49.2:Innovative Laser Patterning of Black Matrix for LCD Manufacture

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Abstract

Patterning the Black Matrix (BM) layer in an LCD typically employs wet-etch lithography. This paper describes an alternative laser-based patterning technique called Assist Liquid^{TM}. This technique meets rigorous customer targets and may offer a more cost effective solution for LCD manufacture.

1. Introduction

Liquid Crystal Displays (LCDs) represent the most widely manufactured form of Flat Panel Display (FPD) in the world today. This market is extremely price sensitive and competition is fierce. In an attempt to reduce costs, manufacturers continue to maintain an interest in new technology to gain a lead on their competition. In recent years the use of laser technology has been increasing in the manufacture of FPDs – notably as a replacement for wet-etch lithography to pattern indium tin oxide (ITO) thin films on the glass superstrates of Plasma Display Panels [1].

In this paper the authors describe a new laser-based technique which allows the direct patterning of the Black Matrix resin used as a contrast enhancer between the RGB pixels in an LCD. This technique combines Rapid Laser Pattering (RLP) with a water jet that acts to enhance the process quality. It solves the problems experienced in previous attempts at laser processing of this material, namely edge taper, feature variation, residue and debris. This technique has the potential to displace wet-etch lithography for this process by offering cost advantages over the incumbent technology – reducing process steps and chemical costs. It could also compliment inkjet technology for printing the colour filter (CF) components, providing accurate features into which the CF could be printed.

A Black Matrix layer is commonly included within the colour filter that is incorporated into modern LCD displays. A simplified schematic cross-section diagram of a typical LCD is shown in Figure 1 [2]. The TFT glass contains thin film transistors, ITO electrodes, and signal lines. The liquid crystal cannot be controlled above signal track and transistors, so normally the light would pass through reducing overall contrast of the display. The function of the BM layer is to prevent light leakage between pixels and therefore improve the contrast of the display. In addition BM can act as a boundary to aid ink jet printing of colour filter cells.

1.1 Existing technologies

The most common technology for producing black matrix is wet-etch lithography. Photolithography is a multi step process: spin coat, solvent bake, expose, develop and cure. A black matrix material is a photoresist itself, so the number of steps is reduced [3,4]. However, some of those steps will involve chemicals, which pose an environmental risk. On the other hand as LCD panels become larger and contain smaller features, consistency of chemical processes can be an issue which can reduce yield. An alternative technique that can reduce the number of process steps, the use of consumables, and at the same time fulfil all process requirements could significantly lower production costs. Some most important requirements are shown in Table 1.

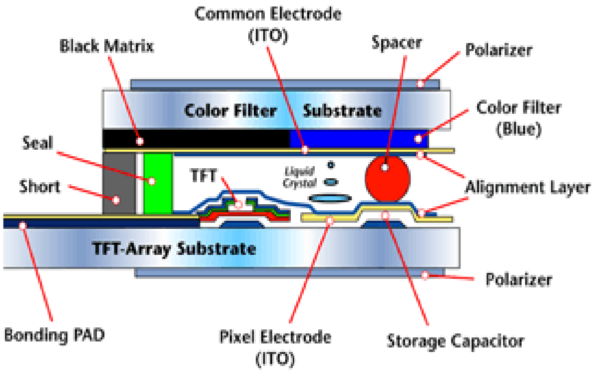


Fig. 1. Simplified cross-section diagram of a TFT LCD display. BM-black matrix tracks are between all colour filter cells.

Parameter	Target
Edge Resolution (Taper)	≤ 1μm
Edge Straightness	Best possible
Residue	98% optical transmission vs. glass

Table 1. Important requirements for black matrix patterning.

2. Alternative laser based technology

An alternative method of producing black matrix is direct laser patterning. The main advantages of this method are the reduction of number of manufacturing steps, as shown in figure 2 and a reduction in the use of consumable chemicals. Laser patterning also offers high flexibility, high yield and scalability but historically there are some problems: edge definition, residue and process repeatability. This paper describes three variations of rapid laser patterning (RLP) of black matrix resin and shows how these issues can be addressed.

