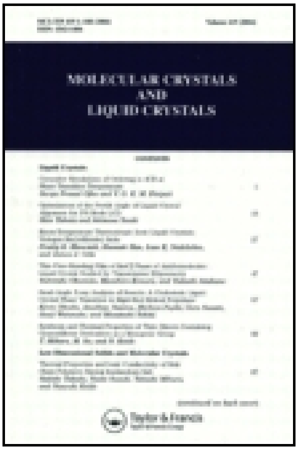

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BISTABLE ALIGNMENT OF NEMATIC LIQUID CRYSTALS AROUND MICROSCOPIC POSTS

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With conventional nematic liquid crystal displays there is only one orientation of the material that is stable without an applied field. In order to maintain an image the pixels have to be continually refreshed, placing an upper limit on the pixel count. Overcoming this requires having some memory within each pixel. To avoid putting an expensive transistor within every pixel one can design the display to be inherently bistable. Here we describe how micron-scale posts on a substrate can stabilize multiple orientations. By engineering the posts we have demonstrated a bistable display with long term memory.

Keywords: bistability; liquid crystal; microstructure; nematic

INTRODUCTION

Bistability is a key technology that allows one to begin to achieve electronic displays that have the look and feel of the printed page. Bistability allows one to have a very high resolution display with a large number of pixels while still being able to use simple passive addressing, rather than the more complex and expensive active addressing schemes. For many applications bistability can also offer low power operation.

An appealing approach to bistability is to use a microstructured surface to align a nematic LC. Microstructured surfaces are attractive because there is considerable scope for being able to engineer the surface to give the required LC alignment, and they can potentially be replicated by a variety of known techniques, offering the prospect of a low cost manufacturing route.

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NUMERICAL MODELLING

It is well known that a simple grooved surface can align LCs [1–3]. The grooves are made on the surface of a material that inherently gives planer alignment of the LC, although without a well defined in-plane direction. Texturing the surface with microscopic grooves then tends to force the molecules to align along the grooves as this minimises the elastic distortion of the director. The strength of this alignment can be tuned by modifying the shape of the grooves [4], but there is only one stable alignment direction at the surface.

An obvious extension is to have grooves in two orthogonal directions. If the grooves are rectangular in section this gives an array of square posts. Figure 1 shows an SEM image of such a surface. The posts are made from photoresist using standard photolithographic techniques and have a square cross-section.

The effect of such posts on the in-plane alignment of the LC was described by Thurston *et al.* in 1980 [5]. The director tends to align along the diagonal of the posts, from one corner to the opposite one, Figure 2. The director field must split and rejoin, creating two defects, in order to ‘flow’ round the post. The energy is minimised when these defects sit at opposite corners, where the director divergence is only 90 degrees, rather than 180.

There are of course two such diagonals for a square post, and in principle these can be used as the basis of a bistable display, with two orthogonal in-plane alignment directions. In practice controlled switching between

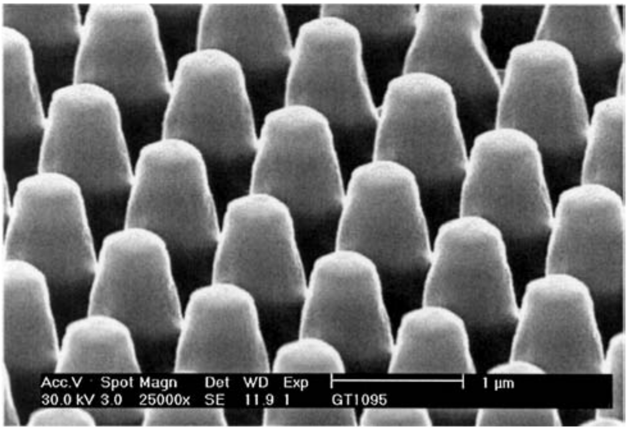

FIGURE 1 SEM image of an array of photoresist posts on a glass substrate.

