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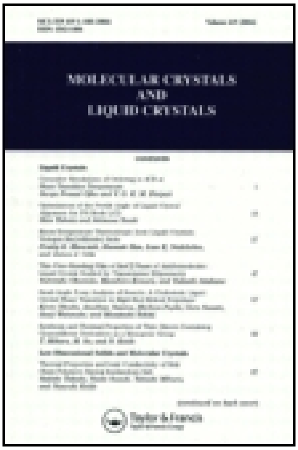

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COMPARISON BETWEEN PIXELATED-METAL-MIRRORED AND NON-MIRRORED FERROELECTRIC LIQUID CRYSTAL OASLM DEVICES

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COMPARISON BETWEEN PIXELATED-METAL-MIRRORED AND NON-MIRRORED FERROELECTRIC LIQUID CRYSTAL OASLM DEVICES

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The resolution and switching characteristics of two Bistable Optically Addressed Spatial Light Modulators (OASLMs) one with and one without a pixelated metal mirror (PMM) are compared. The two devices use amorphous hydrogenated silicon (a-Si:H) Schottky diode structures as their photosensitive layer, Indium Tin Oxide (ITO) layers for electrodes, Nylon-6 alignment layer and a ferroelectric Liquid Crystal (LC) material (ZLI-5014-100) as their modulating layer. Both devices exhibit bistability when driven by alternating monopolar pulses. The pixelated metal mirror OASLM has both higher resolution and better optical efficiency than the non-mirrored device.

Keywords: ferroelectric liquid crystal devices; optically addressed spatial light modulator

I. INTRODUCTION

Optically Addressed Spatial Light Modulators (OASLMs) are basic components in a wide and growing range of Optical Data Processing (ODP) systems. OASLMs are used in ODP systems in order to retain the input data as a two-dimensional array of information (image). This allows the

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information to be processed optically, which is much faster than converting the data into electrical bits and then processing it as in the case of computer used Digital Signal Processing [1]. Examples of optical data processing systems that would benefit from the use of OASLMs are high-resolution three-dimensional projection displays [2,3], optical pattern recognition systems, image/wavelength converters, optical neural networks and optical algebraic and logic processors.

OASLMs using ferroelectric liquid crystals (FLCs) as a modulating material exhibit high speed and high resolution performance. FLC OASLMs can also exhibit bistability with or without an electric field treatment. The photosensitive material used is Hydrogenated Amorphous Silicon (a-Si:H), that combines desirable optical and electrical characteristics such as high optical sensitivity, fast optical response and both low dark and high light conductivities. In addition, a-Si:H can be deposited on large area substrates at relatively low temperatures (220°C) by Plasma Enhanced Chemical Vapour Deposition (PECVD).

The a-Si:H configuration used can be either a Photosensor or a Photodiode. Photosensor configurations have high optical sensitivity due to high photoconductive gain but low frame rate due to low recombination rates [4]. The Photodiode configuration can have either a p-i-n or a Schottky configuration. Both configurations have a photoconductive gain of unity but higher speed of response due to faster recombination. This makes photodiode configurations attractive to work with high speed FLC modulating materials. There is no significant difference between the values of resolution, sensitivity and drive rate of p-i-n and Schottky OASLM devices. From literature, p-i-n OASLM devices have been recorded with resolutions of up to 70 lp/mm [4], sensitivities of 5–10 mW/cm^2 [5,6] and drive rates of 1–5 KHz [5,6]. On the other hand Schottky barrier OASLM devices have been recorded with 100 lp/mm [7], sensitivities of 1–2.5 mW/cm^2 [8,9] and drive rates of 1–3 KHz [8,10].

Due to its low fabrication complexity the photosensor used in the Cambridge University Engineering Department (CUED) is the Schottky barrier structure, which is created by merely depositing intrinsic a-Si:H on to ITO. The p-i-n device has a higher fabrication complexity because it requires the deposition of three different layers (p-doped, intrinsic and n-doped layers).

If a metal mirror is deposited on the top of the a-Si:H layer then a second Schottky barrier appears, which has opposite polarity with respect to the first ITO/a-Si:H layer. This second layer makes the structure of the photosensitive layer more symmetric as shown by Perennes and Crossland [11]. This paper summarises the work done on comparing the performance of two Schottky barrier OASLMs, one with and one without a pixelated metal mirror.

