

P-51.2: Novel Geometries of the Zenithal Bistable Device

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gAbstract

Zenithal bistable LCDs use profiled surfaces to induce bistability in an otherwise standard twisted nematic display. However, the control offered by such surfaces is readily adapted to suit other display modes. For example, pretilt, surface latching field and stable state on cooling are all independently controllable. Three novel modes are proposed: a pi-cell that combines a millisecond optical response and stable bend state; a simple multi-stable device with four greys, and a bistable device with improved viewing angle when operating in transmission.

1. Introduction

The Zenithal Bistable Device [1, 2, 3] is a low cost ultra-low power display with excellent contrast, reflectivity and viewing angle. It is passive matrix addressed and fabricated using existing infra-structure for STN LCD manufacture, giving it distinct cost advantage over other emerging technologies. The structure is similar in construction to a conventional Twisted Nematic (TN) LCD, except that one of the internal surfaces has a sub-micron relief profile to impart alignment to the liquid crystal, instead of the usual rubbed polymer. The profiled surface is designed to give two or more stable states with different pre-tilts. This allows the written image to be retained after the field is removed, maintaining either a high tilt (vertical) or low tilt (planar) alignment of the liquid crystal director. As a surface effect, the stored image is maintained despite mechanical shock and it allows bistability to be achieved with a variety of optical configurations. The design chosen in current products is the simple TN geometry shown in figure 1. It uses a periodic or near periodic grating profile on one surface opposite a rubbed polymer such that the grating axis is parallel to the rubbing direction. When the grating is latched into the low tilt state, the LC forms a TN, whereas the device is a hybrid aligned nematic (HAN) when the grating is latched to the high tilt state. This geometry combines the excellent reflectivity of the HAN state, with the contrast and viewing angle allowed by the TN – HAN combination. The excellent appearance is achieved without the need for compensation layers, and the tolerance on the $5\mu\text{m}$ cell gap is lenient (typically $\pm 0.25\mu\text{m}$ rather than the $\pm 0.05\mu\text{m}$ of STN). Latching occurs for pulse magnitudes of several volts, and durations of hundreds of microseconds.

The profiled surface is manufactured easily and at low cost using simple embossing. A master structure with the appropriate design is defined using conventional photo-lithography. This structure is first copied into Nickel shims, and then into a continuous roll of plastic film supplied to the LCD manufacturer. The original master structure (or its inverse) is then replicated in photo-polymer on the internal surface of the display by UV embossing. No additional costs arise for introducing complex surface profiles,

since any increased complexity occurs in the formation of the original master grating only, and not the film.

Recently, ZBD Displays Limited has begun to commercialise the technology for retail signage applications. Manufacturing is done by Varitronix Limited and trials are underway in a number of leading retail and supermarket chains in the UK. The key advantage of the display is the ability to update all product and promotional information remotely, whilst having a battery life that lasts for years despite the need for the image to be displayed constantly.

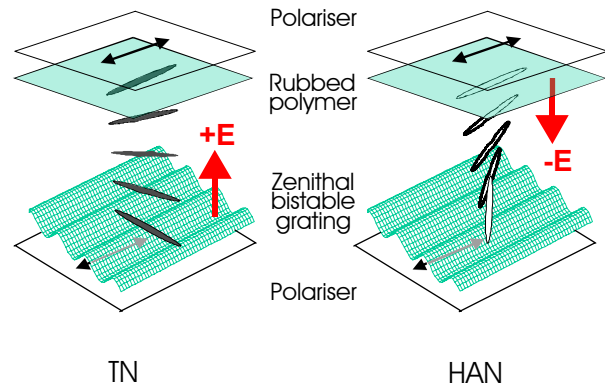


Figure 1 Schematic of the ZBD display.



Figure 2 ZBD used in a retail signage application.

2. Advantages of the bistable surface approach

The director field close to a surface feature is shown in figure 3 [1]. Either the director distorts continuously around the feature (the C state), or the elastic distortion is reduced by the formation of a $\pm\frac{1}{2}$ defect pair (the D state). The example shown has a homeotropic surface condition (the director is locally normal to the surface); this gives a C state with a pre-tilt near 90° and a D state with a substantially lower pretilt. Where the surface is locally planar, the states are reversed. In either case, the relative stability of the states is related to the surface shape and alignment: the C state is favoured by small features with little surface curvature, whereas the D state is favoured at points of high surface curvature. Both states are stable for a range of shapes between two monostable extremes. Typical feature sizes are between 300nm and 1.2 μ m.

