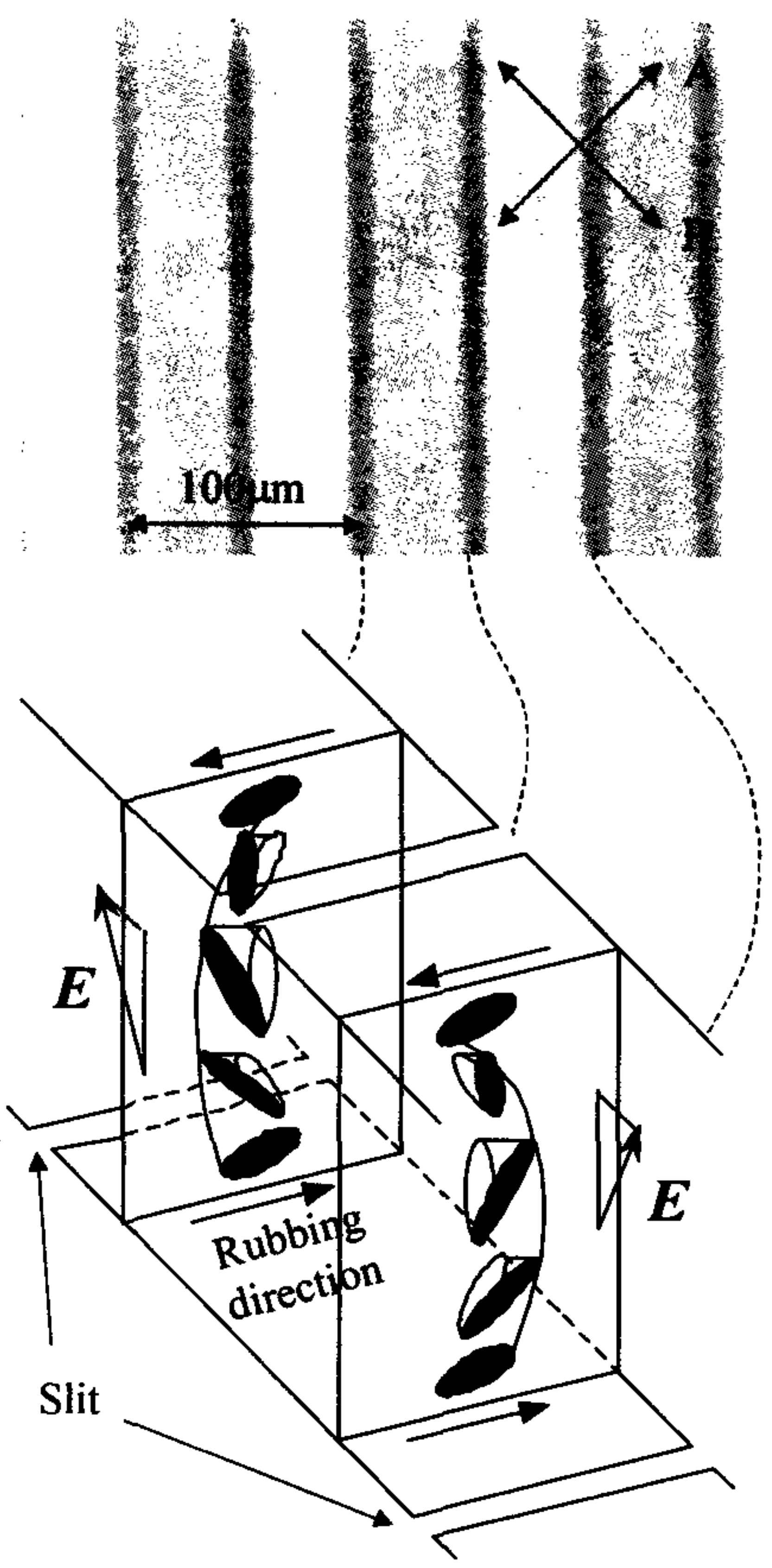

Figure 3 Microscopic image of DDB cell (a) and schematic diagram of the director profile of each domain (b)

