Time-Multiplexed 3D Display

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Abstract

A flat panel field sequential 3D display can be made by illuminating a ferroelectric liquid crystal display with scanning illumination passed through a transparent slab embossed with a grating. The concept is expected to enable wide fields of view, sharp discrimination between views, little blurring at depth, and no repetition of views.

1. Introduction

The demand for 3D stems more from whim than necessity which makes it difficult to gauge exactly what kind of 3D image is sought. Nevertheless people talk wistfully of a display round which three or four people can sit, each seeing what they would if they were looking at a solid object instead of an image. This is not on offer from most 3D concepts because their field of view is limited by lens F-number.

Field sequential displays use compound lenses which have better F-number than lenslet arrays, so offer wider fields of view. Furthermore, the boundary between the views of a field sequential display are defined by a single element which gives a sharp transition between views. This means that there is less blurring of pixels which are either far behind or far in front of the screen of the 3D display as happens with lenslet array 3D displays. Lastly, field sequential 3D displays have the advantage that in principle they need no more pixels than a 2D display with equivalent resolution.

The quality of image produced by field sequential 3D is excellent, but the displays have tended to be bulky, and they require fast-switching ferroelectric liquid crystals which have been slow to gain acceptance. This paper will explain how to make thin field sequential 3D displays, and review progress towards the manufacture of ferroelectric LCD's.

2. Field sequential 3D

A conceptually simple way to make a field sequential 3D display is to show a sequence of views of a solid object on a liquid crystal display, and illuminate each view with rays of light travelling parallel to the axis of the camera which captured the view[1]. Provided that there are enough views, and that the sequence is repeated sufficiently quickly, the result is a flicker-free three dimensional image. The bulk of this concept arises from the space needed between light source and lens - how is this eliminated?

