FULL COLOUR IMAGES ON A BINARY SPATIAL LIGHT MODULATOR

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Abstract Ferroelectric Liquid Crystal over a custom silicon VLSI (FLC/VLSI) backplane technology provides a method of producing low power miniature colour displays. The backplanes are manufactured using a standard silicon wafer foundry process and provides an attractive alternative to current display technologies.

INTRODUCTION

Full colour images have been demonstrated on a Ferroelectric Liquid Crystal over VLSI Spatial Light Modulator (SLM), see Figure 1. A reflective SLM is actively illuminated using three high intensity coloured Light Emitting Diodes (LED's) (RED (670nm, 3cd), GREEN (568nm, 750mcd) and BLUE (450nm, 1cd)). Due to their small size and light weight FLC/VLSI SLM's have many potential applications including head mounted and other applications requiring high portability.

THE SLM

The SLM used consists of a 176x176 array[1] of single transistor DRAM style pixels of 30μm pitch. It was designed at Edinburgh University and is now available from GEC-

Marconi Research Centre[2]. The SLM has an overall active area of 5.28mm x 5.28mm with a pixel flat factor of 81% achieved by post processing planarisation[3]. The planarisation technique involves the deposition of oxide on top of a foundry SLM wafer which is then polished flat using chemical-mechanical polishing. This drastically improves the optical quality of the device and helps prevent the DRAM pixels discharging under intense illumination. The device is filled with a surface stabilised FLC material (Smectic C, SCE13, Merck-BDH) and appears to have a much improved molecular alignment, hence reduced FLC defects and a higher optical through-put efficiency. Using this fast switching liquid crystal and flexible high speed drive electronics the reflective SLM has been operated with a binary viewing frame rate of 1.5kHz (including DC balancing compensation to prevent FLC ionic disassociations).

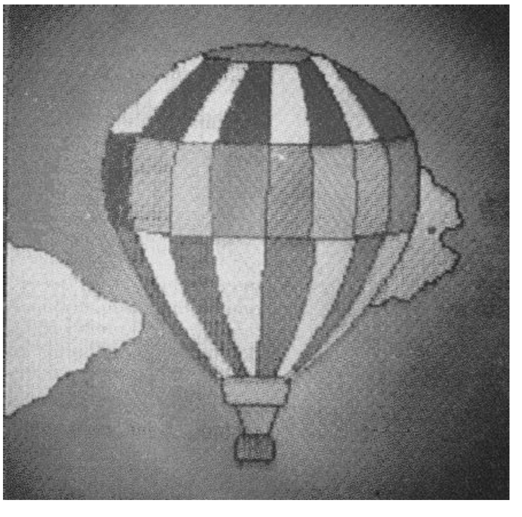

FIGURE 1 A Full Colour Image on an SLM.
(Black and White reproduction)

A pixel appears to be ON when there is an electric field (voltage difference) between the displays front electrode and a DRAM pixel mirror. This electric field changes the FLC molecular orientation so that incident polarised light is rotated on reflection and can pass through an analyser (polariser) to the viewer. This mode of operation is known as amplitude modulation. Figure 2 demonstrates the SLM's pixel operation.