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II. DEVICE FABRICATION

OASLMs made in CUED incorporate a-Si:H as the photosensitive layer, Indium Tin Oxide (ITO) as transparent conductors, Nylon-6 alignment layer and various types of FLC material. The complete fabrication process is as follows: a-Si:H is deposited on an ITO coated borosilicate glass substrate using an Oxford Plasmatech DP800 PECVD machine. The thickness of the a-Si:H is 1.5–2.5 μm. An aluminium mirror is then deposited on the a-Si:H surface. The mirror is then pixelated using a photolithographic process. The size of the pixel on the photolithographic mask is $8 \times 8\,\mu m$ and the gap between the pixels is 2 μm giving a pixel repeat spacing of 10 μm. The samples (with or without a mirror) are then coated with a Nylon-6 alignment layer. A separate ITO coated borosilicate glass substrate is also covered with Nylon-6 and the two alignment layers are then rubbed. One of the two substrates is then sprayed with epoxy spacers and the second substrate is placed on top so that the rubbing directions are anti-parallel. The two substrates are then peripherally glued together. Only two small holes are left open, through which, the LC material can be inserted in the cavity. Cells made in the CUED, have utilised different types of LC materials. These include SCE8, SCE13, CDRR8, DRA2, ZLI-5014-000 and ZLI-5014-100. The OASLMs mentioned in this paper have used ZLI-5014-100 LC material which has a $Ps = -20\,nC/cm^2$.

III. EXPERIMENTS AND RESULTS

A. Experimental Set-Up for Diffraction Efficiency Measurements

To characterise the resolution of OASLM devices the diffraction efficiency of the devices is measured as a function of the spatial frequency of the write image. Figure 1 shows the optical set-up used in such an experiment. This set-up is capable of erasing, writing and reading images from an OASLM device. The write images consist of binary gratings of various spatial frequencies. A continuous wave (CW) incoherent white light source illuminates the metal binary grating and the light transmitted through the grating is then imaged on to the a-Si:H of the OASLM under test, using a one-to-one imaging system. The Modulation Transfer Function (MTF) of the one-to-one imaging system for different wavelengths is shown in Figure 2. The light from a red LED is used as the erase beam. The images are read from the LC side of the OASLMs using a He-Ne red laser ($\lambda = 632.8\,nm$). The read beam is modulated using an acousto-optic modulator and is spatially filtered using a single mode fibre. The output of the fibre is then directed on to the LC side of the OASLM, via a polariser.

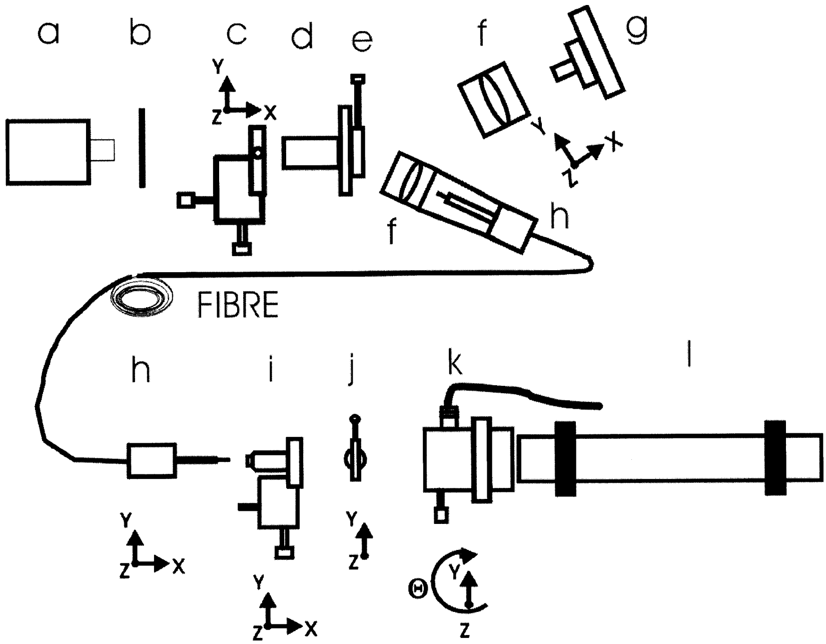

FIGURE 1 Optical set-up for Diffraction Efficiency measurements. Index: (a) White light source, (b) Colour filter, (c) Grating holder, (d) One-to-One imaging lens, (e) OASLM holder, (f) Lenses, (g) Photodiode or camera, (h) Fibre holders, (i) Microscope objective, (j) Iris, (k) Acousto-optic modulator (AOM) and (l) He-Ne laser.(S.Mias).

The reflected light is projected, via an analyser to a large area photodiode or a camera for both quantitative and qualitative examination.