3.2 Electro-Optical Properties

Voltage-dependent transmittance (VT) of the DDB cell was measured. Figure 4 shows the measurement setup. An optical film, in-plane retardation of which was 100nm, was placed on the DDB cell to cancel the residual retardation of the LC layer. The cell was driven using rectangle wave of 60Hz supplied by an external function generator. Figure 5 shows the VT curve. The dark state was obtained at 7V. The VT curve is similar to that of C-OCB. Initial optical bouncing due to twist-to-bend deformation occurred in DDB mode at around 2V.

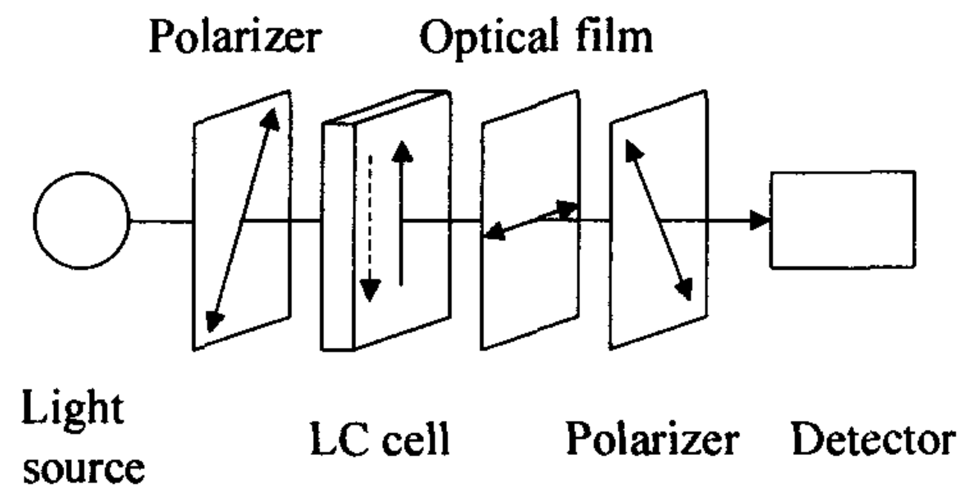

Figure 4 VT measurement setup; Arrows denote transmission axis of polarizer, rubbing direction of LC cell, and slow axis of optical film

