

P-14.1: Transflective and Single Polariser Reflective Zenithal Bistable Displays

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Abstract

Transflective displays are ideal for portable applications used in both bright sunlight and darkened rooms. Display bistability is also advantageous for ensuring low power consumption, but the choice for transflective geometries is then severely limited. Grating-aligned Zenithal Bistable Devices (ZBD™) are readily fabricated in either single polariser reflective or transflective modes using a number of different device geometries. Both retardation and polarisation rotation modes are reported.

1. Introduction

Zenithal Bistable Devices (ZBD) [1, 2] have enormous potential for application in portable products, not only because of the ultra low power consumption they offer, but also because of the superior optical properties. The bistable surface used in ZBD leads to many new device configurations for use in different applications. Reflective devices have been fabricated previously [3] using polarisers on both sides of the cell. However, such geometries are not optimal for use in colour displays, since the high degree of parallax can cause a distracting colour shift when viewed off axis.

The ZBD device uses a grating as the alignment layer instead of the conventional rubbed polymer. This surface stores the image after the field is removed, maintaining either a vertical or near-planar alignment of the liquid crystal director, and the image is retained despite severe mechanical shock. Latching occurs for pulse magnitudes of several volts, and durations of tens of microseconds [4]. The grating alignment is readily varied within each pixel, for example to give error-free greyscale [5], an important requirement to obtaining full colour operation.

Unlike devices that rely on a particular geometry of the bulk liquid crystal configuration to give bistability, surface induced bistability allows image storage from a variety of different optical configurations. ZBD's adaptability is virtually unique amongst the bistable display choices. This paper will outline a number of cell geometries suitable for use with a front polariser only, and an internal reflector. For transflective devices, the mirror is made partially reflective, and a backlight can be operated for readability in low ambient light conditions. It is important that there is no inversion of contrast between transmissive and reflective modes, since this then allows device brightness to be augmented by the backlight in intermediate lighting conditions.

2. ZBD Optical Design

The ZBD grating can be used opposite either a homeotropic or planar surface, as shown in figure 1. The grating may be reversibly latched between a high tilt (Continuous, or C) state, and a low tilt (Defect, or D) state. The pretilt that the director makes

with the surface in the Defect state is related to the grating shape [6] and values θ_D from 10° to 45° have already been demonstrated. Two basic geometries of operation are considered:

- Geometry 1 - Zenithal bistable opposite homeotropic surfaces, figure 1a). This gives Vertically Aligned Nematic (VAN) and Hybrid (HAN) bistable states. The average tilt angle for this geometry is typically 90° and 54° , for the two states, respectively.
- Geometry 2 - Zenithal bistable opposite (tilted) planar surfaces, figure 1b). This is usually arranged to induce a HAN and twisted nematic (TN) as the bistable states. The average tilt angle for this geometry is lower than geometry 1, typically 46° and 10° , for the two states, respectively.

