

### 5.3: Grating Aligned Bistable Nematic Device

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#### ABSTRACT

A grating surface treated with a homeotropic surfactant is found to support two stable pretilt configurations when the groove depth to pitch ratio is optimum. This allows the realisation of a new flexoelectrically selected bistable nematic display operating with sub millisecond switching pulses of less than 25V.

The grating can induce bistability in either the azimuthal plane [4] or the zenithal plane [5]. In this paper the zenithal bistable device (ZBD) is considered.

#### THEORY OF OPERATION

Figure 1 presents results from a finite element model which shows the two stable alignment configurations which can exist on a surface containing a single modulation in which the groove direction is into the page. A perpendicular (homeotropic) boundary condition is assumed at all points on the surface. It can be clearly seen that the configurations lead to a bulk tilt angle which has either a high or low value. Therefore this surface can be used in a zenithal bistable device. The grating surface can be asymmetric as shown or simply a symmetric structure. The latter requires a larger depth to pitch ratio in order to achieve bistability but can offer the maximum possible tilt change ( $90^\circ$  to  $0^\circ$ ). Figure 2 shows the relative distortion energies of the high and low pretilt states as a function of groove depth to groove pitch ratio (asymmetry as figure 1). At a value of 0.65 both states have the same energy and so the surface is expected to have two stable states. Furthermore an energy gap exists between the two states as the low tilt state contains a pair of singularities (defect lines) which are formed or annihilated through a first order transition.

#### INTRODUCTION

Bistable nematic switching offers the realisation of displays which do not suffer the limits in complexity of conventional rms addressing and yet do not require the use of an active matrix. Furthermore the use of a nematic phase rather than a ferroelectric removes shock stability problems, increases the operating temperature range and also allows faster device optimisation due to the ease of modelling nematic systems.

For a nematic device, the bistability can either be due to a bulk effect as in the case of bistable cholesterics [1, 2] or can arise from a bistable surface alignment [3, 4]. In our studies we have concentrated on bistable alignment derived from a grating surface which has the following advantages. Firstly grating surfaces are easy to fabricate for research purposes and are cheap to mass produce over a large area using standard embossing techniques. As the grating is typically made from an amorphous polymer, the alignment is dominated by the surface profile which can be easily measured using scanning electron microscopy or atomic force microscopy (AFM). Finally the distortion of a nematic on a grating surface can be readily modelled using finite element approaches.

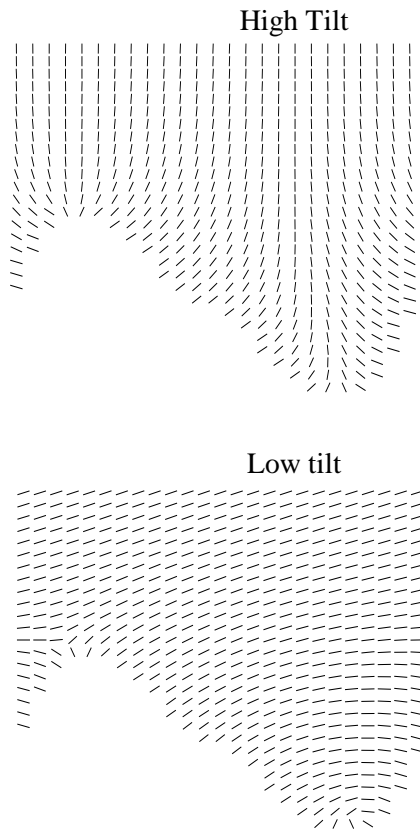


Figure 1. Two stable nematic configurations on a grating surface.

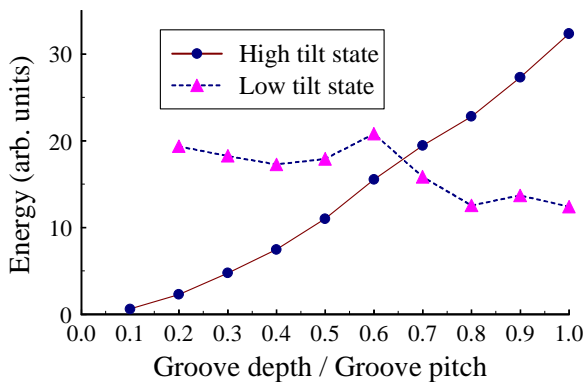


Figure 2. Distortion energies of the high and low pretilt states as a function of groove depth/groove pitch..

