11.2: Zenithal Bistable Device (ZBD™) Suitable for Portable Applications

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Abstract

Zenithal Bistable display devices have been made which are compatible in size and functionality with current mobile phone or pager displays. Radical improvements in the viewing characteristics particularly in reflective mode are shown. Furthermore this paper describes: low voltage operation; fast latching times; and broad-margin matrix addressing.

1. Introduction

Bistable displays offer low power operation in infrequently updated products. Examples include personal organisers, palmtop computers and mobile communications applications. There are many examples of bistable displays which are based around both liquid crystal and non-liquid crystal technology. However, to our knowledge the grating-aligned ZBD device [1-5] is the only example giving bistability with a high degree of multiplexability and shock stability.

Whilst we have shown these desirable effects in single pixel test cells in a number of publications [1-4], the work presented here represents our first serious attempt to fabricate a display which might be used in a product. In order to be compatible with very low power, portable applications, it was necessary to fabricate a reflective mode device, hence the work described shows how this progression was made.

It was discovered during the course of the work that there exist a huge number of possible device geometries for ZBD. This allows a large amount of freedom in the optical device design, and hence the final reflective demonstrator devices show excellent contrast and viewing characteristics. Moreover, microsecond latching times, low voltage (<20V) and wide operating window are now obtained routinely.

2. ZBD Prototype Displays

In order to show the compatibility between the ZBD and a range of portable products, the display size and resolution were chosen to be approximately the same as a mobile phone or pager display. The display area is 2x2cm and it contains 83x90 pixels. The grating was made by the hard-contact photolithograpy process which together with other fabrication details have been described in a previous publication[1].

In order to address the displays described throughout this paper, a set of electronics was constructed. The electronics allow the ZBD cell to be addressed with a single update of an image, after which the power is removed to show the bistability. The electronics consists of a set of switches to route the row and data waveforms as shown in figure 1

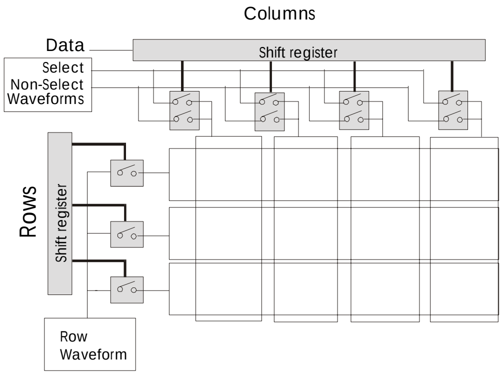

Figure 1: Block diagram of the ZBD demonstrator electronics

To write an image on to the display the data is read into the column shift register. Where a ‘1’ is output to the column switches, the select waveform is chosen. A ‘0’ produces the non-select waveform. Each row of the display is written twice in succession. The first time the row waveform switches the selected pixels to the white state, while leaving the remaining pixels unchanged. The second time the row waveform is inverted, and the previously unselected pixels are switched black, and the white pixels remain white. The addressing sequence then moves onto the next row. This form of addressing is inefficient in terms of the update speed, but it leads to a simpler and more flexible set of electronics to drive the display. A simple bipolar strobe pulse gives good operating characteristics. An example addressing sequence is shown in figure 2. This sequence is compatible with standard STN drivers.

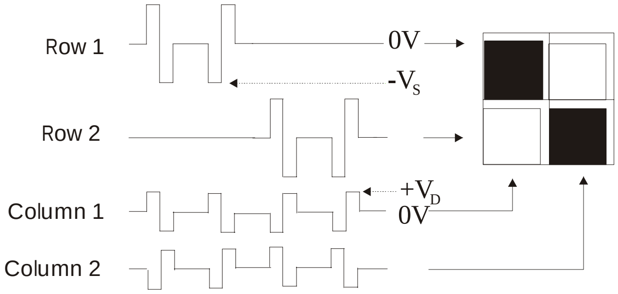

Figure 2: Example waveforms for a 2x2 pixel ZBD cell addressed using the demonstrator addressing scheme

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3. ZBD Transmissive Display

ZBD achieves bistability using a grating structure with a homeotropic anchoring condition. Typically two states exist which have different surface pretilts. In one state the director points along the normal to the grating substrate (high-tilt), whilst in the other state, a lower surface tilt is realized which is dependent on the topology of the grating (low-tilt). Most of the work reported to date has used the device geometry shown in figure 3.