B. Measurement Criteria

The measurement criteria used are similar to [3] where the "cell" and "overall" efficiencies have been defined. The "cell" efficiency is the intensity of the first diffracted order divided by the intensity of the zero order measured when the light has been reflected off the OASLM, which is placed between crossed polarisers (maximum contrast). "Overall" efficiency is the ratio of the first diffracted order divided by the zero order reflected off the OASLM but in this case the zero order is measured with the cell between parallel polarisers. While these two efficiencies give us an idea about the maximum contrast and the proximity of our LC layer to a half-waveplate, they do not give any information on the reflectivity. Hence, a third type of efficiency has been used, called the "optical" efficiency, which is the ratio

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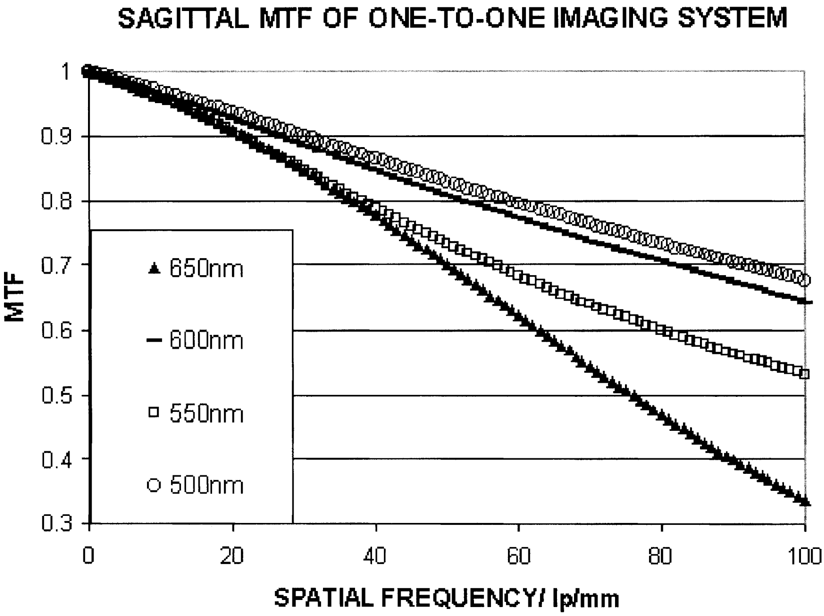

FIGURE 2 The MTF of the one-to-one imaging system for different wavelengths. (S.Mias)

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of the first diffracted order measured between crossed polarisers, divided by the intensity of the laser beam before the beam has reached the OASLM. Table 1 summarises the definitions of the different efficiencies.

TABLE I Different Efficiencies and their Meanings

Efficiency	Equation
CELL	$\frac{I_{1st}}{I_{0\,crossed}}$
OVERALL	$\frac{I_{1st}}{I_{0\,parallel}}$
OPTICAL	$\frac{I_{1st}}{I_{laser}}$

I_{1st} = Intensity of the first diffracted order.
$I_{0crossed}$ = Intensity of the reflected zero order of the OASLM, with crossed polarisers.
$I_{0parallel}$ = Intensity of the reflected zero order of the OASLM, with parallel polarisers.
I_{laser} = Intensity of the laser beam after the polariser and before the OASLM.

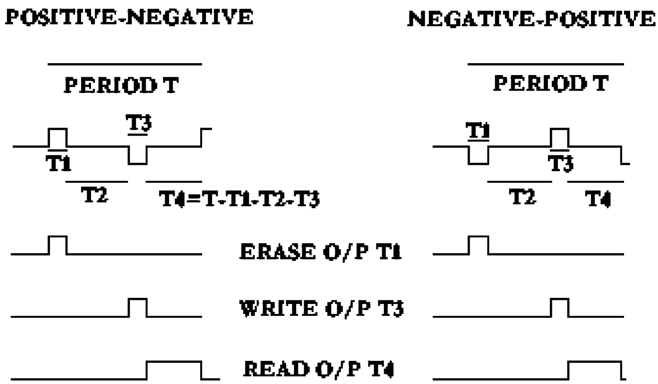

FIGURE 3 OASLM driver outputs. (s.Mias)

C. Oaslm Drive Waveform

The waveform generator produces bipolar pulses with variable voltage amplitudes (0–66 V) and pulse widths (0.1–10 ms). The period between the pulses can be varied from 0.05–100 ms. The offset of the voltage can also be varied from 0–6 V. The driver also produces two separate outputs for driving an erase LED and the AOM (see Fig. 1) in synchronisation with the erase and read periods respectively (see Fig. 3).