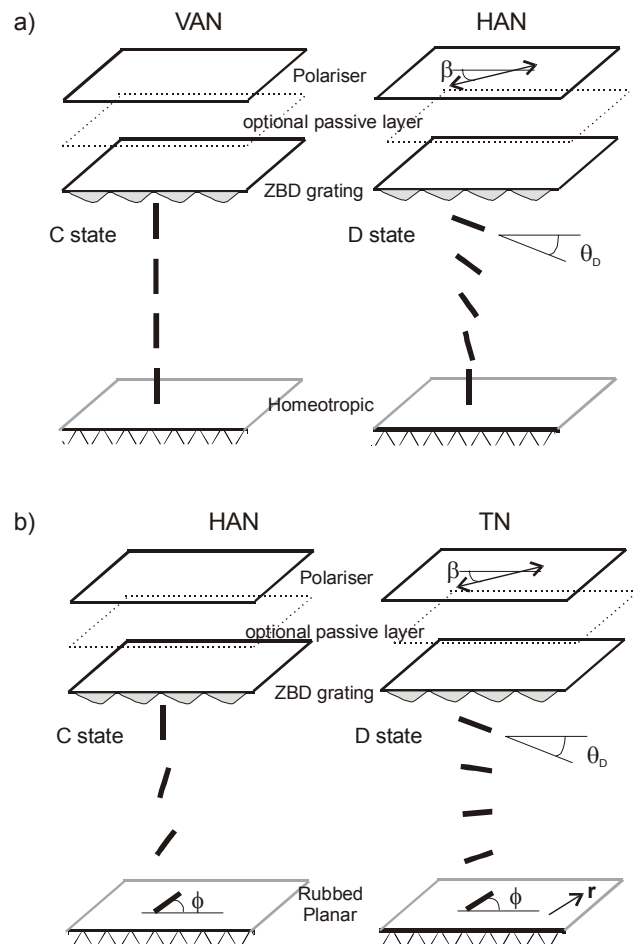


Figure 1. Two ZBD cell configurations

Both geometries incorporate a front polariser oriented at an angle β with respect to the low tilt director orientation at the front plate. In the TN geometry of figure 1b) the director at the reflective plate at the rear is at the angle ϕ with respect to the front plate director; that is, ϕ is the twist angle of the TN state. In either case, an additional passive compensation layer may also be included between the polariser and the cell to give improved optical performance. Similarly, internal passive components could be added in front of the reflector although these have not been considered.

Thus, ZBD offers several parameters that can be varied to give high reflectivity, high contrast and wide viewing angle: the birefringence (Δn), cell gap (d), polariser orientation (β) twist angle (ϕ) and Defect state pre-tilt (θ_D). (The pretilt of the rubbed planar surface may also be varied, but to a limited extent and so is kept as a constant 2° in the present work). Within this design freedom, the liquid crystal mixture should be chosen to give low voltage ZBD latching across a wide temperature range. The mixtures reported in [4] presently have a lower Δn limit of 0.12. However, respectable performance has been found from the commercial Merck mixture MLC-6812-000, which has low Δn of 0.089, which is currently the low birefringence limit for operation. This mixture can be addressed at $300\mu\text{s}$ per line for a latching field of just $6\text{V}/\mu\text{m}$.

Liquid crystal devices may be considered to operate in two basic modes, either retardation mode (wherein contrast is dominated by the difference in the optical retardation of the two states) or polarisation rotation mode (in which contrast is dominated by a difference in twist angle between the two states). Solutions for ZBD operating in both modes are reported below.

3. Retardation mode

Solving the Jones Matrix for the reflection from a polariser, retardation plate and mirror gives:

$$R = 1 - \sin^2 \delta \sin^2 2\beta \quad [1]$$

where $\delta \approx (\pi \Delta n d \cos^2 \bar{\theta}) / \lambda$ and $\bar{\theta}$ is the average tilt. For one of the bistable states to give a zero reflection and appear dark, then equation [1] has the solution $\delta = \beta = m\pi/4$; $m = 1, 3, 5, \dots$, such that the retardation plate acts as a quarter wave plate. Most previous attempts to produce a bistable single polariser reflective or transfective display have used a quarter wave plate condition in one of the states to give a dark state. The device acts as a circular polariser in the dark state that absorbs the light after the change in handedness that occurs on reflection.

The VAN - HAN mode of figure 1a) is readily operated in this configuration. The retardation of the HAN state is chosen so that $\Delta n \cdot d \cdot \cos^2(\theta_D + \pi/2) = \lambda/4$. Of course, the VAN state gives $\Delta n \cdot d = 0$, and all wavelengths at normal incidence are reflected. For $\theta_D = 18^\circ$, the cell gap required for MLC-6812-000 is $4.5\mu\text{m}$. Throughout this work, the optical response of the liquid crystal was evaluated using the scattering matrix approach [7] to solving Maxwell's equations. The rear reflector was modelled as a planar,

optically thick, silver layer and the polariser was assumed to be ideal. Unfortunately, this simple arrangement gives a rather chromatic reflectivity and the black state is leaky, as shown by the simulation result of figure 2. Improved performance is obtained by including a passive two or three layer achromatic quarter wave plate between the polariser and liquid crystal cell. The VAN state then appears dark and the HAN state acts as a half-wave plate and rotates the state of polarisation through 90° , which thereby appears reflective. Results for the viewing angle for this reverse mode geometry is shown in figure 3. Further improvement to the viewing angle of this configuration is available using a simple negative retardation plate with optic axis parallel to the cell normal (homeotropic discotic) to compensate for the off-axis reflection of the dark (VAN) state.

