ZENITHAL BISTABLE DISPLAYS

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The advantages of using bistability have long been recognized as a means to display large amounts of information on passively addressed liquid crystal devices. Recently, there has been a resurgence of interest in bistable displays, one of the more promising of which is the Zenithal Bistable Device, ZBD™.

ZBD relies on grating alignment of a nematic liquid crystal to produce two stable states. This leads to a number of attractive features, including low voltage operation, excellent optical properties and image retention, even when subjected to mechanical shock. Grating alignment layers are ideal for fabrication on plastic substrates, which then allows complex images to be displayed on devices with manufacturing tolerances similar to those of the conventional twisted nematic displays used in watches.

Recently, ZBD Displays Ltd. became the Defence and Evaluation Research Agency's (DERA) first spin-out company. The company aims to capitalise on the unique properties of this technology. The presentation will review the strategy behind ZBD Displays Ltd., and include results from the latest glass and plastic demonstrators.

DISPLAY REQUIREMENTS FOR PORTABLE PRODUCTS

The growth in use of portable electronic devices has been substantial over the past decade, driven largely by the mobile telecommunications and personal digital assistant markets. Coupled with this growth has been an increasing demand for higher levels of displayed information, without a concomitant increase in display power budget. The usual choice for such applications is the Supertwist Nematic (STN) Liquid Crystal Display, due to its low cost and reasonable degree of complexity. The type of reflective mode display presently used in mobile phones has a typical power consumption of about 0.15mW (for a 1.7" diagonal 60×24 pixel STN). The power increases with higher levels of complexity and display size; for example, a 4" diagonal 320×200 STN typically consumes about 3mW. This relationship between power and complexity proves restrictive for products such as the electronic book, where battery life is limited to several hours. In the near future, yet greater complexity will be required in products that combine the functions of the mobile phone, palm-top computer and electronic book. Display power will be a major issue for such applications.

At present, much research effort is dedicated for display products that provide the attractive appearance and high degree of complexity, whilst minimising power consumption. Recently [1], highly reflective LCDs have begun to be used in portable products (eg electronic games). These combine thin film transistor (TFT) to achieve the high levels of complexity, with a carefully designed micro-relief internal reflector to provide efficient usage of the ambient light. This type of device is sufficiently reflective to allow full colour operation using conventional colour filters. However, even for a 4” diagonal display the power consumption can be as high as 50mW. For example, a typical AA sized battery may deliver 0.6Ah, which corresponds to a lifetime of less than 12 hours for driving the display only.

Other important criteria for displays in portable products are weight and durability. Of course there is an indirect weight reduction associated with the battery required for low power devices. However, the greatest improvements envisaged presently are through the use of plastic substrates. As well as reducing display weight several-fold, this will also improve device durability significantly. There are other advantages to using plastic substrates. The reflectivity and contrast of reflective LCD will also be improved because the display can be mounted closer to the surface of the product rather than lying behind a thick protective sheet. The display many be shaped, or even curved, adding to product appeal. Eventually, foldable and roll-up displays will become possible, for the variety of applications where this is ergonomically desirable.

Significant problems for manufacturing STN with plastic substrates are the tolerances associated with maintaining the correct cell gap and alignment properties over the cell area. These tolerances become particularly difficult to achieve at high display complexities. The situation is worse for TFTs on plastic substrates. Problems arise associated with the low process temperature limit, the effect of substrate swelling during the multiple photolithographic steps used to produce the transistors, and the relatively high thermal coefficient of the substrate. TFTs are likely to be a prohibitively expensive solution for portable product displays for the foreseeable future.

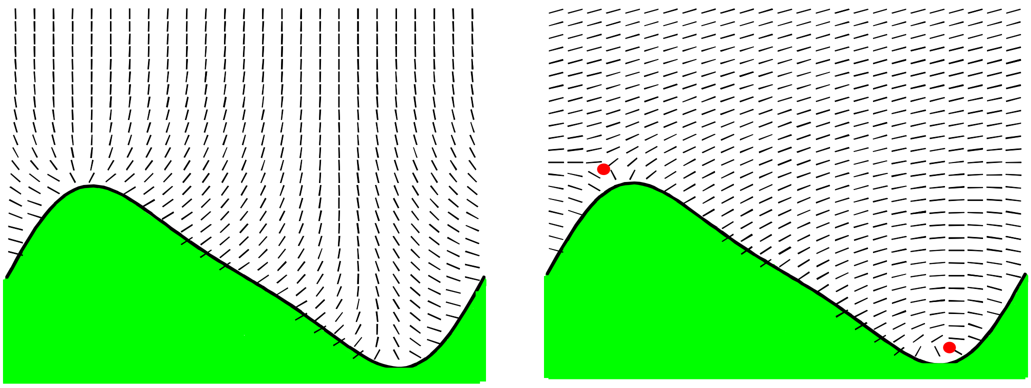
We propose an alternative approach that is ideally suited to portable products with requirements for complex information display: the Zenithal Bistable Device or ZBD™ [2]. In the present work, we hope to show that ZBD is the ideal candidate for portable products both because it stores image and so uses no power where the image does not change, and because of its suitability for manufacture using plastic substrates.