D. Experimental Results

Two devices made with the LC mixture ZLI-5014-100 were tested in our optical DE set-up. One device (SLM 17) had a pixelated metal mirror and the other device (SLM 11D) had none. A comparison of the diffraction efficiencies of the two OASLMs is shown in Figure 4. The devices were driven under different conditions (see Fig. 5) because the mirrored device requires a higher drive voltage. The results show a significant increase in both resolution and optical diffraction efficiency due to the presence of the mirror layer (see Fig. 4).

E. Analysis of Experimental Results

The reason for the higher optical diffraction efficiency is the existence of the mirror that increases the light reflected towards the photodiode. The higher resolution is probably due to the balanced photosensor structure of the ITO/a-Si:H/Al, which has two Schottky diodes. The presence of the above balanced photosensor structure eliminates the need for the use of an erase beam due to almost non-existent image sticking. The balanced

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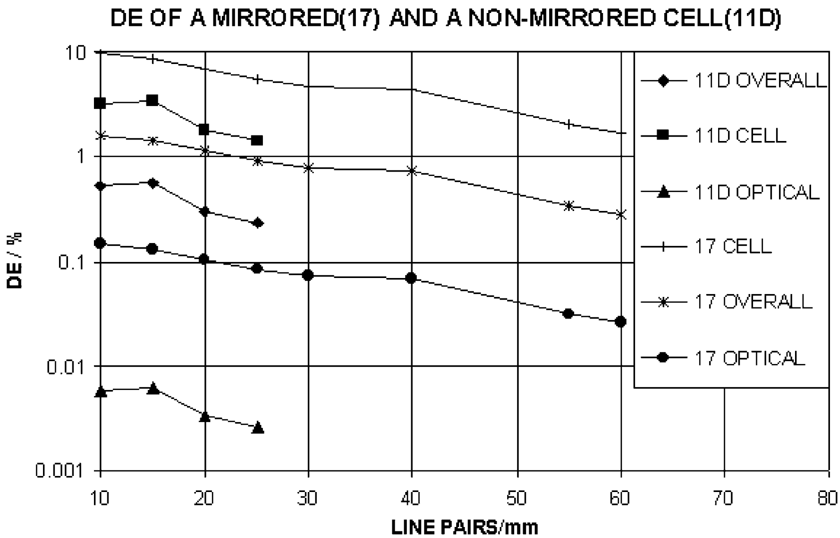

FIGURE 4 Diffraction Efficiency of non-mirrored and mirrored OASLMs. Above 25 lp/mm the DE of the non-mirrored device (11D) falls below the measurement capabilities of our equipment. (S.Mias)

photosensor structure also means that the device needs less of a DC offset in order to give the maximum first order intensity as shown in Figure 5.

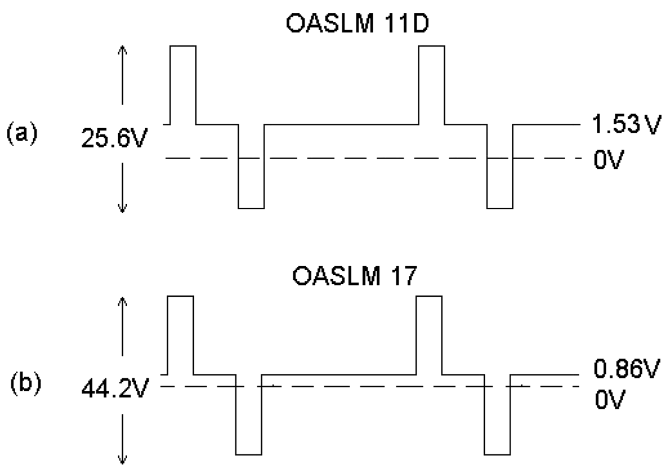

FIGURE 5 Average Drive Voltages for non-mirrored (a) and mirrored (b) OASLMs. (S.Mias)