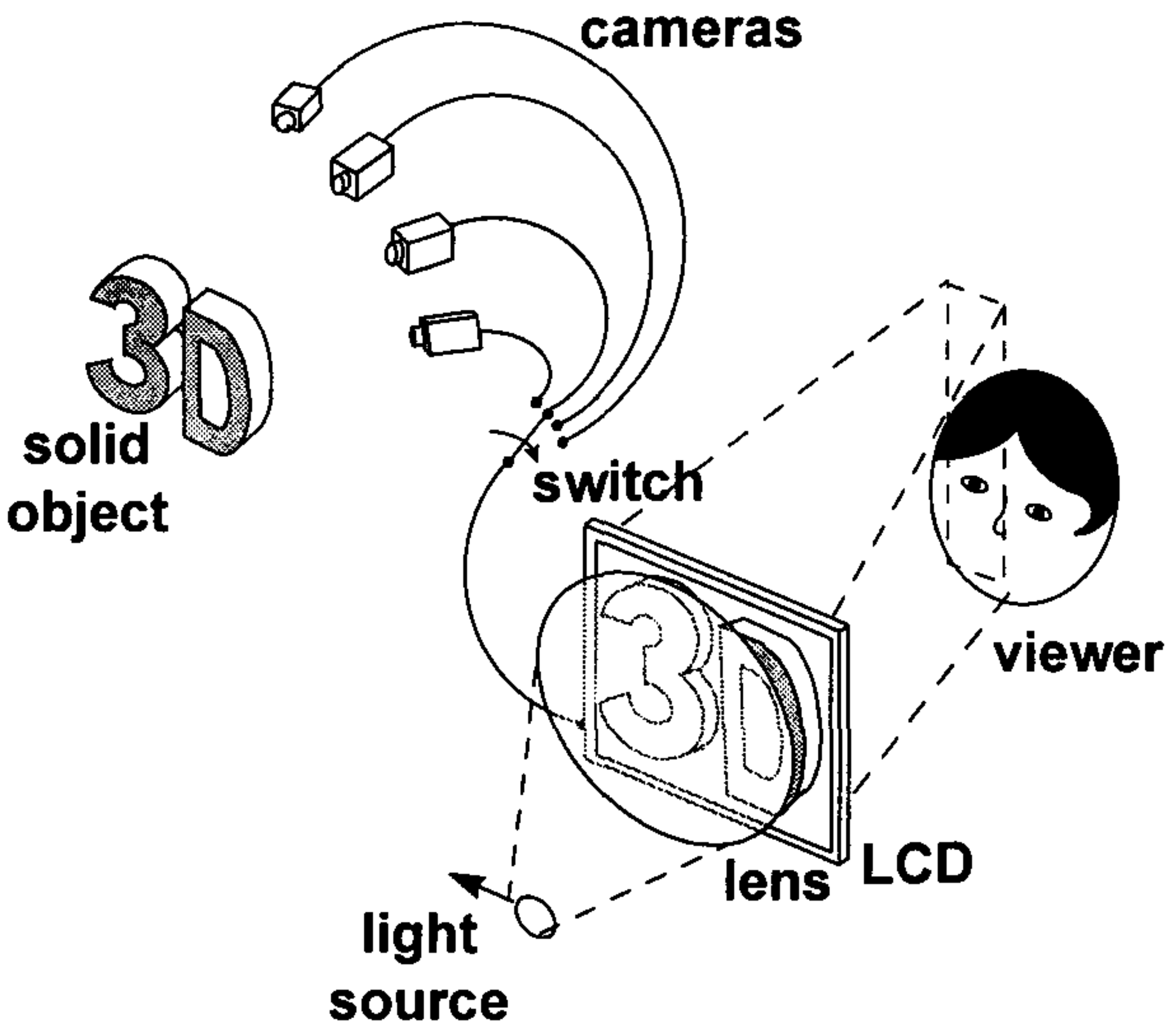

Figure 1 A field sequential 3D display comprises a high frame rate LCD illuminated with scanning rays of light.

3. Flat panel scanned illumination

If a ray is shone vertically up to a mirror angled at 45^0 to the vertical, the ray is deflected into the horizontal plane. Variations of ray angle in the vertical plane are converted into variations in the horizontal plane, as shown in figure 2.