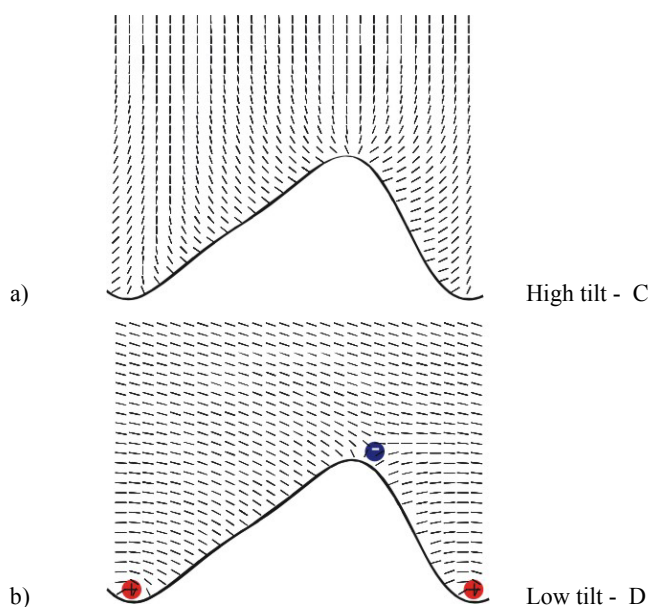


Figure 3 Bistable Pre-tilts from a ZBD surface

Bistability of this kind will occur for a single surface feature, such as isolated pillars or holes of the correct shape [4]. However, to give uniform alignment and switching voltages over a microscopic area, these features must be repeated to form a periodic or near periodic structure. The grating shape may be varied over length scales much smaller than a pixel, to give analogue greyscale [3], or multi-domain structures. Alternatively, a random distribution of features may be used to vary the latching voltage and/or optical properties, for example to give scattering states.

Latching between the states is polarity dependent: it relies on surface polarisation induced by the elastic (flexo-electric) and order parameter (ordo-electric) gradients close to the surface. When the local anchoring of the director is strong, this polarisation is high, allowing devices with 5 μ m cell gaps to be latched with pulses typically 10V and 200 μ s in duration [5]. Latching is always from C to D when a positive field is applied to

the grating, and a negative field latches D to C.

Uniquely amongst bistable LCD technologies, both the bistable states *and* the bistable latching between those states is dictated by the design of the surface, and its occurrence is independent of the director profile in the bulk of the sample, the cell gap or opposing surface. Previously, both VAN-HAN and HAN-TN displays have been demonstrated. The present work aims to show the adaptability of the ZBD surface in a variety of other device geometries.

3. Control of properties through surface design

As well as providing a low cost and reliable method of manufacture, profiled surfaces offer a simple route for manipulating LC alignment. Independent control of the pre-tilt and the latching voltages is demonstrated below, as well as the ability to select one state to form preferentially on cooling.

3.1. Pre-tilt control

For a surface that is locally homeotropic, the continuous C state has a pretilt θ very close to 90° irrespective of the surface design. The defect D state, on the other hand, gives a pretilt θ that strongly depends on the relative position of the disclinations, and therefore surface shape. An approximate relationship [6] is:

$$\theta = \pi/2 - a/L \quad (1)$$

where a is the distance between $+\frac{1}{2}$ and $-\frac{1}{2}$ defects and L is the distance between repeating defects (equal to the pitch for a periodic grating), as shown in figure 4. For the simple blazed sinusoidal gratings shown in figure 4, the D state pretilt is dictated by the blaze, ranging from 0° for the symmetric grating to approaching 90° for strongly blazed gratings. Trapezoid grating shapes give multiple defect positions, thereby allowing multi-stable pretilts to be defined [6]. Gratings with D state pretilts ranging from 0° to 55° have been produced in practice. For the

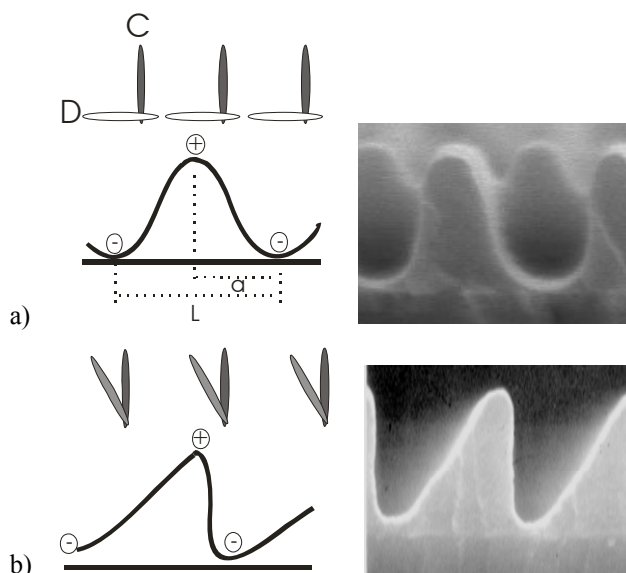


Figure 4 a) 5° and b) 45° pretilt gratings.