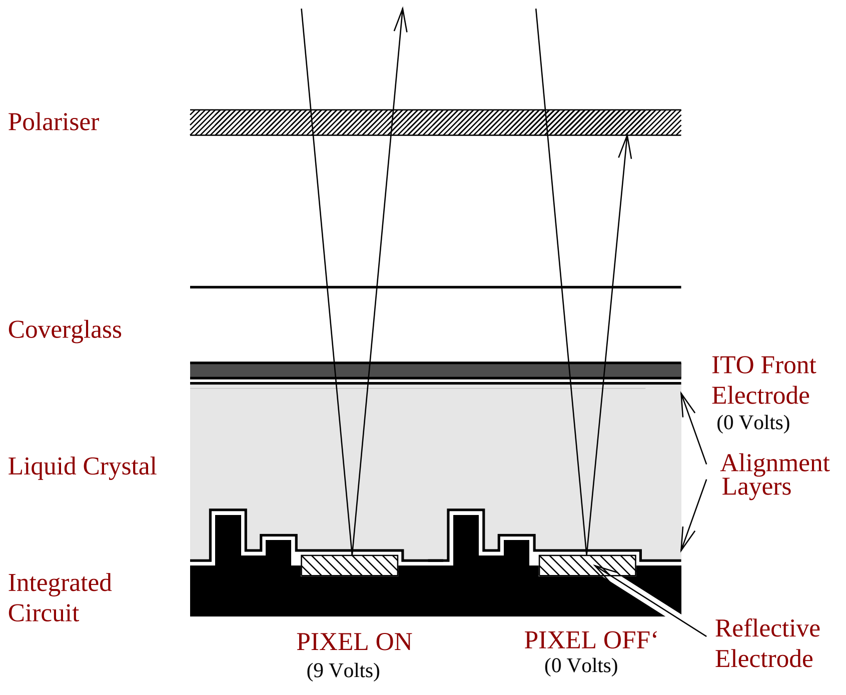

FIGURE 2 SLM Pixel Operation.

SLM DRIVE ELECTRONICS

The PC to SLM drive electronics consists of a Field Programmable Gate Array (FPGA) PC board (ALTERA RIPP10) and up to 2Mbytes of SRAM. With the reprogrammable logic approach new interface designs and driving schemes can be easily implemented and tested. For example, the user can easily and independently predefine the length of the blanking period, the liquid crystal settling period and the viewing period for each binary frame being displayed[1]. This is achieved by setting up and programming register values in an FPGA.

The FPGA hardware architecture enables us to take advantage of an artifact of the human visual system which has a non-linear perceptual response to brightness[4]. This perceptual response can approximated using $\log_2$ steps that increase by a factor $2^{1/2}$ between steps - and is almost binary weighted. From this an appropriate set of operating drive parameters are obtained and are loaded into the FPGA registers. This scheme has been demonstrated to produce many different colour levels with RED, GREEN and BLUE LED's.

THE COLOUR SYSTEM

Figure 3 demonstrates how a colour image is formed on the display using the colour sequential field technique, similar to that used with the Texas Instruments Deformable Mirror Device (DMD)[5]. Sixty four different colours are possible, including black and white, with a 6 binary frame, 3 LED illumination system operating at an overall viewing frame rate of 50Hz. The technique involves cycling through a series of binary images, with each frame being illuminated by a coloured LED for an appropriate period of time. Colour mixtures are perceived, since the human visual system effectively averages the different coloured pulses of light over a short period of time. This technique demonstrates Grassmans laws of additive colour[6] - i.e. RED + GREEN = YELLOW etc..

The colour images viewed on the SLM correlate very well to the same image when viewed on a PC monitor screen although slight colour differences do exist. This is due mainly to the LED's not operating quite in the ideal parts of the visible spectrum. For example, the GREEN LED is actually more YELLOW in colour. This can be observed in Figure 4, which portrays the Spectral Power Distribution (SPD) of the LED light sources used to illuminate the SLM.

In the constructed optical system (Figure 5) the 3 coloured LED's are orthogonally and centrally aligned, using non-polarising beam splitters, to illuminate the SLM through a single polariser. A small white light holographic diffuser can also be inserted in front of the input polariser to spread the LED illumination more evenly across the active area of the SLM. The drive electronics produce 3 control signals which turn on the appropriate LED when a frame is valid for viewing. The colour balance of the system is set by being able to vary (pre-programme) the LED ON time and the blanking period for each binary frame.