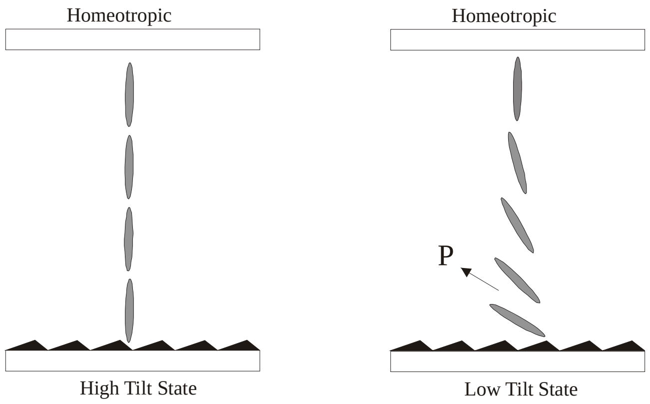

Figure 3: Original ZBD Geometry

In this configuration the grating groove direction is placed at 45 degrees to the axes of crossed polarizers. The opposite substrate is treated with a homeotropic alignment layer, hence the high-tilt state appears black and the low-tilt state appears white when the cell thickness satisfies the half wave-plate condition. Latching between the states is determined by the polarity of pulses applied to the cell, which couple by flexoelectricity and ordoelectricity to the liquid crystal material. Bipolar pulses may be used for selection and in this case the polarity of the latter half of the pulse determines the bistable configuration selected.

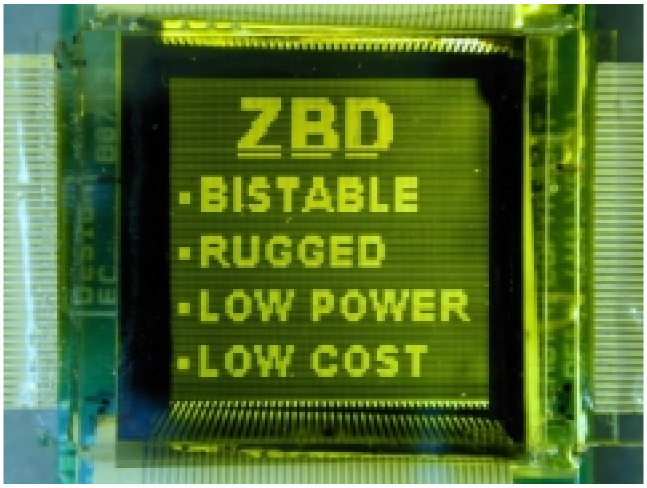

Figure 4: Transmissive ZBD display with zero power applied to the cell.

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A transmissive display was made using the configuration shown in figure 3. The cell gap was 4μm. The normal-incidence contrast ratio was 20:1, and the bright state allows the yellow backlight to pass through the display. A photograph of the transmissive display is shown in figure 4.

Using the electronics described in Section 2, it is possible to determine the minimum data (V_D) and strobe (V_S) voltages required to address the display for a given latching pulse width. The results are shown in the Table 1. The device was held at room temperature (23.5°C). The results illustrate, not only that the device may be operated over a very wide range of selection pulse widths, but also that very low voltage driving is possible. The line-address time was limited by the electronics to 8 times the slot width plus a 2ms delay. Multiplexing studies of test cells however suggest that these devices may be driven with line-address times which are simply double the selection pulse width.

Table 1: Minimum switching voltages for transmissive display

Slot Width (μs)	V_D (V)	V_S (V)
38	7.1	21.7
63	5.2	17.9
125	4.1	14.3
250	3.2	12.1
500	3.0	10.9

4. Design Freedom for ZBD Geometry

Clearly in the configuration shown in figure 3 there are two sources of flexoelectricity – the bulk and the surface. The arrow shown in figure 3 denotes the direction of the bulk flexoelectricity coefficient due to splay which exists in the hybrid low-tilt state. Indeed devices made using this geometry switch with the pulse polarity which one would expect from the sign of the bulk flexoelectricity. However if the homeotropic anchoring condition on the flat substrate in figure 3 is replaced by the planar anchoring condition, then the component of the bulk flexoelectricity which couples to the applied electric field for the low tilt state changes sign. Test cells made using a planar aligned counter-electrode switch with fields which are, to within error the same as those made using the original ZBD geometry, and the two switched states are selected using the same pulse polarity. This tells us that the contribution to switching made by bulk flexoelectricity is not very significant compared to the contribution made by the surface [6,7], so allows exploration of improved device geometries.