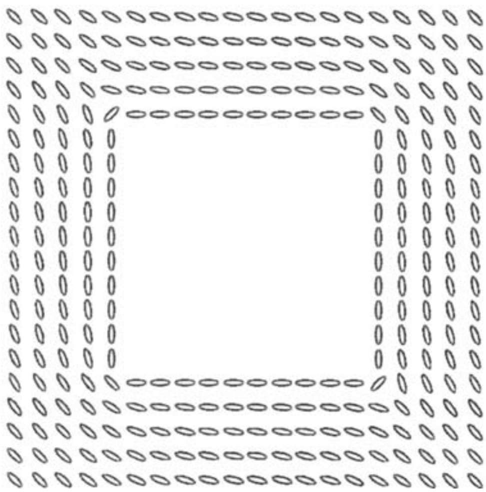

FIGURE 2 Modelled alignment of LC around a post, in a plane parallel to the device substrate. This is one unit cell of a periodic structure, with cyclic boundary conditions. The direction of the long axis of the ellipsoid is the local director alignment.

these two states is difficult – in a standard cell configuration the applied field is orthogonal to both states and there is nothing to enable preferential selection between them. The degeneracy between the two in-plane alignment directions can be lifted by reducing the symmetry of the square posts – for instance by tilting the posts. A few degrees of tilt in the direction of one of the diagonals is enough to favour that orientation.

Thurston *et al.* had a 2D model and so were only able to model the in-plane alignment of the LC. Recently we have been able to use a 3D model [based on the work described in Ref. 6] and have looked at the tilt profile of the LC around the posts, both in modelling and in experiments [7], and have found that it is possible to have two different tilt profiles for the same in-plane alignment direction. Figure 3 shows the two different tilt profiles. The models show the results for a 3 micron thick cell, with a regular array of square posts that are 0.7 microns across and 1.0 micron tall. The cell gap is 3 microns, and the counter-surface is flat and treated to give homeotropic alignment. For clarity just the alignment of the LC at the surface of the posts in half of the unit cell is shown.

In the absence of the posts the tilt would vary linearly (one elastic constant approximation) from the planar side to the homeotropic surface. With the posts there are two different tilt profiles – one has a suppressed tilt profile around the posts (Fig. 3a) giving a planer state and one has an enhanced tilt profile (Fig. 3b) giving a very tilted state.

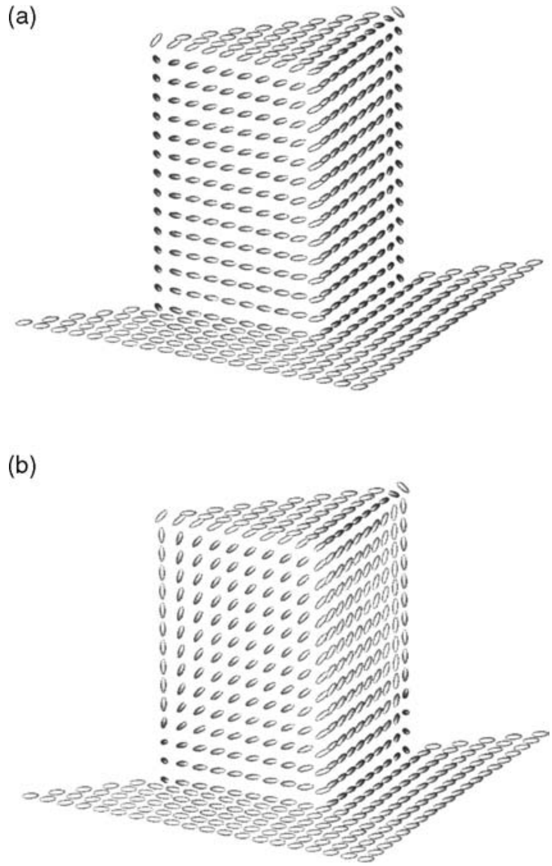

FIGURE 3 Model results for the LC alignment around a post. For clarity only the molecules adjacent to the post surface are shown, and only half the unit cell is illustrated, sliced by a vertical plane which is parallel to the diagonal in which the post is tilted. Figure 3a shows the more planer (*P*) state and Figure 3b shows the more tilted (*T*) state.