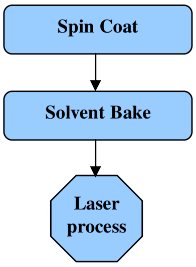


Fig. 2. Processing steps for novel laser process.

3. Experimental setup

The system consists of a high power DPSS laser, beam delivery optics, and galvanometric scanner as shown in figure 3. All substrates are LCD grade glass 0.8 mm thick with 1 µm thick black matrix resin. The laser used is a Starlase AO4 which features high peak power, high average power nanosecond duration pulses. At 6 kHz repetition rate the output pulse energy is 53 mJ with pulse duration of 35 ns. The Starlase range of lasers is manufactured exclusively by Powerlase Ltd, UK. The laser beam is attenuated externally using a proprietary Powerlase unit. The beam is homogenized by a beam shaper unit which is manufactured by LIMO GmbH.

The homogenized beam illuminates a rectangular test mask 0.4 mm × 1.2 mm. This mask plane is relayed to the substrate and demagnified using an f-theta 163 mm focal length scan lens. A HurryScan 25 galvanometric scanner manufactured by Scanlab GmbH is used to scan the beam across the sample. At the workpiece, the beam shape is 90 µm × 290 µm.

The laser processing results were assessed using a Nikon LM1500 optical microscope fitted with a 12 Mega pixel camera that delivered images into Lucia G software. This software allows microscopic measurements to be made against a Nikon calibrated standard.

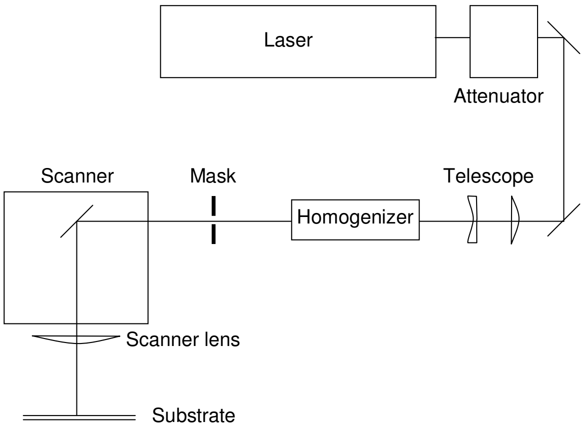


Fig. 3. Processing steps for novel laser process.

4. Results and discussion

Several methods of laser based BM patterning are considered, including top ablation, through glass ablation (dry) and through glass with water jet. These tests demonstrate the progression towards Assist Liquid™ in terms of quality and throughput. These three methods are illustrated in Figure 4.

4.1 Top Ablation

The black matrix is ablated using the conventional laser based method where the laser beam irradiates the upper surface of a coating. This is a well known technique and is used for other thin film processes [1]. Good single pulse ablation relies on the melt and vaporisation of the whole thickness of the film within the pulse duration, and this can be achieved in the case that the film thickness is less than the optical absorption depth. In the case of black matrix resin the film thickness is several times greater than optical absorption depth which means that all laser energy is absorbed only in the top layer of the coating. To remove the complete BM layer, the pulse energy must be high enough to transfer energy to the rest of the coating through thermal conduction or other non-optical processes. Thermal energy transfer within the BM layer is an isotropic process, which means that there will be an even spread of energy both downwards and sideways which reduces resolution of material ablation and produces ragged edges.

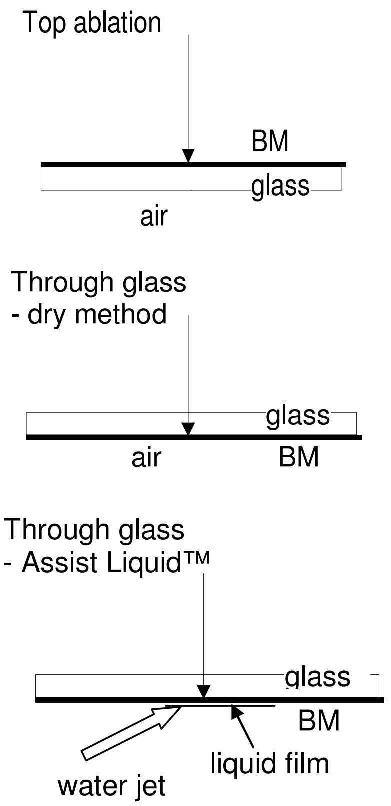


Fig. 4. Three investigated laser patterning methods for BM

Generally the shape of the edge of the removed material corresponds to the profile of the laser beam. Although at the mask the edges are very sharp, the image after an optical system (projection lens) becomes blurred. The beam profile edge width is comparable to the optical resolution of this projection system:

$$d = 0.6 \cdot \frac{l}{\mathrm{NA}}$$

Where NA is numerical aperture of projection system, and l is wavelength of 1.064 µm.