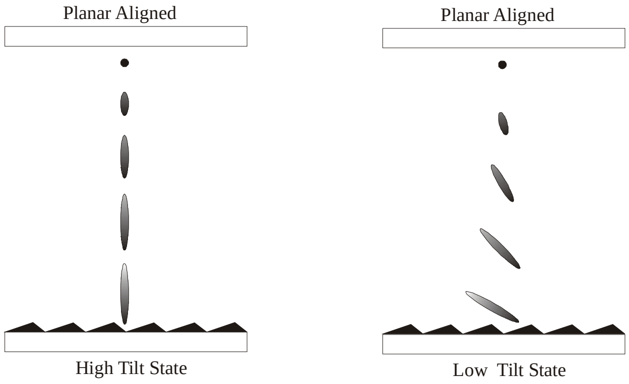

Figure 5: Twisted ZBD Configuration

The configuration shown in figure 5, with planar anchoring on the counter-electrode, places the grating along one of the crossed polarizer axes. This yields a very high normal incidence contrast ratio of 130:1 in transmissive mode without compensation. The form-birefringence of the grating was therefore a dominant factor in reducing the normal incidence contrast ratio of the transmissive demonstrator shown in figure 4. In addition, the device optics in the twisted ZBD configuration is relatively insensitive to device thickness. This device geometry is analogous to a normally white TN display but with a hybrid-aligned dark state.

5. ZBD Reflective Displays

To show the relevance of the ZBD display in portable products it was necessary to dispense with the backlight and fabricate a reflective device. Hence a reflective demonstrator display device has been constructed using the twisted ZBD configuration shown in figure 5. The display is a two-polarizer device in which the back-reflecting polarizer is RDF-C film (3M). RDF film diffusely reflects one polarisation and transmits the other. Hence if the polarizer transmission axes are crossed the twisted state is bright in transmission and dark in reflection. Conversely the hybrid state looks dark in transmission and bright in reflection. As a result, this display could be used in transflective mode. For maximum contrast in reflective mode however, the 3M film was made black, and the device thickness was optimised at 4.5μm. Rubbed Probimide 32 (Ciba Geigy) was used as the alignment layer on the counter-electrode surface.

Under these conditions a photopic contrast ratio of 43:1 was observed at normal incidence using a PhotoResearch 714 Spectrophotometer and an illumination angle of 30°. Moreover no contrast inversion was observed anywhere in the viewing cone. Note that no compensation films were used to improve the optics of any of the devices presented in this work. Figure 6 shows theoretical contrast ratio for a 60° viewing-cone for this dual-polarizer reflective geometry. The model is based on the 4x4 Matrix method [8,9] but assumes monochromatic light, perfect polarizers, and ignores the effect of the grating alignment layer and the diffuser on the optics. Hence it is an indicator rather than an absolute measure of device performance. Nevertheless the modelling confirms the observation that we obtain good viewing from this twisted dark state versus hybrid bright state device.

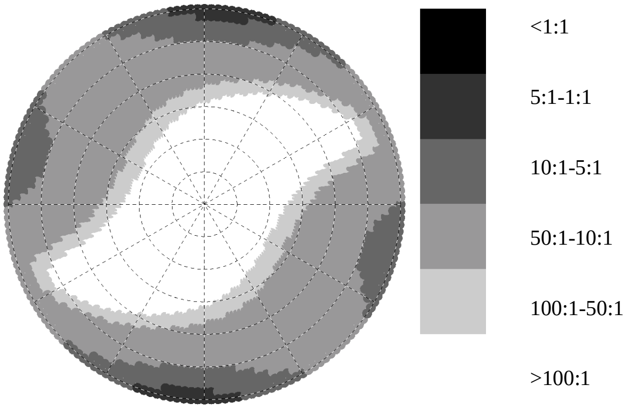

Figure 6: Theoretical viewing characteristics of dual polarizer reflective ZBD display.

The reflective display device operating characteristics at 22°C are shown in figure 7: V_S maximum and minimum represent the range of strobe voltages for which the display can be addressed, for a given data voltage from 3-8V. The open symbols in figure 7 represent the minimum V_S, whilst the equivalent closed symbol represents the maximum V_S for the same V_D.