The two states seem to arise as a consequence of a balance between the defect energies at the post edges and the influence of the flat surfaces at both the top and between the bottom of the posts. Both the flat horizontal surfaces tend to force the LC into a planar state, and for a very short post this effect dominates and one finds just one state with low tilt around the posts. This does however result in line defects along the leading and trailing edges of the posts – these are the extensions into 3D of the defects seen in Figure 2. The energy of these defects obviously increases as the post height is increased and for tall posts it is this effect that dominates. The consequence of this is that the LC tilts very strongly and becomes almost homeotropic around the posts. By tilting, the LC undergoes a less severe change in direction at the edges, reducing the defect energy. This is however at the expense of increased distortion at the top and bottom of the posts.

For an intermediate post height these two effects balance out and there are two stable states with similar energies. One state is substantially planar (P-state) and one is strongly tilted (T-state), but both have the same in-plane alignment, along the diagonal in which the post is titled. When viewed between crossed (or parallel) polarisers, with the in-plane alignment direction at 45 degrees to the polarisers, the two states exhibit different birefringence, and one appears darker than the other.

A particular feature of these devices is that in both states there are defects. The nature of the defects clearly plays a role in stabilisation of the two states, and presumably also influences the switching dynamics.

EXPERIMENTAL RESULTS

We have fabricated devices that use such microscopic posts to align a nematic LC and observed that there are indeed two states that exhibit long term zero-power stability, and that are optically distinct [7]. These post aligned bistable nematic (PABN) devices do have two states which do indeed have the same in-plane alignment direction but have different tilt profiles – the T state is generally the lower in energy. It is possible to switch between the two states by applying simple square voltage pulses, provided that the LC material has negative dielectric anisotropy. With the commercially available materials that we have so far tried the switching only occurs with reasonable voltages at elevated temperatures. Figure 4 shows switching characteristics for a device measured at 80°C – this device was filled with ZLI-4788-000 (Merck). The two graphs show the pulses that will switch the device for the two switching directions. The switching is basically sign dependent, although there is an isolated switching region of the opposite sign for short pulse lengths. There is also some asymmetry – a lower voltage is needed to switch from T to P than in the opposite direction. Flexoelectricity is a plausible candidate for the origin of the sign dependent switching as both states have some distortion of the director. With modified LC mixtures we can now achieve similar performance to that shown in Figure 4 at room temperature.

An attractive feature of using microstructures to align the LC is the scope for optimising the device performance through engineering the microstructure. The PABN device is very flexible in this respect as many aspects of the size, shape and arrangement of the posts can be modified – for example the post height, width, cross-section shape, tilt angle and tilt