The NA is defined as:

$$\mathrm{NA} = \sin(\theta)$$

Where θ is acceptance half-angle. NA is a ratio of lens aperture and working distance. For the experimental system, the optical resolution is ~ 8 µm, and test results show an edge width of that order which is insufficient for a LCD production. The edge width can be improved marginally by using multi-pulse ablation where the fluence of each pulse is only slightly above ablation threshold. However, as the number of pulses increases, the process becomes more difficult to control, because super-positioning of multiple pulses in the same place must be achieved with high accuracy.

A further disadvantage of this process is residue. Vaporized material is partially deposited back onto the irradiated zone and surrounding area. For multi-pulse ablation the residue is removed with successive pulses but not from the remaining BM tracks. This deposit is lightly attached to the original coating, and if not cleaned it can contaminate the substrate at a later stage. The effect of redeposition of ablated material can be partially minimized by using compressed gas to blow the fumes away, and employing fume extraction system. However, during experimental trials the authors did not succeed in producing a clean surface using these methods. During these trials the fluence range for this process was 1.0–5.5 J/cm^2 for each pulse, and tests involved either 1 or 2 pulses per pixel.

Figure 5 shows the best results obtained using this method. The process repeatability is good and edges are straight, but they are relatively wide: ~5 µm and ~4 µm for single and double pulse ablation respectively and there is evidence of significant residue.

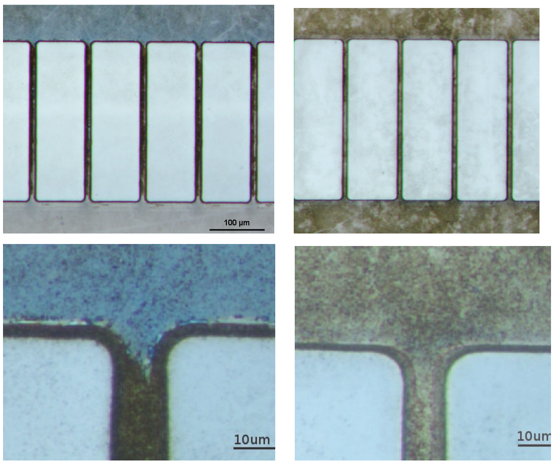


Fig. 5. Left - Top Ablation, single pulse at 5.5J/cm^2, right - top Ablation, two pulses at 3.0J/cm^2 each

4.2 Through Glass Ablation – Dry Method

A different ablation technique is where the laser beam irradiates the BM coating through the glass [5]. The main difference between this method and top ablation is that the energy is absorbed at the glass-coating interface. In this case the BM layer removal mechanism is different, since the laser energy causes vaporization of the BM resin at the interface, causing rapid pressure build up which enables explosive ejection of the BM material. A clear benefit of this method is that the edge taper is much smaller, which gives an improvement of the resolution of the patterning. However, the explosive removal mechanism is variable and therefore the edges of the BM are ragged. Figure 6 shows one of the best results obtained using this method.