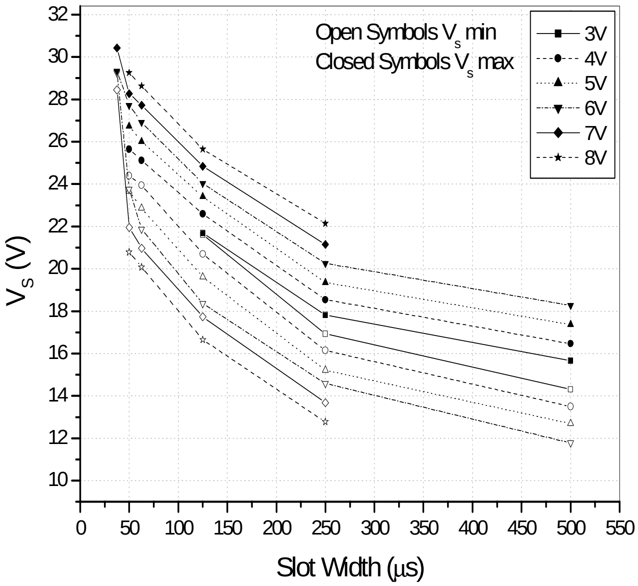

Figure 7: Maximum and minimum strobe voltages required to switch reflective ZBD display for a range of data voltages.

Figure 8: Reflective twisted unpowered ZBD display. Grating made in S1813.

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The data presented in figure 7 show once again the large range of latching pulse-widths (31-500μs) for which the whole device shown in figure 8 can be addressed. It is clear from these data that there is an operating window, which increases approximately linearly with V_D except at very short slot-widths. Note that for V_D=8V, V_S may vary by as much as 10V without perturbing the device from full switching. These results imply high tolerance to manufacturing variations such as thickness spread in the device or to operating conditions such as temperature fluctuations. Moreover, observation of test cells shows that over a small area ~1mm^2 the intrinsic partial switch width is ~0.3V. This suggests that production-line standard processing conditions leading to improved cell uniformity may lead to further reductions in the data voltage. This may prove important for products which need to show moving images.

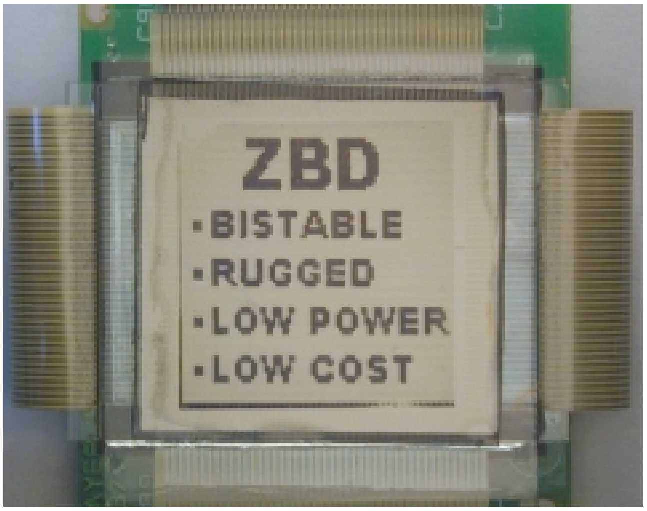

Figure 9:Reflective unpowered ZBD display. Grating made using clear resist

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Despite the excellent contrast ratio and viewing characteristics which have been observed, the reflective display shown in figure 8 has one obvious flaw: the Shipley 1813 photoresist, from which the grating is made, has a distinctive brown coloration after hard-baking. The hard-bake process is necessary to render the resist material insoluble in liquid crystal. This coloration is clearly visible when the device is switched to the bright-state. A clear resist has therefore been used to make the grating for the device shown in figure 9. Some further work is required to optimize this system, but full switching and good viewing is readily obtained.

6. Conclusions

Uniform, low voltage, high speed devices have been constructed which mimic the size and functionality of some portable products. Excellent multiplexability and good viewing characteristics have been demonstrated in the reflective ZBD display module. Prototype evaluation shows very wide operating margins for matrix addressing which will become important in enabling plastic cell fabrication for which cell gap control is a greater problem. Therefore, as a result of this work, the ZBD device has taken a significant step closer to becoming a commercial bistable display technology.

7. References

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