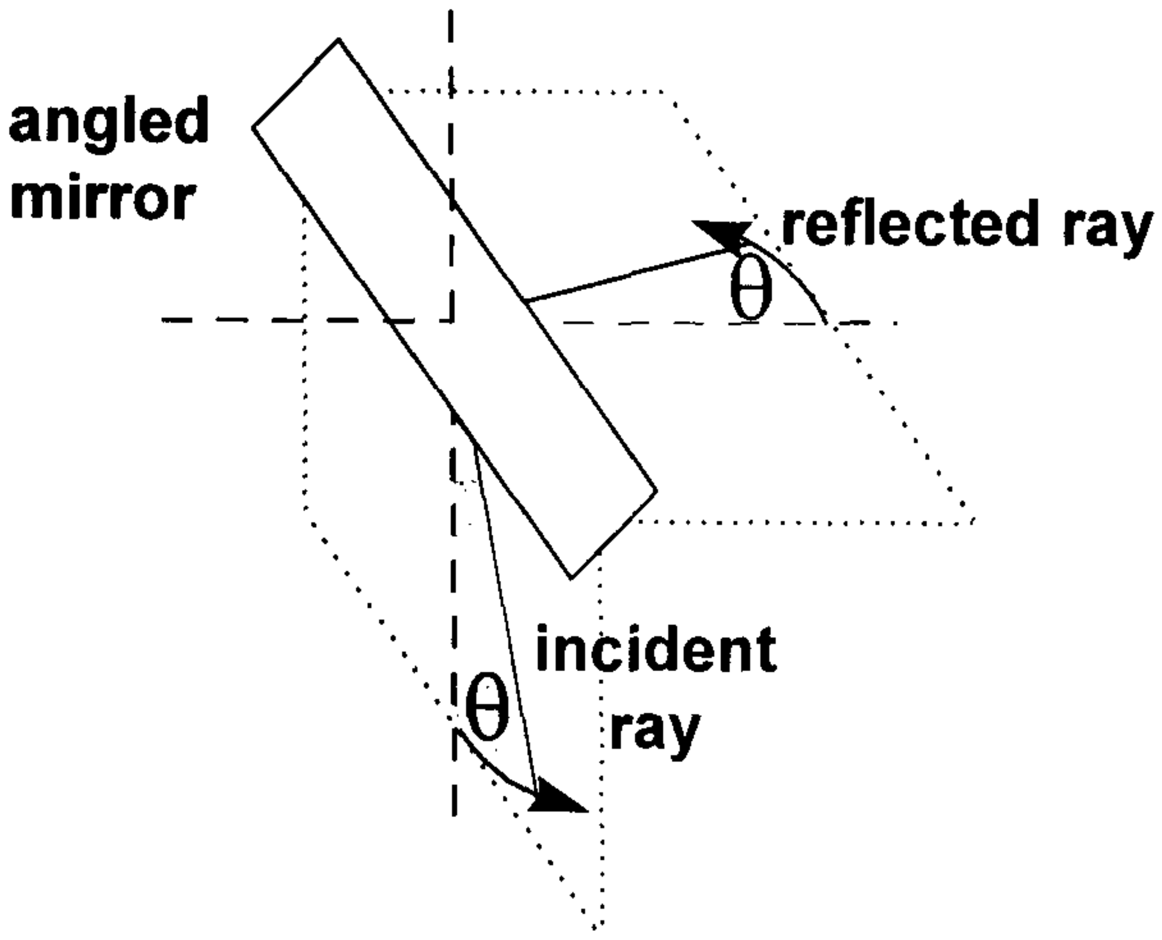

Figure 2 An angled mirror converts ray deflection in the vertical plane to ray deflection in the horizontal plane.

If a set of rays are shone up vertically so as to illuminate the entire base of a stack of mirrors angled at 45^0 to the vertical, and the mirrors are partially reflective, then collimated light will emerge from the whole of the front face of the stack, as shown in Figure 3.