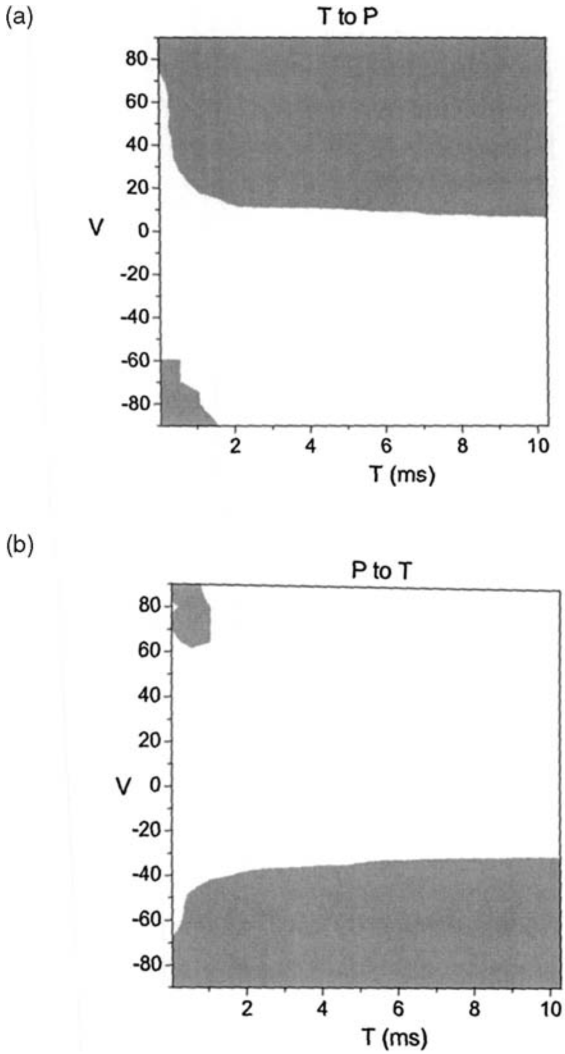

FIGURE 4 Switching results for a PABN device filled with ZLI-4788-000. Data recorded at 80°C. Monopolar square pulses are applied to the device – the y-axis is the pulse amplitude in volts, and the x-axis is the pulses duration in ms. Pulses that result in switching to the opposite stable state are shown as the grey shaded regions. The unshaded region represents pulses that leave the device in the starting state. Figure 4a shows pulses that will switch the device from the *T* to the *P* state (Fig. 4a). The opposite switching direction is shown in Figure 4b. The voltages are measured w.r.t. the posts.

direction can all be varied using standard photolithographic techniques. We have explored many of these parameters by fabricating devices and measuring the properties – as an example Figure 5 shows how just one of these parameters, the post height, affects the transmission in the two states, measured with the devices between crossed polarisers. For these particular devices the difference in the transmission for the two states increases almost linearly with post height, the other post dimensions have less of an effect. This may not necessarily always be true – there is quite a complex interrelationship between the different parameters.

Another potential advantage of microstructure alignment is the ability to replicate the microstructure onto the substrate surface rather than having to use photolithography each time. Figure 6 is a photograph of prototype PABN device made using flexible plastic substrates. An array of posts similar to that in Figure 1 has been replicated onto the inside surface of one of the substrates. The device performance is very similar to that of the devices made on glass with photoresist posts. The image shown is stable, and there is no power connected to the device.

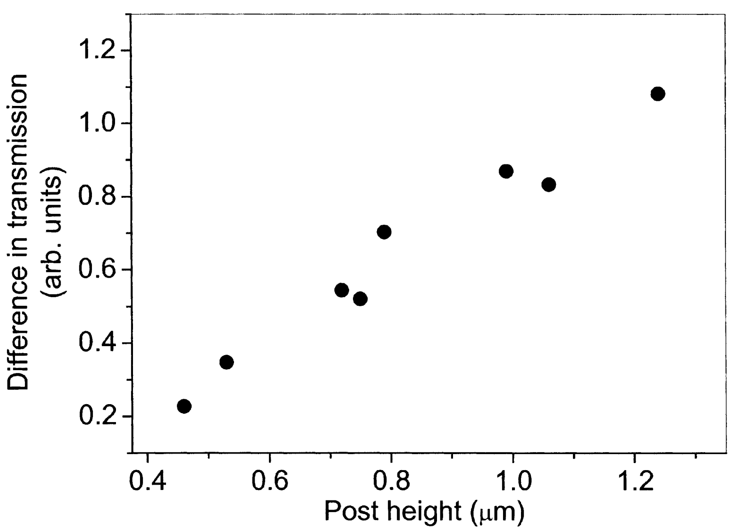

FIGURE 5 Experimental measurements of the difference in the transmission of the two states in a series of PABN devices with different post heights. The transmission in each state was measured between crossed polarisers, with the in-plane alignment direction of 45 degrees to the polarisers. The post heights were measured using an SEM.