THE ZENITHAL BISTABLE DEVICE, ZBD.

ZBD is based on grating alignment layers to give two stable states of the liquid crystal molecules, rather than the single alignment direction used in conventional LCD. Bistability has two main advantages. Unlimited complexity is possible using passive, line-at-a-time addressing which is achieved without the need for costly, non-linear elements (such as the TFT) at each pixel. Also, the display effectively stores the image and only requires electrical input when the image changes. For applications that require infrequent updating, such as text, this is far more efficient than the conventional LCD where power is needed constantly.

ZBD differs from other bistable liquid crystal effects since it is based on a bistable surface alignment. This leads to a number of advantages. The image is insensitive to variations of the panel, such as those caused by mechanical shock or due to temperature and cell gap changes. It also allows bistability to be added as a property to a variety of LCD geometries. For example, different properties are possible using different mono-stable surfaces opposite the bistable surface [2 – 5]. The use of gratings allows simple manufacturing techniques to be employed, such as embossing, which are ideally suited for fabrication of devices with plastic substrates. The control that gratings offer also readily allows the switching properties to be varied within each pixel, thereby providing a simple method for achieving greyscale [3].

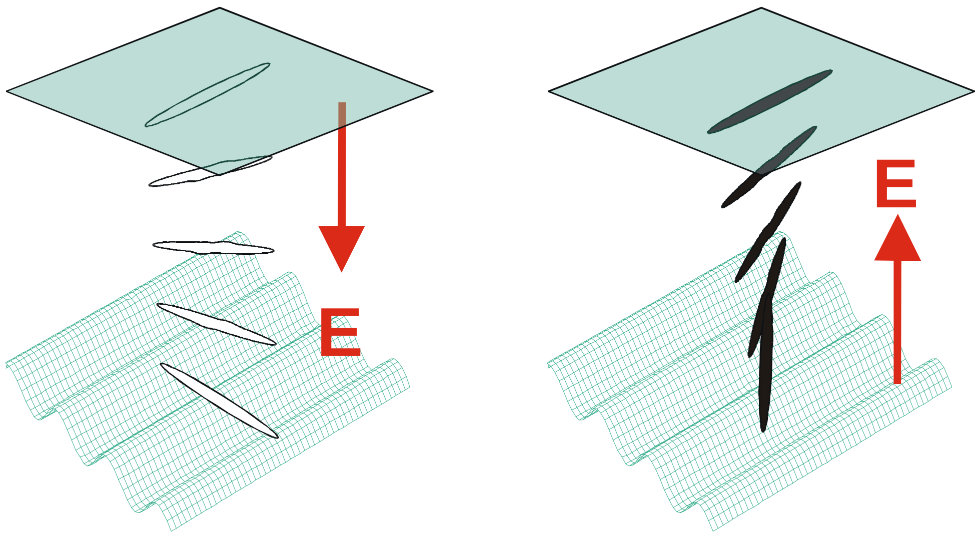
An example of a ZBD surface is a mono-grating of suitable pitch and amplitude coated with a homeotropic layer to give two stable states with differing pre-tilts, shown in figure 1. A typical grating has a pitch of about 1.0μm and amplitude of 0.8μm. Common to all liquid crystal materials is a flexoelectric polarisation caused by the elastic deformation of the liquid crystal close to the grating surface. This allows electrical pulses of opposite polarity to latch between the high and low tilt alignment states.



continuous state *defect state*

Figure 1: Theoretical director profiles close to a ZBD™ grating

Previously, the ZBD surface has been used opposite a simple homeotropic surface [2]. The bistable surface director configurations of figure 1 then lead to a vertical aligned nematic (VAN) for the high tilt continuous state and a hybrid aligned nematic (HAN) for the low tilt defect state. Such a device is very insensitive to variations of cell gap, but it requires additional optical compensation layers to achieve a wide angle of view in both vertical and horizontal viewing quadrants. Improved optical performance [6] may be achieved using the grating opposite a rubbed polymer alignment so that in the defect state the configuration is that of a twisted nematic (TN), whereas the continuous state then has hybrid alignment, figure 2. These states appear black and white, respectively, when between parallel polarisers and placed in front of a reflector. This geometry retains the attractive properties previously reported for ZBD, but ensures excellent appearance in either transmissive of reflective configurations. The reflectivity was 150% that of a typical commerical STN panel, and the contrast ratio measured at 40 :1.