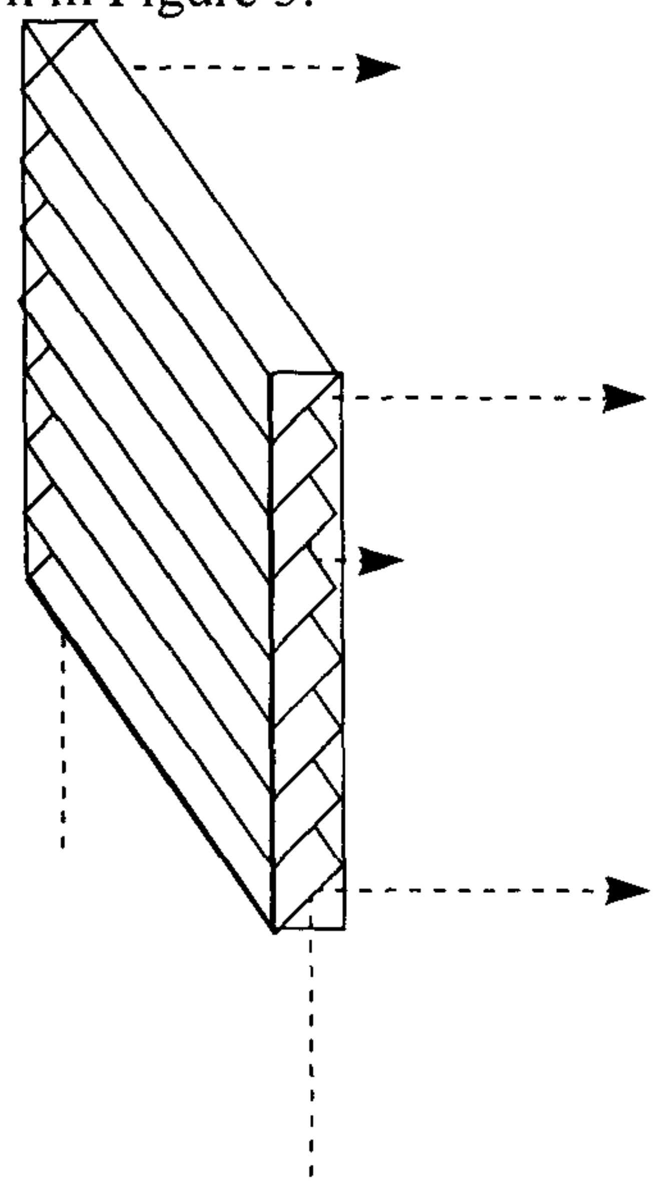

Figure 3 Collimated light emerges from the face of a stack of partially reflective angled mirrors if the base is illuminated with collimated light.

Alter the angle of the injected rays in the vertical plane, and the angle of the emergent rays in the horizontal plane will alter by an equal amount. The injected rays can be formed by placing a spot source of light in the focal plane of a lens segment, and the angle of the injected rays can be altered by moving the spot source of light in the focal plane of the lens segment, as shown in figure 4.