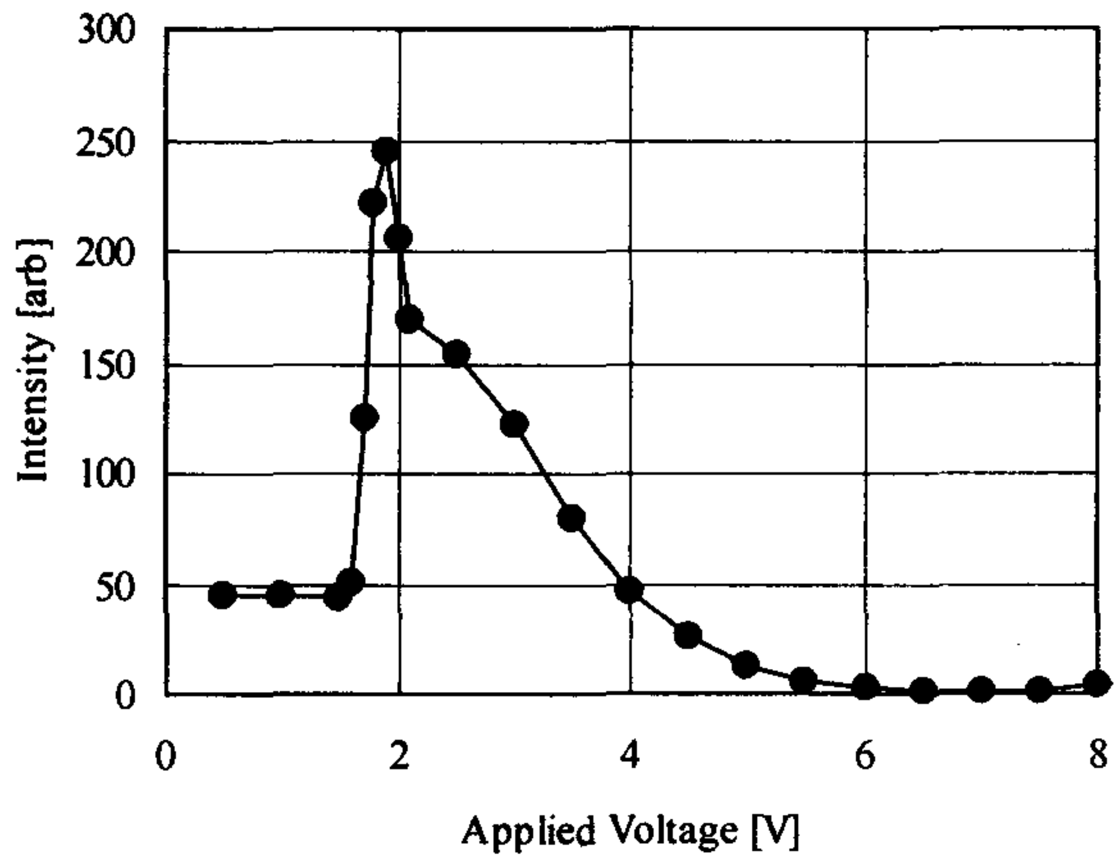

Figure 5 VT curve of DDB cell

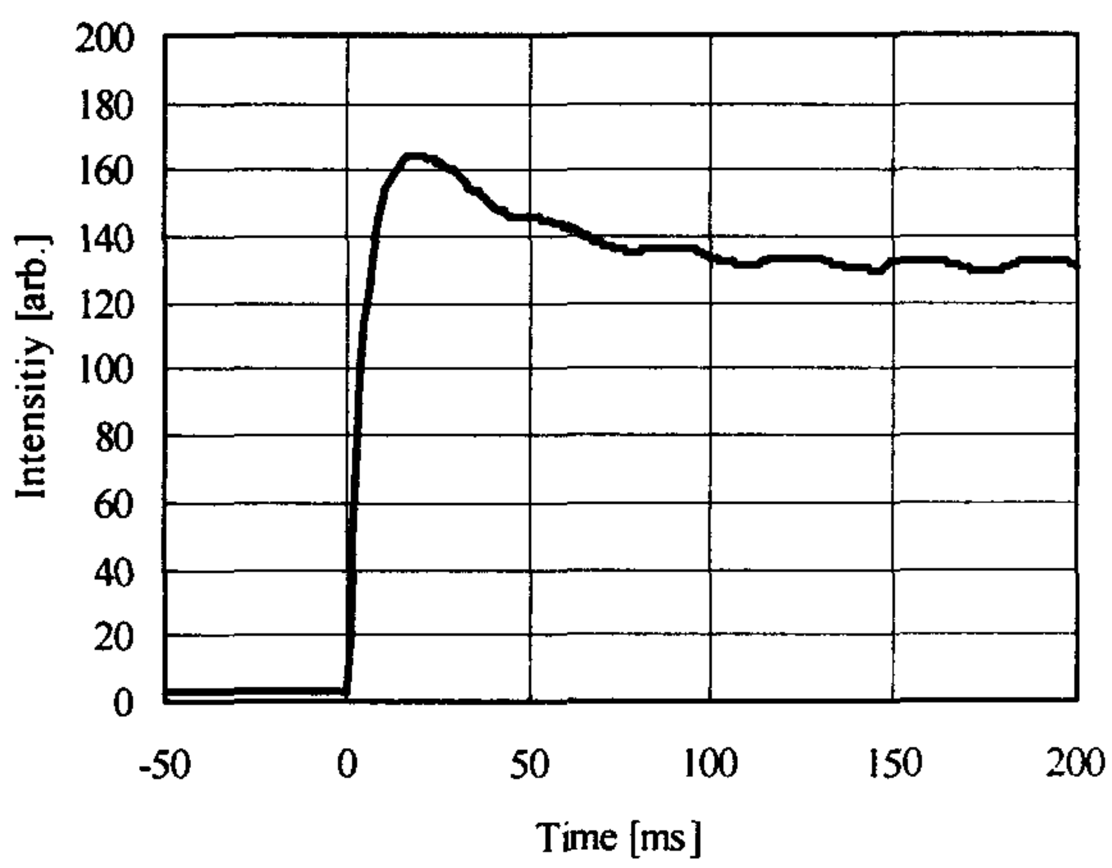

Figure 6 Response curve from dark state to bright state of DDB cell

Switching properties of the DDB cell were also measured. Figure 6 shows the response curve from dark state to bright state. Bright state was set at 2.5V. The response of DDB mode exhibits overshooting phenomena, which is also observed in C-OCB mode [19]. The response time from dark state to bright state, which is defined as the time to reach 90% of the final intensity, was 5ms. The time from bright state to dark state was less than 1ms. DDB mode exhibits fast response comparable to other bend modes and proves to be one of the fastest nematic LC mode.

4. Viewing Angle Simulation

Viewing angle properties were simulated using a commercial simulator (Shintech's "LCD master"). OCB mode exhibits wide viewing angle properties using hybrid-aligned discotic-liquid-crystal (DLC) films [20]. In contrast, DDB cell has mutually compensating adjacent domains so that it does not require DLC films. Figure 7 shows the simulated optical configuration of DDB mode. A simple circular polarizer (CP), which consists of a linear polarizer (LP) and a quarter-wave plate (QWP), was used on each side of the DDB cell [21,22]. A negative c-plate and a positive a-plate were placed between CP and the LC cell. Film parameters are summarized in Table 2. The cell gap was set to 7μm. The LC material shown in Table 1 was used.