To realise a working ZBD, we need to include a method for selecting which state the system switches into. Figure 3 shows how the bistable grating surface can be constructed opposite a flat homeotropic surface to form a fully homeotropic state (a) or a splayed state (b). The

latter possesses a flexoelectric polarisation (P) which will couple to any dc component of an applied waveform. Thus the sign of pulse which favours P will lead to state (b) while that which is opposed to P will induce state (a). The b to a transition is also aided by the positive dielectric anisotropy of the nematic. The extra splay/bend energy which exists in state (b) must be taken into account when designing the grating to ensure that both configurations have equal energy. Optical contrast is obtained by placing the groove direction at 45° to crossed polarisers. Additionally the viewing characteristics of this hybrid structure can be improved by addition of a suitable compensation film [6].

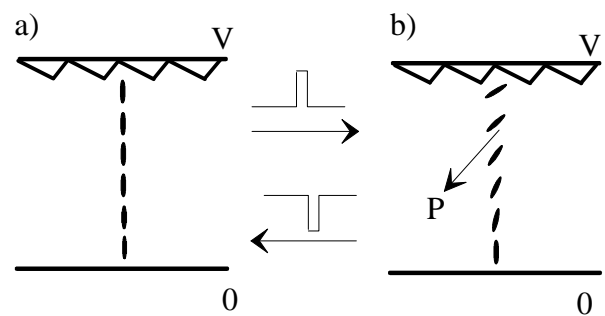


Figure 3. Configuration of zenithal bistable device.

### EXPERIMENTAL

Gratings used in this study were fabricated in photoresist (Shipley 1805) using off axis hard contact photolithography as shown in figure 4.

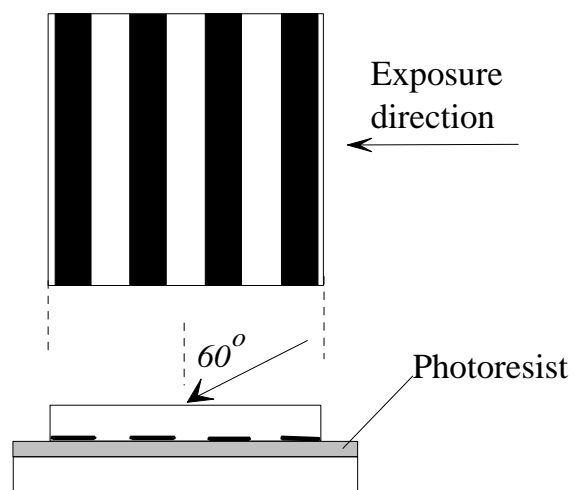


Figure 4. Top and side view of exposure geometry

The typical exposure time for a  $0.55\mu\text{m}$  resist layer was 450s at  $1.2\text{ mW}/\text{cm}^2$ . This was followed by 10s development in Shipley MF319 and a rinse in water. Finally the photoresist was exposed to deep UV (254nm) and baked to  $180^\circ\text{C}$  to ensure insolubility in the presence of the liquid crystal. ZBD cells were constructed with one grating surface and one flat photoresist surface both treated with a chrome complex surfactant to induce homeotropic boundary conditions.

Figure 5 and 6 show the profiles of typical bistable surface. The former profile is obtained using an exposure at  $60^\circ$  to the normal. This surface induced a bulk pretilt of  $50^\circ$  in the low tilt state. Figure 6 shows another bistable surface formed from a normal incidence exposure in thicker resist. In this case the pretilt of the low tilt state is  $0^\circ$ .

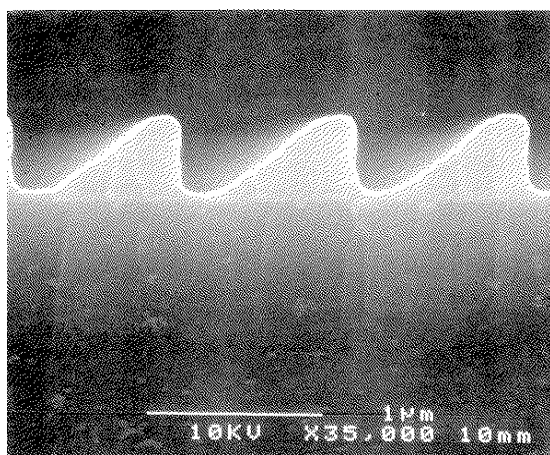


Figure 5. Profile of a typical bistable grating surface resulting from exposure at  $60^\circ$ .