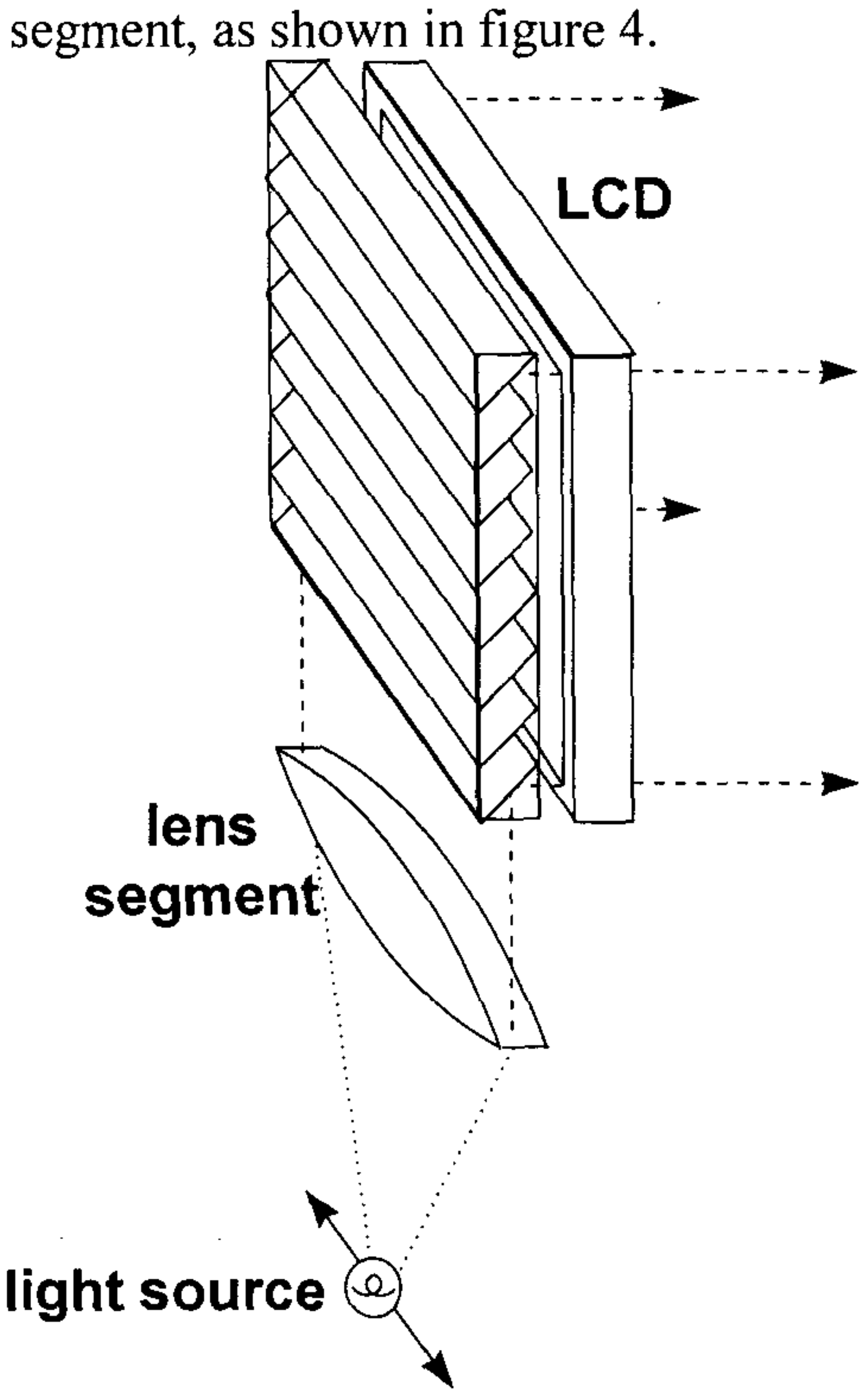

Figure 4 Illuminate the base of the stack with a light source collimated by a lens segment, and move the light source to scan view direction.

The lens segment and scanning source of light need be no thicker than the mirror stack, so that the whole illumination system is flat. The lens segment and scanning source of light can in principle of course be folded behind the mirror stack with prisms in order to make a system which fits behind the liquid crystal display without overlap.

This concept was tested satisfactorily by placing a stack of microscope cover slips in a transparent bath of water whose sides were spaced so that the cover slips settled at 45^0 to the sides, with partial reflection taking place at each glass/water interface. However components tend to be less expensive if they can be moulded, and an alternative way of making a flat panel illuminator is to use gratings.

Gratings alter the angle of incident rays by diffraction, and if a ray travelling in some arbitrary direction is incident on a grating, then it is the components of ray direction orthogonal to the lines of the grating which are altered by diffraction, while the component of ray direction parallel to the lines of grating remains unchanged, as shown in figure 5. In this respect a grating behaves like a tilted mirror, and the stack of partially reflective mirrors can be replaced by a slab of transparent material embossed with a weak diffractive grating. If a ray is injected into the base of the slab, then each time the ray reflects off the side embossed with the grating, part of the ray will be diffracted out of the slab with an azimuthal angle determined by the resolved part of ray direction in the plane of the slab. A flat panel scanning illuminator can then be made by collimating light from a spot source of light into the base of the slab with a lens segment.