ZBD devices operating in the TN mode, a pretilt of about 5° is ideal.

Many factors dictate the grating shape in the photolithographic process, ranging from the photo-resist material and depth, exposure wavelength, angle and dose, and post-exposure bake. Figure 5, shows how different shapes and pretilts were obtained by varying the mark to space ratio in the grating mask.

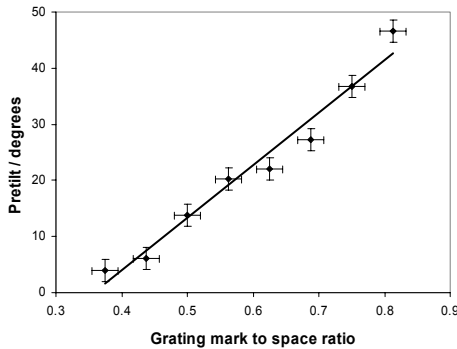


Figure 5 Example of grating pretilt versus fabrication variable.

3.2. Latching voltage control

The grating shape also dictates the latching voltages, since sharp features and/or deep structures lead to a lower energy of the D state, whereas shallow structures favour the C state.

The latching voltages also depend on the anchoring energy, and hence depend on the material used for the photo-polymer surface. For a homeotropic surface, anchoring is related to the surface energy: decreasing the surface energy (increasing contact angle) increases the latching voltage from C to D (V_{CD}) and decreases V_{DC} , as shown in figure 6.

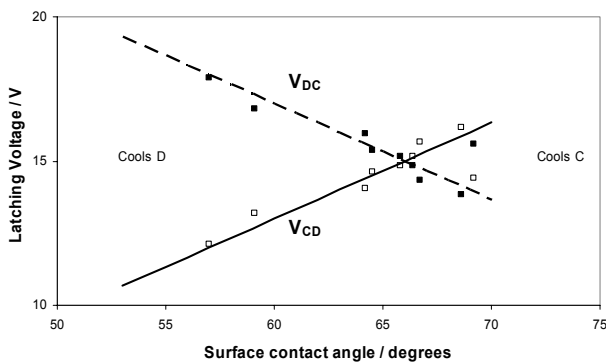


Figure 6 Typical latching voltages V_{CD} and V_{DC} versus photopolymer surface contact angle (measured for mono-bromonaphthalene, Mixture B [5] and $500\mu s$ pulses..

4. Novel ZBD Geometries

4.1 The Pi-cell

The operation of the pi-cell [7, 8] is well known. High pretilts surfaces are arranged to induce a splayed state in a positive $\Delta\epsilon$

nematic liquid crystal (S). Application of a high electric field across the cell induces a meta-stable bend state (B). Switching of the bend state is fast, often in the millisecond range, since viscous back flow acts to aid movement of the director close to the surfaces, rather than impede it. However, the bend state is meta-stable and its use is limited by growth of the splayed state from the inter-pixel gaps and around spacers.

Figure 7 shows a high tilt ZBD grating surface arranged opposite a high-tilt mono-stable surface. This arrangement enables the Bend (or Pi) configuration to be induced by latching the grating into the D state. This is particularly advantageous if the grating is designed to be C state stable. This is because the inter-pixel gaps remain in the HAN state, and therefore do not de-stabilise the B state. Also, lower pretilts than the conventional pi-cell can be used, because the bend state is mediated through a bistable latching transition at each surface.

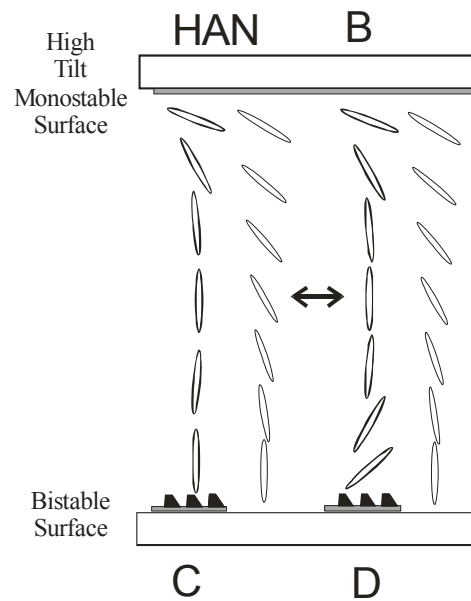


Figure 7 A Pi-cell in which the Bend (B) state is nucleated through latching of a ZBD grating.