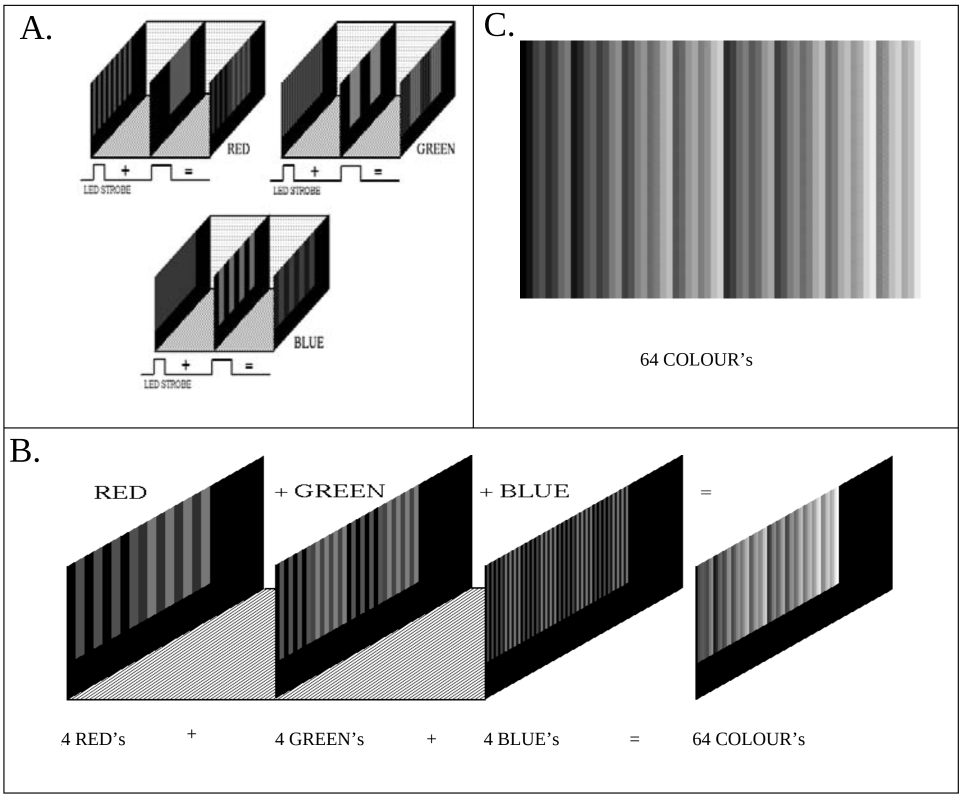

FIGURE 3 (A) 2 Monochrome binary frames, for each LED, produce 4 monochrome colour levels. (B) 4 RED's followed by 4 GREEN's and 4 BLUE's produce 64 different colours. (C) Simulated test image demonstrating 64 different colours. (Black and White reproduction)

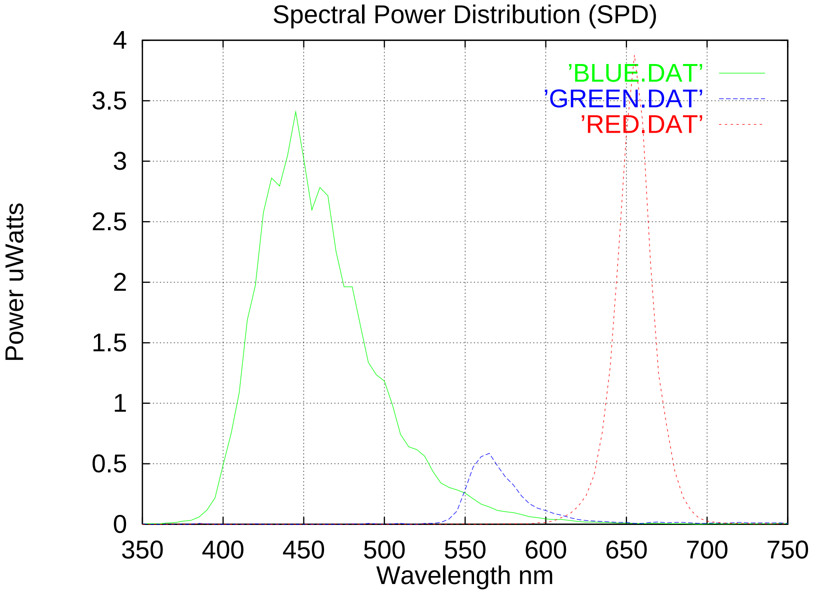

FIGURE 4 LED Spectral Power Distribution.