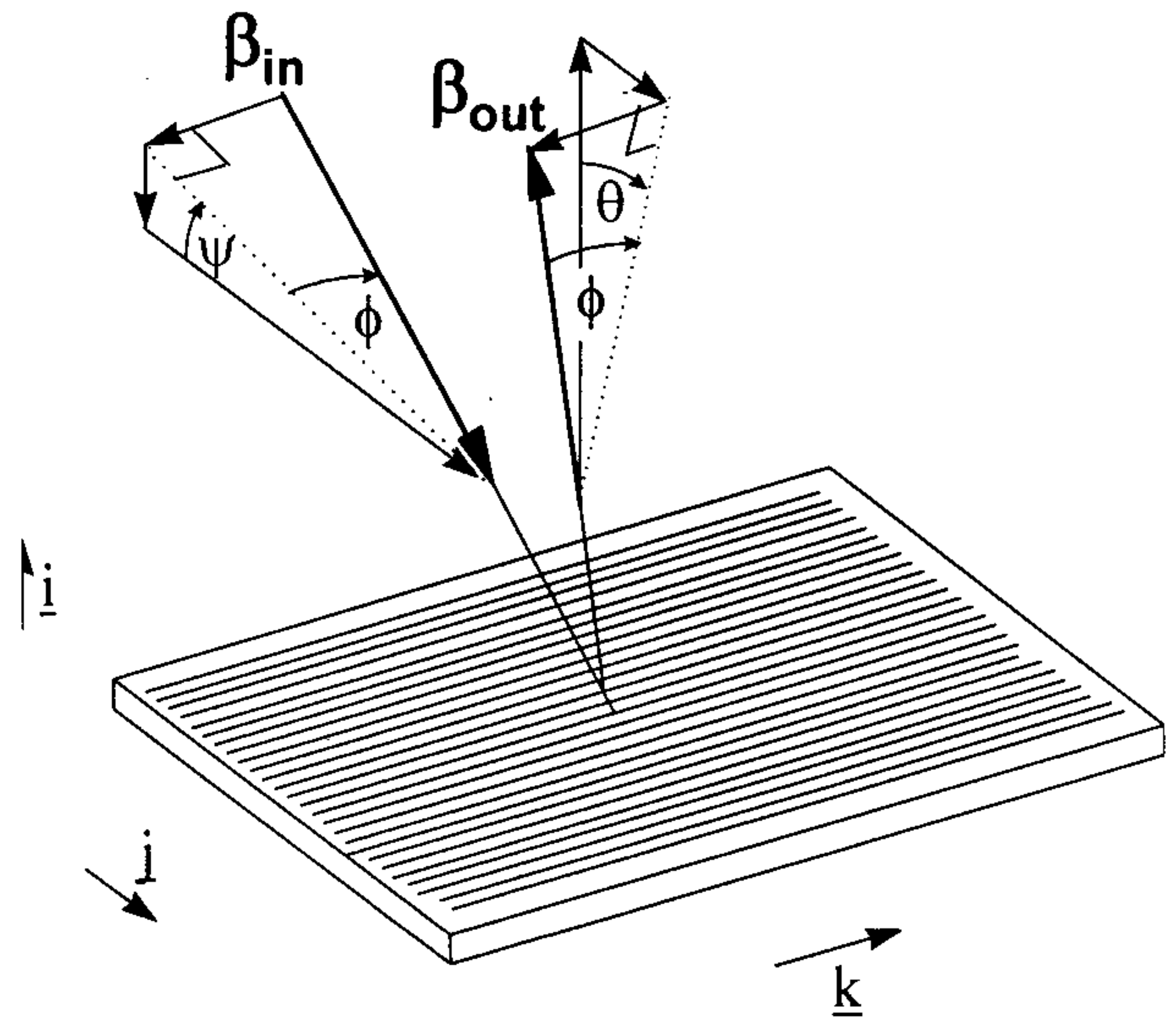

Figure 5 The component of ray direction parallel to the lines of a grating is unaltered by diffraction off the grating.

The embossed grating must be weak in order that rays can propagate through the whole of the slab so as to illuminate all parts of the liquid crystal display. Because the grating is weak, light passing from air into the slab and back into air is barely affected by the grating, so the grating is transparent. This means that it can illuminate liquid crystal displays which work by reflection, an advantage if the display substrate is crystalline silicon.

By making the lens segment circularly symmetric, this illumination scheme can be designed to have an almost unlimited field of view[2]. Furthermore, over the last few years graphics rendering chips have become fast enough to drive liquid crystal displays at the frame rates needed for frame sequential 3D, while light emitting diodes are now bright enough to deliver the switchable illumination needed to control view direction. It is now the frame rate of liquid crystal displays which limits the field of view of frame sequential 3D: what progress has been made?

4. High frame rate displays

A liquid crystal display with a frame rate high enough for field sequential 3D is likely to comprise ferroelectric liquid crystal and poly-silicon transistors. Ferroelectric liquid crystal is binary, so grey scale is likely to be multiplexed by a combination of spatial and temporal multiplexing. If there are 2 elements per pixel, then 4 time frames are needed to get 8 bits of grey scale, so a 16 view display operating at an image repetition rate of 60 Hz will require a frame rate of 3.9 kHz.