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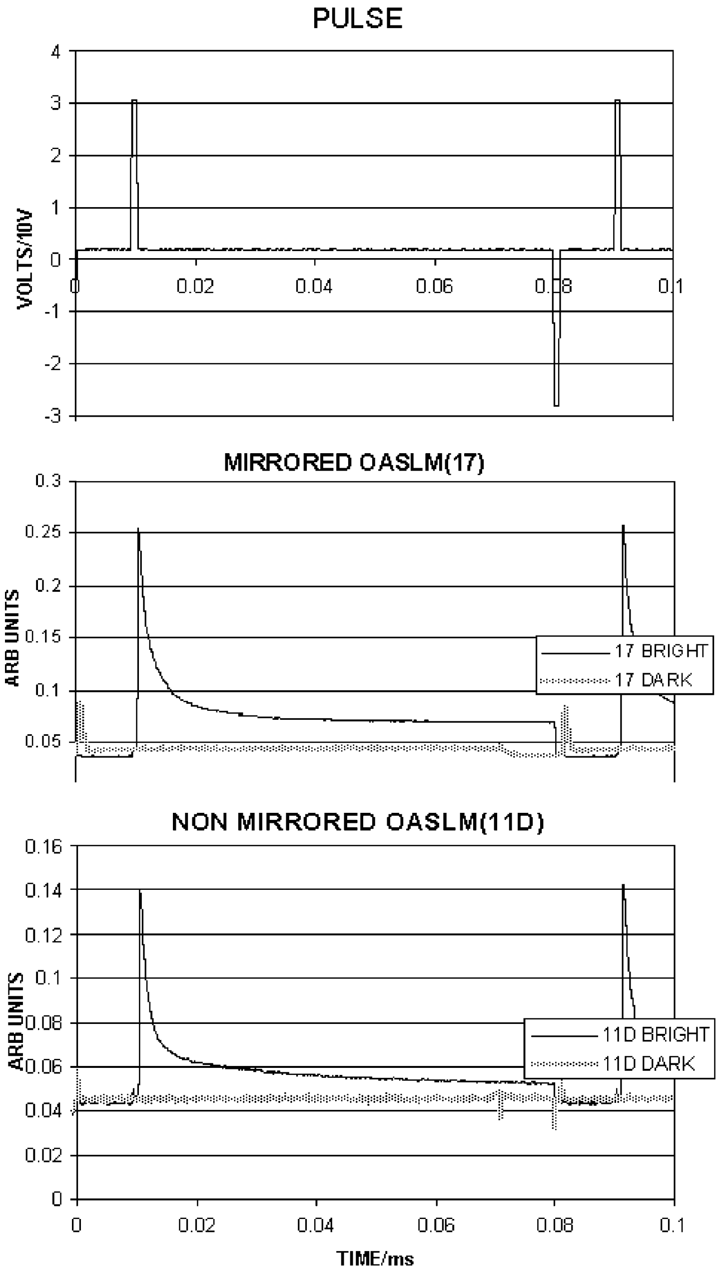

FIGURE 6 (a) Alternating monopolar pulses used in the bistability tests of OASLMs, (b) Bistability of mirrored OASLM and (c) Bistability of non-mirrored OASLMs. (S.Mias)

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The reason for the absence of image sticking with the balanced structure is that OASLMs need a quick movement of charges to and from the a-Si:H/LC interface in order to work. Firstly, during the erase period, the depletion region on the Al/a-Si:H interface increases, pushing electrons away from the LC layer and switching the LC layer into a single state. During the write period the polarity of the bipolar pulse is reversed and hence the ITO/a-Si:H depletion region increases, while the Al/a-Si:H barrier becomes negligible. The light applied on to the a-Si:H creates electron-hole pairs within the ITO/a-Si:H depletion region. The electrons move towards the a-Si:H/Al/LC interface and switch the LC layer to its second bistable state. Finally, during the read period the drive voltage goes to zero and hence there is no further effect on the charge distribution. Any charges still trapped near the a-Si:H/Al/LC interface are again swept away by the increase of the Al/a-Si:H depletion region during the new erase pulse.

The bistability of the device and the effect of the offset on the write process are examined using the same experimental set-up. If a device is bistable then the LC layer must remain in its new state when switched from one bistable state to another. Complete relaxation is a sign of monostable behaviour. To examine the bistability of an OASLM device, the OASLM is placed within the same experimental set-up as above and switched from one state (dark) to another (bright) while illuminated using 1ms alternating monopolar pulses (see Fig. 6). The bistability of the OASLM is then observed using a photodiode connected onto an oscilloscope. The bistability signals for both the mirrored and non-mirrored device are also shown in Figure 6. The read period is quite big (70 ms) in order to ensure that no significant relaxation occurs within a large period of time. The results show that the LC layers of both cells relax to a stable multidomain state after the cell has been switched.

IV. CONCLUSIONS

The performance of two OASLMs devices utilising the same LC layer(ZLI-514-100), one with a pixelated metal mirror (PMM) and one without have been compared. The PMM OASLM has been found to have both a higher resolution and a higher optical efficiency than the non-mirror OASLM.

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