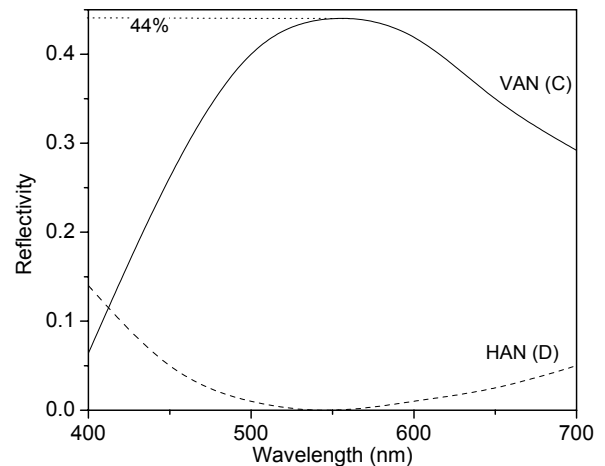


Figure 2. Simulation of a ZBD cell operating in a simple retardation mode. Improved operation needs a front $\lambda/4$ plate

When the reflector is partially silvered to give transfective operation, a circular polariser opposite to that of the front plate is used at the rear to ensure that the VAN state again appears black. In the HAN state, however, circular polarised light is incident on the front polariser, so that a quarter of the light from the lamp is transmitted. This compromise is identical to that found for existing transfective TN and STN displays. The calculated peak transmission is 23%. This arrangement ensures that the contrast is maintained on reflection and transmission, with the light state in both cases being the HAN. Although the viewing angle in transmission is poorer than in reflection due to the high average tilt angle of the HAN state, it is found to be satisfactory in practice. Again, further improvements are possible using a rear hybrid aligned discotic compensator.

4. Polarisation Rotation Mode

Unlike other bistable liquid crystal effects, ZBD allows greater degree of freedom of design for single polariser reflective modes. For example, it allows choices to be made from the wealth of different twisted nematic geometries with good single polariser optical characteristics [8]. Of course, in order to use one of the polarisation rotation modes, the TN state should be designed to

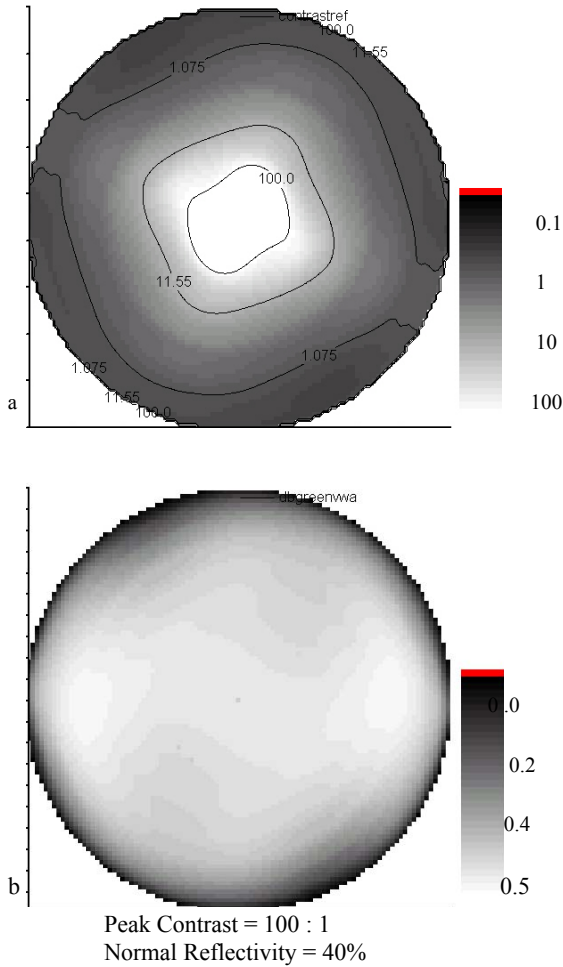


Figure 3 Full (180°) viewing angle characteristics for the VAN=HAN ZBD with front quarter wave plate operating in reflective mode: a) contrast ratio; b) reflectivity