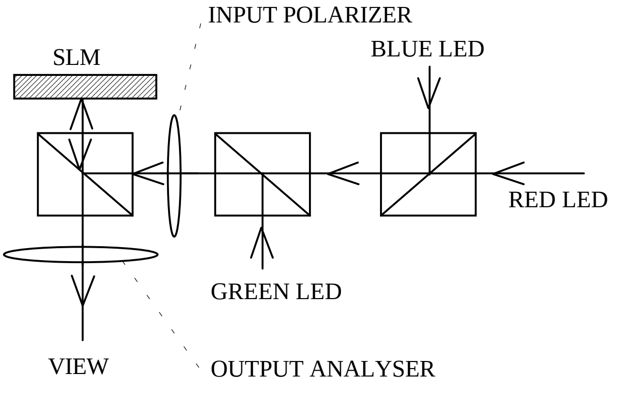

FIGURE 5 The Optical System

Optical Efficiency

Optical inefficiencies due to the SLM being more efficient at reflecting light in some parts of the spectrum than others and use of low intensity LED's are factors used in adjusting and deciding upon the LED ON time for each binary frame. Figure 6 shows the ideal transmission spectra calculated for a single SLM pixel with a 2μm cell thickness. The SLM pixel model tells us that the SLM is most efficient at reflecting light in the green part of the visible sprectrum - hence why the system can operate using a relatively low intensity GREEN LED (Figure 4).

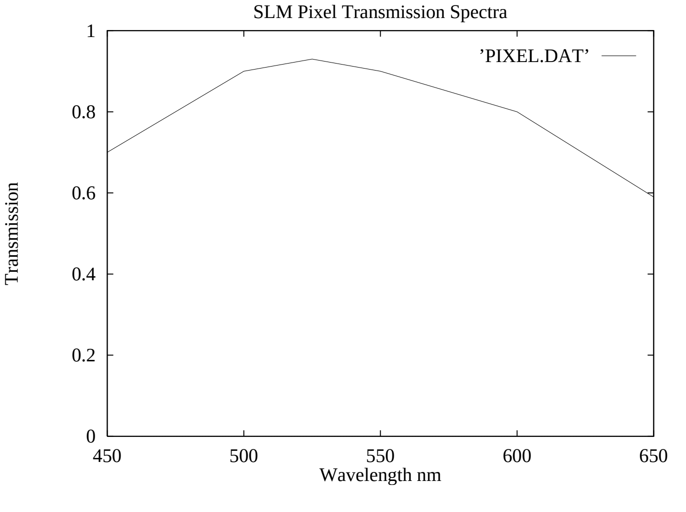

FIGURE 6 Transmission Spectra a single SLM pixel.

With careful adjustment of certain parameters (for example cell thickness) the effects of variation across the visible spectrum can be kept to a minimum[7]. Silicon micromaching of spacer layers in the liquid crystal layer cell probably offers the most accurate method of optimising the optical transmission of reflective SLM's in the visible part of the spectrum.

CONCLUSIONS

A full colour SLM display system has been constructed. With a high quality planarised FLC/VLSI SLM and the flexible drive electronics a user definable colour display is possible. The system also has the potential for many more colours. Work is now ongoing to characterise the system in detail and includes an investigation into improving the optical performance of reflective SLM's using micromachined spacer layers.

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