Twisted Nematic (Black) *Hybrid Aligned (White)*

Figure 2: *New ZBD™ Configuration.*

Figure 3 is a photograph of a reflective demonstrator of the type that might be suited for application in a mobile phone. The performance characteristics of the demonstrator are listed in Table 1. The material used was a typical commercial STN mixture, requiring a cell gap of 4.5µm. The panel was addressed using simple bi-polar strobe and data waveforms, in which the pixel image is dependent on the magnitude and polarity of the trailing pulse. Typical voltages required were 24V strobe (V_S) and 4V data (V_d), although significantly lower voltages have been achieved in test cells. This leads to an energy requirement for a single image update of less than 4µJ. If the image requires constant updating the power consumption is about five times greater than that of an STN panel (due to the higher capacitance and addressing waveform frequency). However, substantial power savings are possible where the image is updated infrequently, with images written 2 years ago still remaining unchanged on test cells in our laboratory.

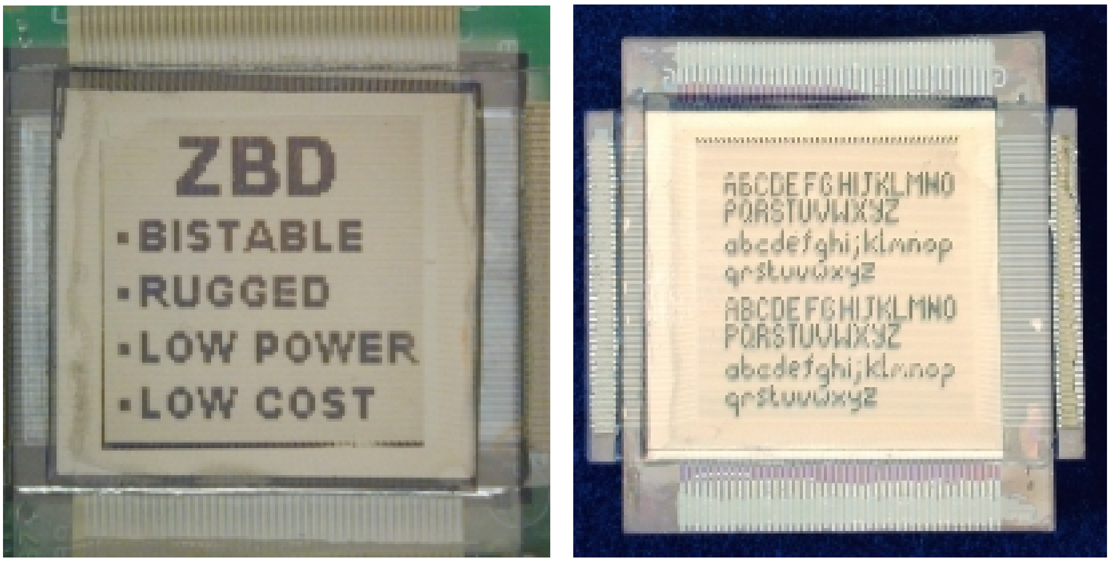


Figure 3: Photographs of an un-powered 2” diagonal 90 × 83 reflective ZBD.

Size	2cm × 2cm
Complexity	90 × 83
Addressing	$24V_S \pm 4V_D$
Contrast	Pixel: 40 : 1 Panel: 15 : 1
Reflectivity	150% that of commercial STN
Line Address Time	100μs
Frame time	40ms
Update energy	4 μJ
AA battery life at 1Hz update (including driver power)	≈ 1000 hour
Image storage	➢ 2 years

Table 1: Performance of ZBD™ Demonstrator.

PLASTIC DISPLAY

The manufacturing tolerance of such a device is more akin to that of the simple twisted nematic LCD used in watches than it is to STN. Bistable latching has been shown to vary linearly with cell gap, and with a wide range of grating shapes and temperatures. Where such variations occur, the two states may be addressed across the whole cell simply by applying sufficient voltage (usually about 4V) to discriminate between the states in the thickest regions. Thus, the most important tolerance for ZBD in this configuration is that required for the optical characteristics, which are the same as for the conventional TN. This tolerance to cell gap variations is an important requirement for plastic LCDs.