give a good dark state. The reflectivity of a TN ZBD shown in figure 1b) is given by [9]:

$$R = \left(1 - \frac{2\alpha^2}{1+\alpha^2} \sin^2 \gamma \right)^2 + 4 \sin^2 \gamma \frac{\alpha^2}{1+\alpha^2} \left(\frac{\sin \gamma \sin 2\beta}{\sqrt{1+\alpha^2}} + \cos \gamma \cos 2\beta \right)^2 \quad [2]$$

where $\alpha \approx (\pi \Delta n d \cos^2 \bar{\theta}) / \phi \lambda$ and $\gamma = \phi \sqrt{1+\alpha^2}$. This has a simple dark state solution of $R = 0$ for $\beta = 0$ or $\pi/2$, $\gamma = \pi/2 + m\pi$; $m = 0, 1, 2, \dots$ and $\alpha = 1$. The higher order solutions for which the twist angle ϕ is greater than $\pi/2$ (and $\Delta n d$ is higher) have not been considered in the present work, due to the complication of the twist that would be induced in the HAN state by the chirality. Thus, we restrict attention to the lowest order

solution $\phi = \pi/(4\sqrt{2})$ ($=63.5^\circ$) with $\Delta n d \cos^2 \bar{\theta} = 0.354\lambda$. For ZBD, the average tilt in the TN configuration is $\bar{\theta} = (\theta_D + \theta_p) / 2$.

The light state is then the HAN geometry with a reflectivity given by equation [1]. The polariser may be parallel (or perpendicular) either to the director in the defect state of the TN, or to the director of the rubbed surface. Results for both cases are plotted in figure 4. It is clear from equation [1] that the preferred solution is with the polariser parallel to the director in the defect state, since this leads to the polariser being parallel to the director throughout the cell when in the HAN state. In this case, $R = 1$ independently of wavelength, as shown in the simulated results of figure 5. This gives superior optical performance compared to previous single polariser geometries. They suffered from the residual retardation close to the surfaces in the high field state leading to chromaticity of the white state. With ZBD, all of the twist is removed in the HAN state and there is no residual retardation.

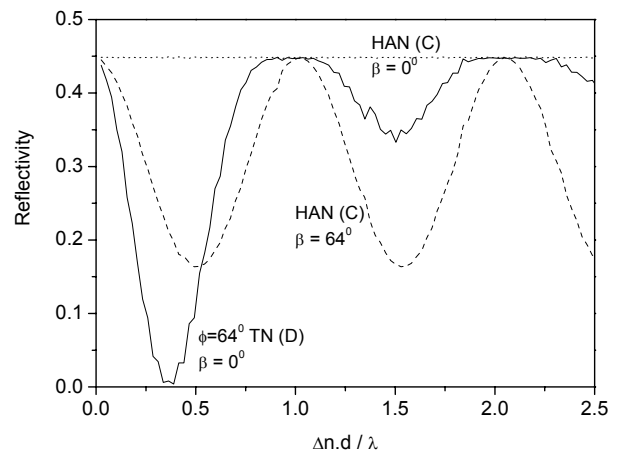


Figure 4 Solutions for single polariser HAN-TN ZBD

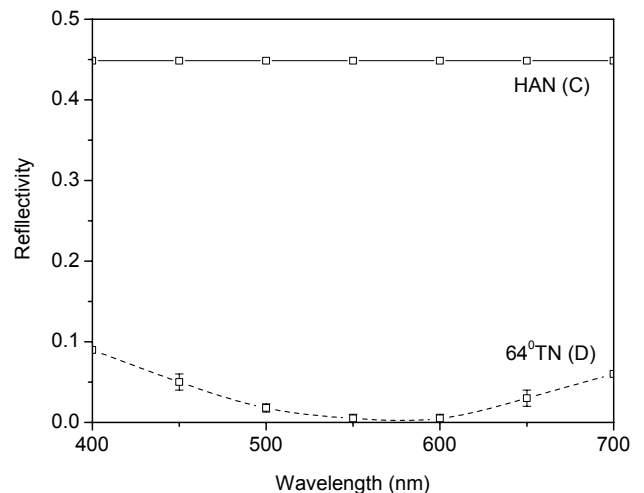


Figure 5 Simulated results for single polariser HAN-TN ZBD

Using $\theta_D = 12^\circ$ leads to a required cell gap of just $2.24\mu\text{m}$. This is considered too thin for commercial LCD manufacture. Increasing $\theta_D = 60^\circ$ gives an acceptable cell gap of $d = 3\mu\text{m}$, yet the viewing

angle remains satisfactory, due to the self-compensating effect in reflection, as shown in figure 6.