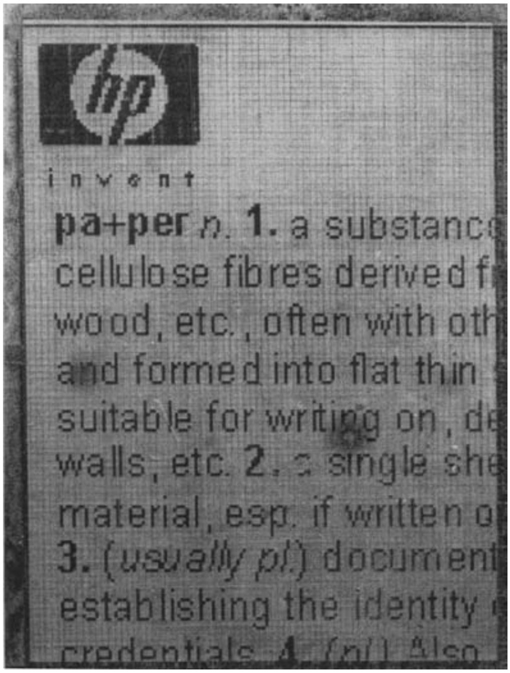

FIGURE 6 A prototype 2 inch diagonal PABN device made on flexible plastic substrates. The posts have been replicated onto the inside surface of one of the substrates. The device is operating in a reflective mode, with parallel polarisers.

DISCUSSION

We have shown that microscopic posts can be used to give bistable alignment of nematic LCs, with simple switching, reasonable optics and scope for optimising the device performance through engineering the microstructure. Devices can also be made by replicating the posts onto plastic substrates. In the PABN device that we have discussed above the flat counter surface is treated to give homeotropic alignment, and the posts are tilted by a few degrees along one diagonal to reduce the symmetry. Both these restrictions can be lifted and it is possible to actually have up to eight possible states [7], though not all are necessarily optically distinct. These different states arise because of the two possible in-plane alignment directions (the diagonals across the base of the post), two different tilt profiles and, with a homeotropic counter surface, the possibility of either a positive or negative tilt away from the base of the posts. It may not, however, be possible to select all of these states by applying simple pulses. With a negative dielectric LC material it is possible to select between two different tilt profiles, as we have described in this paper. With a positive dielectric material, however, then we do not see such simple switching. Instead the LC tends to switch between different in-plane alignment directions, although as noted above, in that case it is very difficult to get uniform, well controlled selection of the switched state. There is clearly much scope for investigating the switching dynamics in these devices.

REFERENCES

[1] Berreman, D.(1973). Alignment of liquid crystals by grooved surfaces. *Mol. Cryst. Liq. Cryst.*, *23*, 215–223.
[2] Cheng, J. & Boyd, G. D. (1979). Liquid crystal orientational bistability and nematic storage effects. *Appl. Phys. Lett.*, *35*, 444–447.
[3] Cognard, J. (1982). Alignment of nematic liquid crystals and their mixtures. *Mol. Cryst. Liq. Cryst. Suppl. Ser.*, *1*, 1.
[4] Wood, E. L., Bradberry, G. W., Cann, P. S., & Sambles, J. R. (1997). Determination of azimuthal anchoring energy in grating-aligned twisted nematic liquid-crystal layers. *J. Appl. Phys.*, *82*, 2583–2487.
[5] Thurston, R., Cheng, J., & Boyd, G. (1980). Mechanically bistable liquid crystal display structures. *IEEE Trans. Elect. Dev. ED-27*, *11*, 2069–2080.
[6] Newton, C. J. P. & Spiller, T. P. (2001). A novel approach to modelling nematic liquid crystal cells. *Mol. Cryst. Liq. Cryst.*, *372*, 167–178.
[7] Kitson, S. & Geisow, A. (2002). Controllable alignment of nematic liquid crystals around microscopic posts: Stabilization of multiple states. *Appl. Phys. Lett.*, *80*, 3635–3637.