Recently, ZBD cells have been made using plastic (PES) substrates. PES was chosen since it combines low optical retardation (<10nm) with a high maximum working temperature (200°C). In addition, the PES substrate includes an SiO_2 layer which prevents the oxygen or moisture from entering the cell. Figure 4 shows a photo of a typical test cell. The overall thickness is 800μm although much of this is the thickness of the polarisers. Flexing of the cell does not disturb the switched state except for brief optical transients that are due to flow in the bulk of the LC. Furthermore the cell is not affected by moderate point pressure.

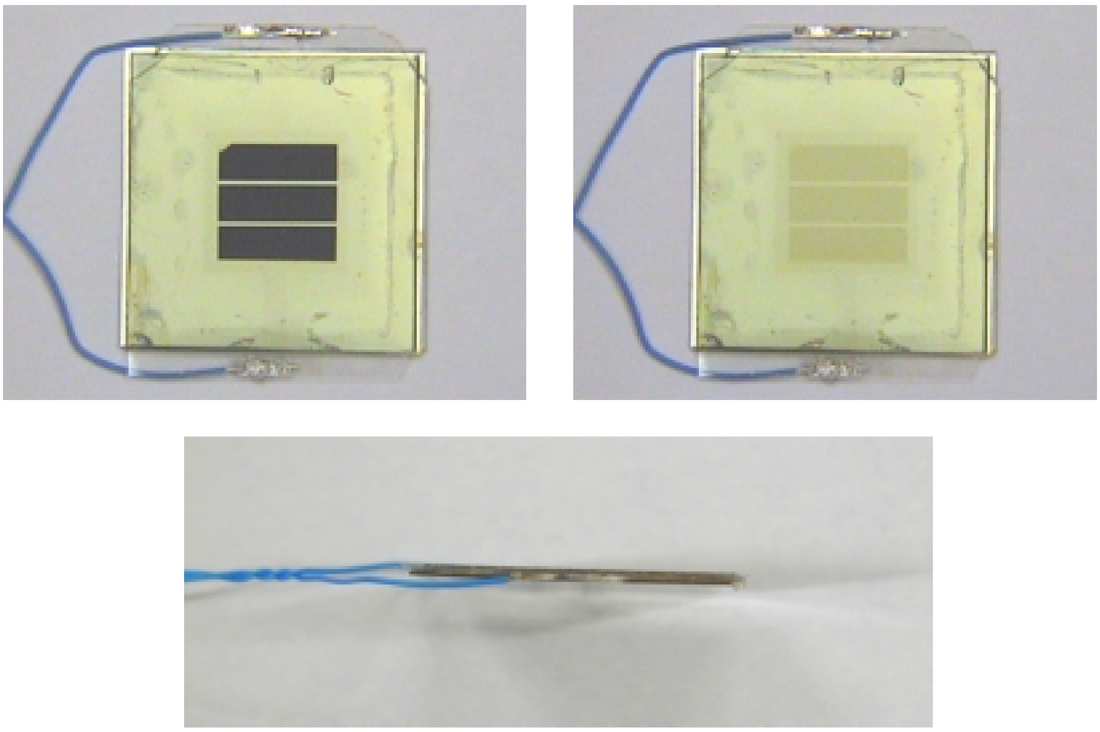


Figure 4. Photographs of a 1cm^2 plastic ZBD test cell.

POTENTIAL MARKETS

There is a proliferation of products where the ability to display complex images, without the continuous drain on power, in which the image remains even after severe shock. Hand-held, battery powered products often fall into this category, from test and field equipment, through Global Satellite Positioning (GPS) and Personal Digital Assistant (PDA) to the mobile phone. Increasing display complexity in these portable products will necessitate dramatic improvements to power consumption without compromising image quality. Not only is this possible with ZBD, but the technology is readily adaptable to manufacture with plastic substrates at relatively low cost. A range of new products then becomes practical. For example, electronic labels and smart cards require displays that receive power only when transactions are made, but for which the image cannot be disrupted through either fraud or neglect.

Other existing products are at present being held back by the display. A good example is the electronic book where complex displays of greater than 6" diagonal are essential. Existing products are weighty, due to the glass LCD, protective casing and large batteries. The display has poor resolution (about 100 dpi) because of the limit of STN multiplexibility and the battery life, dominated by the display, is limited to between 5 and 10 hours of continuous use. As well as the enormous weight reduction and the increased display resolution that are possible using ZBD, a battery life well in excess of 1000 hours is estimated for typical usage.

ZBD Displays Ltd. is the first spin-out from the UK's Defence Evaluation and Research Agency (DERA) to be venture capital funded. We aim to commercialise this exciting new technology and to begin to meet this market need.

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