Ensuring that the 64° TN gives a good dark state in transmission requires the use of an extra retardation plate between the rear polariser and the cell. Additionally, use of a high pretilt defect state can lead to significantly poorer viewing angle unless a hybrid aligned discotic compensator is used. This leads to a reduction in the peak transmittance in this geometry.

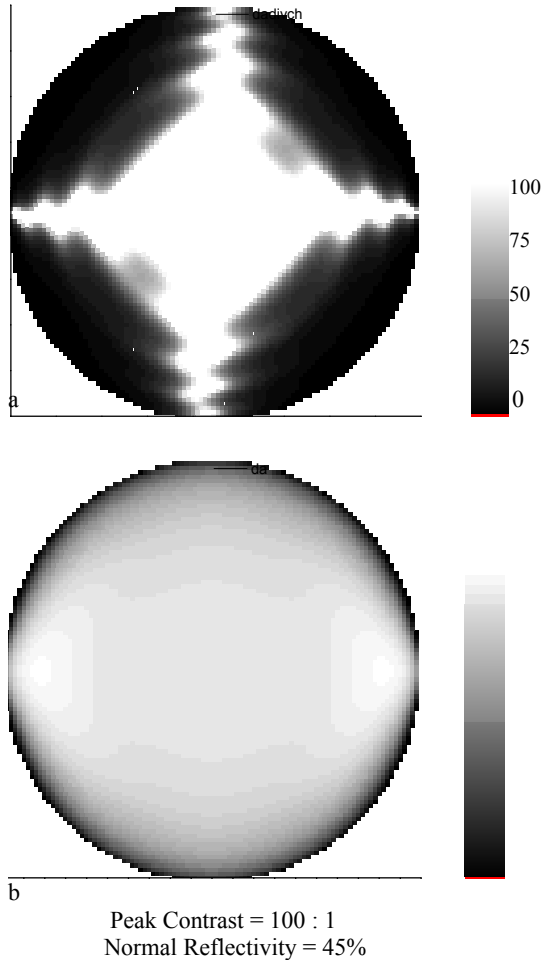


Figure 6 Full (180°) viewing angle characteristics for the HAN – 64° TN ZBD operating in reflective mode: a) contrast ratio, b) reflectivity (Pretilt in the defect state was taken as 60°)

6. Conclusion

A summary of the three geometries presented is given in table 1. This is the first time that single polariser and transmissive mode operation has been demonstrated in a ZBD device. It is highly desirable to combine high reflectivity, transmissive operation and low power in a single display for portable products. The need for bistability is especially important in transmissive geometries, since the occasional use of the backlight will drain power, which must therefore be kept to a minimum when used in reflective mode. Despite the importance of this combination, achieving

bistability and transmissivity in the same device is surprisingly rare. The performance of the ZBD configurations described in this work is superior to that achieved for existing transmissive displays, and it is proposed that the ZBD technology provides the ideal solution for future portable products. Of the configurations presented, the VAN-HAN ZBD geometry gives the best compromise for transmissive performance, whereas the HAN-64° TN ZBD gives superior performance in reflection, although compromising the transmission somewhat.

Table 1 ZBD single polariser reflective geometries. (HD is a hybrid discotic compensator)

ZBD Mode	Front Passive layer : reflect	β (°)	$\Delta n \cdot d / \lambda$	d (μm)	View Angle (CR>10)	Rear Passive layer: transmit
VAN-HAN	-	45°	0.25	4.5	58°	$\lambda/4$ plate + HD
VAN-HAN	$\lambda/4$ plate	45°	0.25	4.5	46°	$\lambda/4$ plate + HD
HAN - 64° TN	-	0°	0.354	2.2 to 3.0	>75°	$\Delta n \cdot d$ plate + HD

7. References

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