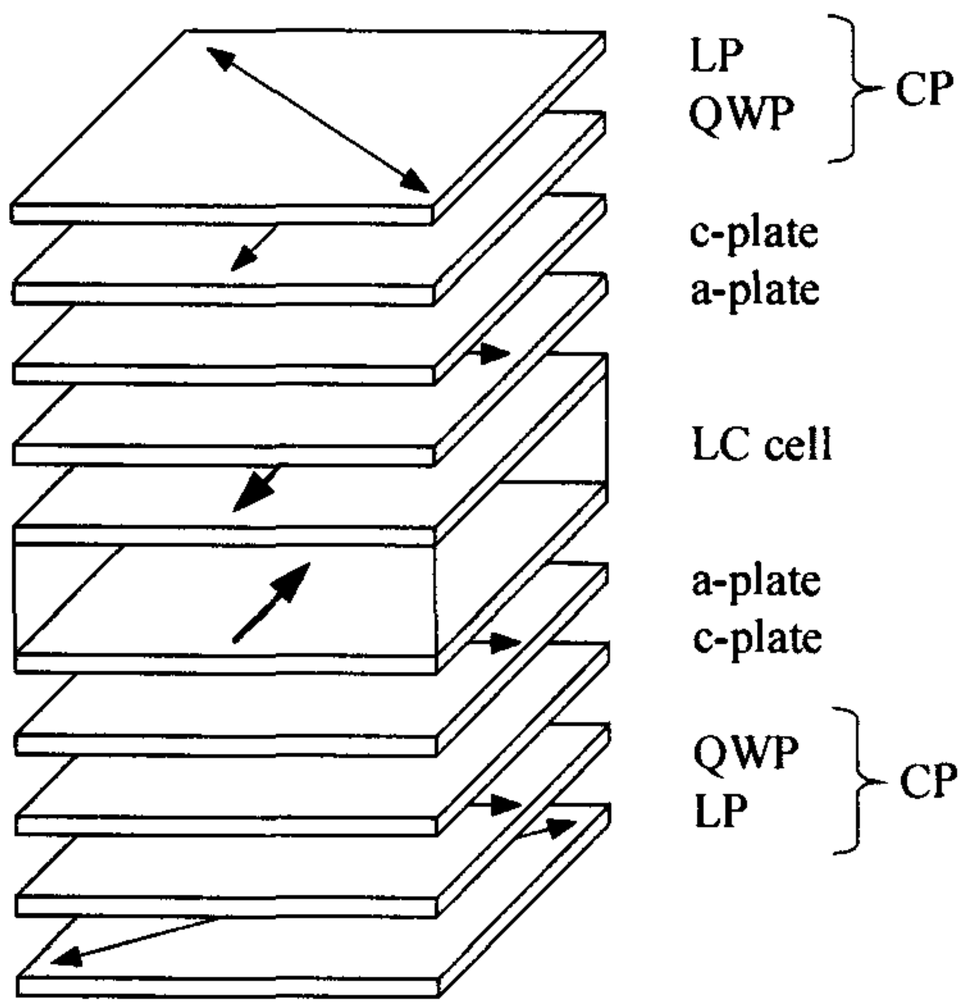

Figure 7 Optical configuration for viewing angle simulation; Arrows denote transmission axis of LP, slow axis of optical film, and rubbing direction of LC cell

Figure 8 and 9 shows iso-transmittance contour of bright state (2.5V) and iso-contrast contour, respectively. Both transmittance and contrast have symmetric profiles in horizontal direction which is perpendicular to the rubbing direction. DDB provides wide and symmetric viewing angle properties in contrast to C-OCB showing strong asymmetry in the direction perpendicular to the rubbing direction.

Table 2 Film parameters used in the simulation

Position	Film component	Item	Value
Front	LP	Abs. axis	45°
	QWP	Ra	140nm
		Slow axis	90°
	c-plate	Rc	260nm
	a-plate	Ra	50nm
		Slow axis	0°
(LC cell)			
Rear	a-plate	Ra	50nm
		Slow axis	0°
	c-plate	Rc	260nm
	QWP	Ra	140nm
		Slow axis	0°
	LP	Abs. axis	135°

Ra denotes in-plane retardation; Rc denotes retardation across the thickness; Optical axis is defined as angle from right direction.