4.1 Ferroelectric liquid crystal

While ferroelectric liquid crystals themselves easily switch at the frame rates needed for field sequential 3D, an active matrix of transistors is needed in order to deliver data to each pixel at these high frame rates. When the scanning illumination concept was first proposed about 15 years ago, the amorphous silicon transistors then available switched too slowly for field sequential 3D. Instead the shuttered projection 3D display was developed in which the roles of liquid crystal and light source are interchanged.

With shuttered projection, the image is formed at the light source in the form of a cathode ray tube which even ten years ago was capable of kiloHertz frame rates, and it is view direction which is controlled by the liquid crystal element, configured as a shutter - no active matrix is needed. Shuttered projection displays waste light, are bulky and, like so many three dimensional displays, have a narrow field of view which is restricted by off-axis lens aberration. However the projected 3D image can have a diagonal as large as 50 inches[3], while bulk is diminishing as cathode ray tubes are replaced with microprojectors. Despite the 1.5 micron cell gap for the ferroelectric effect (versus 3 microns for the nematic phase) which is often cited as a manufacturing obstacle, ferroelectric shutters with widths of over 300 mm have been sourced without difficulty and are reliable.

Large ferroelectric panels have also been developed for the display of two dimensional images because the bistability of the ferroelectric effect means that at the frame rates sufficient for two dimensional images, no thin film transistors are needed. While two major manufacturers have put significant effort into this[4, 5], the yields of amorphous silicon active matrix displays are now such that there is little reason to change to ferroelectric liquid crystals for the display of two dimensional images. Nevertheless the more recent program is reported to have delivered good results, and the production of large ferroelectric panels is not seen as an obstacle.

4.2 Poly-silicon transistors

Recent progress on high frame rate ferroelectric displays has been driven by the projection industry who want the ferroelectric effect because it retains its contrast over a wide field of view, allowing the design of high étendu systems which give bright images. The ferroelectric liquid crystal is deposited on a silicon integrated circuit in order to reduce the number of connectors by demultiplexing the signal on chip. The ferroelectric liquid crystal effect has no grey scale and if illumination comes from a low cost arc light with constant brightness, 256 frames are needed in order to achieve 256 grey levels. This means that the ferroelectric liquid crystal display must have frame rates of several kiloHertz, and the mobility of crystalline silicon is conveniently sufficient to demultiplex data at these high frame rates. Ferroelectric LCOS (Liquid Crystal On Silicon) displays are now in production[6], and yields and quality are reported to be excellent. There is no technical reason why one could not assemble a small, mobile phone-sized 3D display by placing a flat panel illuminator over a ferroelectric LCOS display and work progresses towards this. But users want 3D displays which are bigger than a silicon integrated circuit, so a fast switching equivalent of amorphous silicon is required.

Poly-silicon thin film transistors have been under development for some time because they have the mobility needed to allow demultiplexing within the liquid crystal display. Recent advances in both the laboratory and the production line have brought the mobility of poly-silicon as high as half that of crystalline silicon, and manufacturers now speak seriously about integrating large parts of a personal computer within a liquid crystal display[7]. Transistor arrays made of poly-silicon remain more expensive than for amorphous silicon, but now easily have the cost and performance needed for field sequential 3D.

5. Conclusions

Field sequential 3D displays can be made on a flat panel by placing a ferroelectric LCD over a transparent slab embossed with a weak diffraction grating and edge-illuminated with LED's. Ferroelectric shutters and displays with widths of greater than 300 mm have been made without difficulty despite the narrow cell gap. Polysilicon is now manufactured with sufficient mobility to make ferroelectric displays with the frame rates needed for 3D. Field sequential 3D displays enable wide fields of view, a sharp transition between views, pixels which do not blur at depth, and no false stereo. In combination with the latest graphics engines and high brightness LED's, it is expected that the displays will deliver good quality 3D images at an acceptable manufacturing cost.

6. Acknowledgements

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7. References

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