4.2. Double ZBD

Bistable gratings may be used on both top and bottom surfaces. If the same design is used on both surfaces then only three states can be achieved, usually 2 HAN states and a VAN state. This is because the applied field has opposite polarity for the two surfaces: a latching pulse applied to one surface will tend to latch the opposite state on the other surface to form HAN alignment. Combining asymmetric ZBD surfaces, however, enables all four possible states to be achieved: HAN1, HAN2 VAN and B, as shown in figure 8.

The principal of operation for a double ZBD that uses the high and low tilt gratings of figure 4 is shown in figure 9. The gratings were designed to give lower latching voltages (at a given pulse duration) on one surface than the other for both bistable transitions. Independent latching of both surfaces is ensured by latching the higher voltage surface first [9]. With two-stage addressing sequences, a HAN state is induced by the first pulse [V1], and then a smaller pulse of opposite sign [V2] can selectively

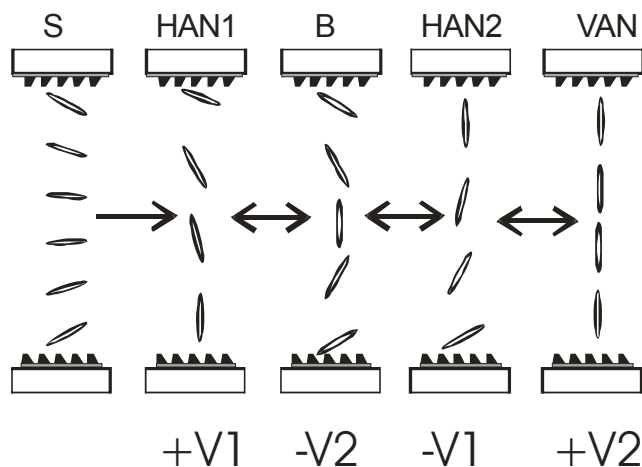


Figure 8 Double – ZBD Operation. $|V1| > |V2|$

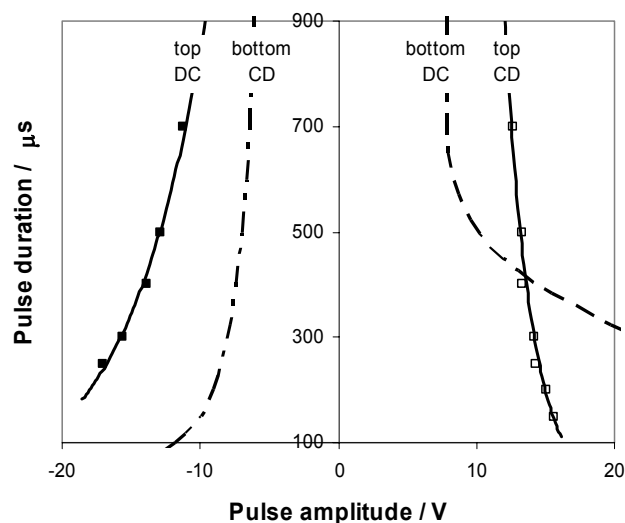


Figure 9 Latching Voltages for asymmetric Double ZBD.

latch into either the B or VAN state, depending on polarity. All states are selectively addressable using a four pulse sequence, as shown in table 1. In practice, the splay state only occurred on first cooling, so only three distinct transmission states were achieved in this device due to the similarity of the tilt in the HAN1 and B states. However, it is foreseen that device may be constructed in which four transmission states are possible. Such a device would be ideal for a simple bistable display with four greyscales and capable of animation.

4.3. Wide-viewing angle ZBD

The current design of ZBD shown in figure 2 gives good viewing angle when used in reflection. However, its viewing angle is poor for transmission or transreflective modes due to the tilt in the HAN state. Using Double ZBD, but with low tilt on both surfaces and a

90° twist between the gratings allows bistable latching between TN and VAN states. Such a display gives exceptional viewing and contrast in reflective, transmissive and transreflective modes.

Table 1 Example addressing sequences for double ZBD (pulse = 700µs).

Voltage	+15	-10	-15	+10
Top	D (5°)	D (5°)	C (90°)	C (90°)
Bottom	C (90°)	D (45°)	D (45°)	C (90°)
Bulk alignment	HAN 1	Bend (splay)	HAN 2	VAN
Average Tilt	47.5°	46.7° (12.5°)	67.5°	90°

5. Conclusion

The ZBD surface is highly controllable and allows many new LC modes to be demonstrated. The potential to design a device which combines superior optical properties in both transmissive and reflective modes, video response rate and image storage for ultra-low power has been shown. Such a combination will be ideal for portable applications.

6. Acknowledgements

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7. References

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