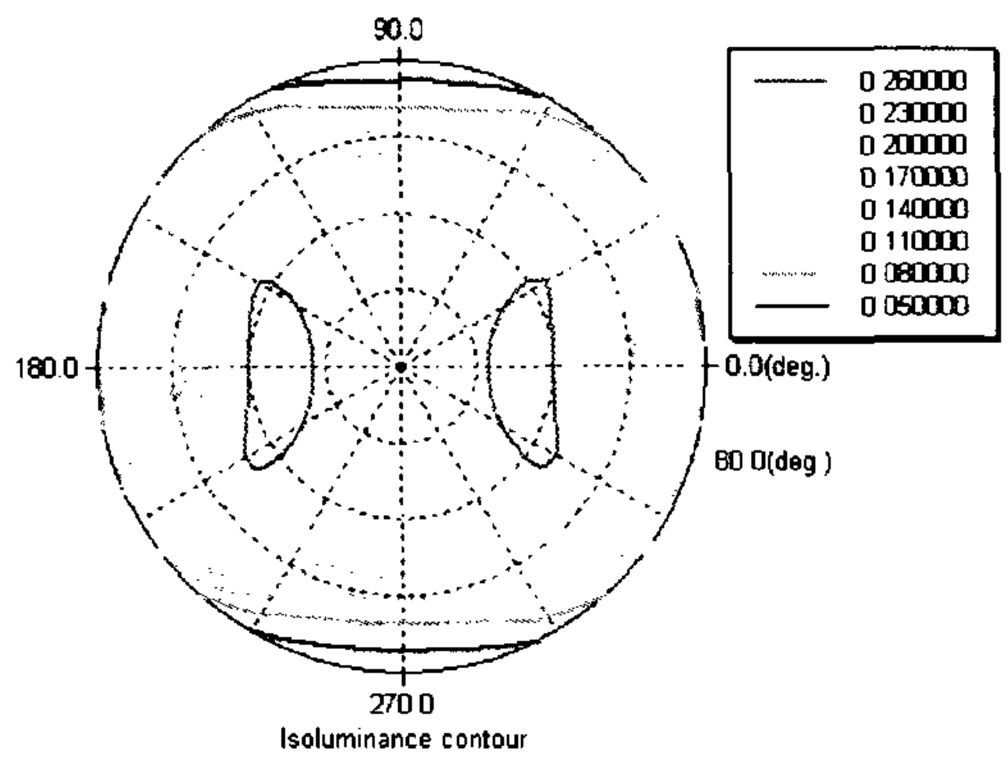

Figure 8 Iso-transmittance contour of bright state (simulation)

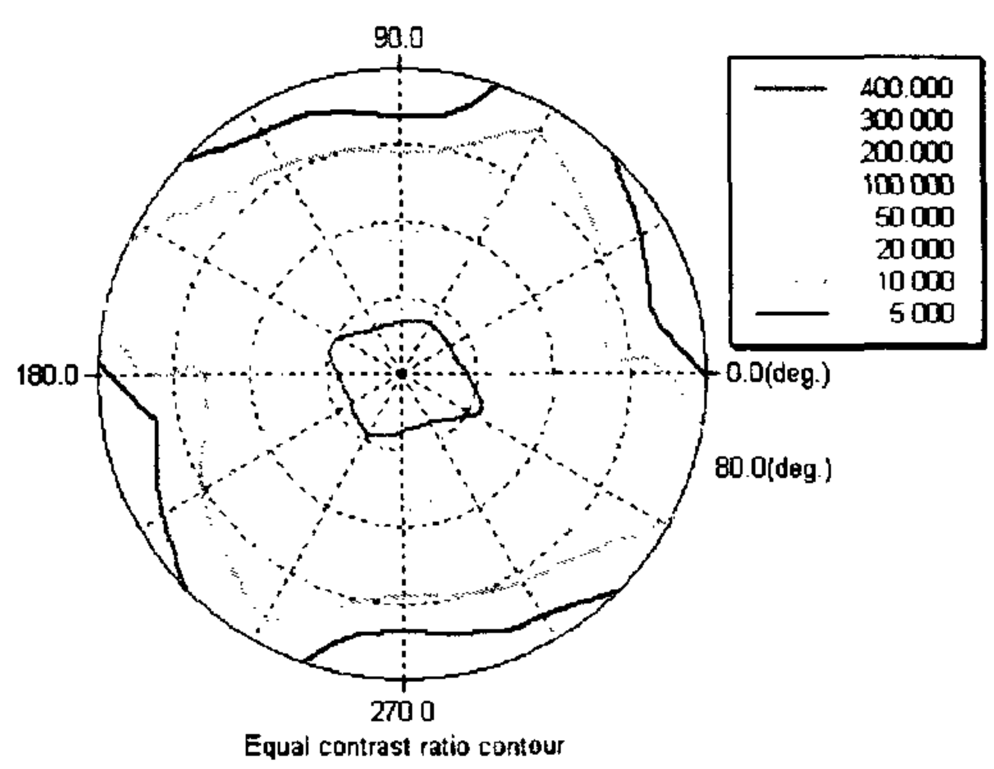

Figure 9 Iso-contrast contour (simulation)

5. Conclusion

Novel fast-switching LCD with DDB mode has been proposed. DDB alignment is achieved using antiparallel-rubbed cell filled with chiral-doped LC. DDB mode does not involve the initialization for the splay-bend transition, which is the major concern of OCB mode. DDB mode exhibits wide and symmetric viewing angle properties in addition to fast response.

6. References

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