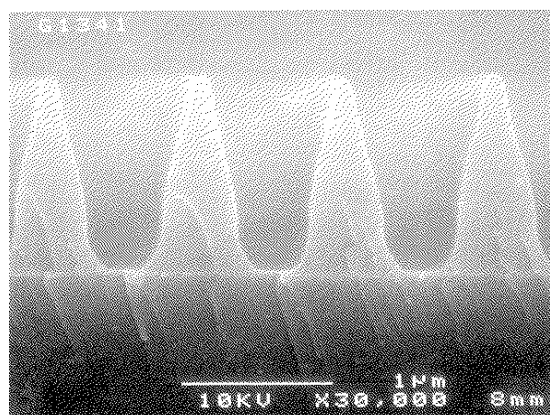


Figure 6. Profile of a typical bistable grating surface resulting from exposure at normal incidence.

## RESULTS

Figure 7 shows the applied voltage pulses and the optical response from a ZBD made using the surface shown in figure 6 and filled with E7 (Merck). The cell gap was set to  $2.3\mu\text{m}$  which corresponds to the half waveplate condition for E7 ( $\Delta n = 0.225$ ).

For pulses above the switching threshold it can be seen that only the first pulse in each pair changes the state. The second pulse leads to a transient optical effect but does not latch into the opposite state. This proves that the switching is dependent on the sign of the applied pulse. The optical response times were typically  $\tau_{\text{on}} = 20\text{ms}$  and  $\tau_{\text{off}} = 1\text{ms}$ .

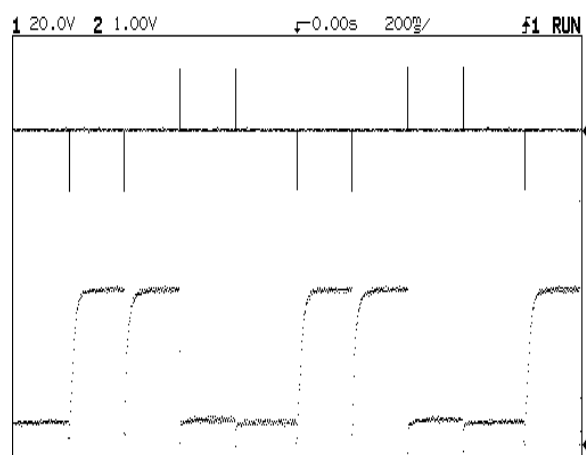


Figure 7. Optical response (lower trace) of a ZBD to pulse pairs.

The threshold voltage for full switching was found to depend on pulse length as shown in figure 8. When slightly lower voltages are applied, only partial switching is obtained in small micron scale domains. This provides a realistic opportunity for greyscale operation due to the excellent consistency of the grating surface and the resulting consistency of domain formation across test samples ( $1\text{cm}^2$ ). Figure 9 shows an image written onto a  $16 \times 16$  demonstrator cell. The device operates at 35V and has a sub millisecond line address time. Once written the image is stable for many months and is immune to mechanical compression except when the cell walls are forced to touch each other.

ZBD devices have also been made with gratings on both surfaces. These have been switched between uniform low and high pretilt states using a two-frequency nematic (TX2A, Merck). However the dielectric loss in such materials make two-frequency selection undesirable for the realisation of high level multiplexed displays.

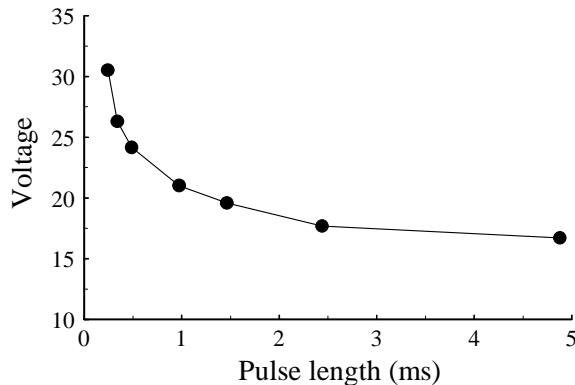


Figure 8. Switching threshold voltage versus monopolar pulse length.



Figure 9. 16x16 ZBD demonstrator (1cmx1cm).

## CONCLUSIONS

This work has shown both theoretically and experimentally that a grating surface of optimum profile can support two stable pretilt states. Switching and final state selection has been achieved by coupling to the flexoelectricity present in one of the states when the grating is opposite a flat surface. The flexoelectric

coefficients of nematic materials have not been optimised for existing commercial displays and so significant improvements to the ZBD are expected through the use of new novel materials. Further improvements are also likely through the optimisation of the grating profile and the surface anchoring energy.

The ZBD is probably the first nematic device to achieve surface bistability from a reliable surface treatment. Indeed the use of gratings ensures easy scaling of such devices to large areas as well as excellent compatibility with plastic substrates. Thus the technology is well positioned to offer displays are low power, rugged, lightweight and high resolution for a wide range of portable information systems.

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