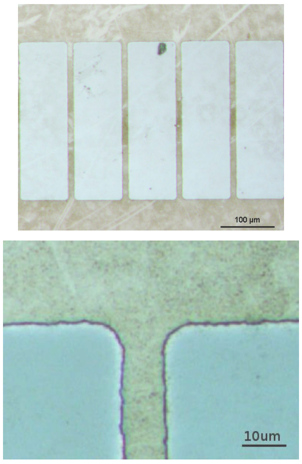
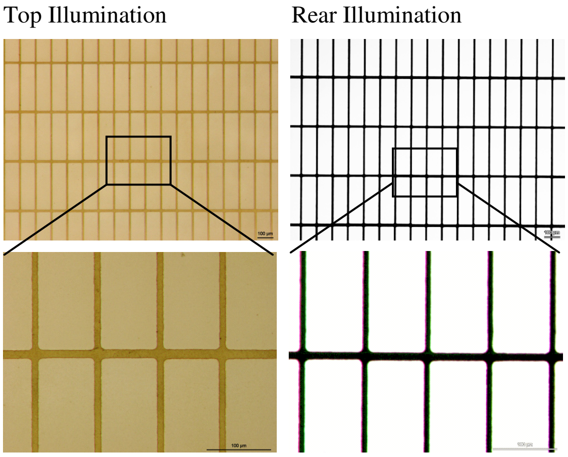


Fig. 6. Through glass ablation, dry method, 1.0J/cm^2

5.2 Through Glass - Assist Liquid™

A variation of the above method is when a water jet is used in conjunction with the laser beam beneath the substrate. It serves to remove debris and ensure consistent material removal. The water jet is produced by a small water pump with a 1 mm diameter circular nozzle. The water pressure is about 1.4 bar, and the flow rate 0.4 litres/minute. The nozzle is positioned under the sample at ~ 10° angle to the surface. The water jet after hitting the sample flows on the surface as a uniform film. The estimated water film velocity was 2 metres/second.

The energy requirements are similar as for the previously described method: the ablation threshold is at about 0.5 J/cm^2, and consistent and repeatable results are achieved at 1.0 J/cm^2. The operating window in terms of fluence is relatively large, so process control should not pose significant problems in this area. An example of patterned BM is shown in figure 7. As can be seen in the figure the patterned BM has sharply defined edges (good resolution), straight edges, high contrast and no evidence of residue. The patterned BM in question is on a grid with pixel size of 290x90µm on a 300x100µm pitch. The line width is 10µm.


Top Illumination

Rear Illumination

Fig. 7. Through Glass, Assist Liquid™, 1.0J/cm^2

6. Comparison with Customer Targets

Measurements were taken using a calibrated microscope for a statistically significant number of pixels. Straightness is assessed by digitising a microscope picture, extracting the edge profile, and performing statistical analysis over the full length of the long edge. Table 2 compares customer targets with achieved results. The edge resolution and straightness results show a significant improvement over other laser patterning methods which exceed the customer target.

Figure 8 shows the visible transmission spectrum for each of the 3 laser processing methods. For the Assist Liquid^{TM} method the transmission is greater than 90% across the visible spectrum compared to uncoated glass, and as such does not meet customer specification. However when compared to the transmission at the RGB wavelengths for a populated LCD colour filter as shown in figure 9, it is clear that transmission is 10-20% greater – allowing for some attenuation by the colour filter. Which begs the question is >90% transmission fit for purpose?

	Customer Target	**Assist Liquid^{TM}**
Edge Resolution (taper)	< 1µm	0.6 µm
Edge Straightness	Best possible	± 0.6 µm (std. dev. over 290 µm)
Residue	98% optical transmission vs glass	> 90%

Table 2. Comparison between customer targets and Assist Liquid^{TM} technique

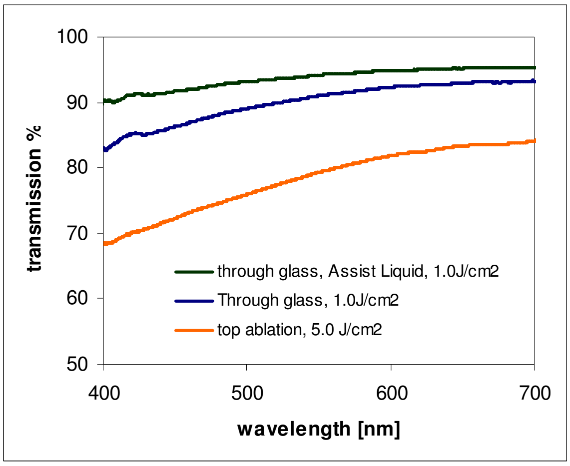


Fig. 8. Visible transmission spectrum of the three laser techniques (Note that the reference level of 100% is the transmission of bare glass).

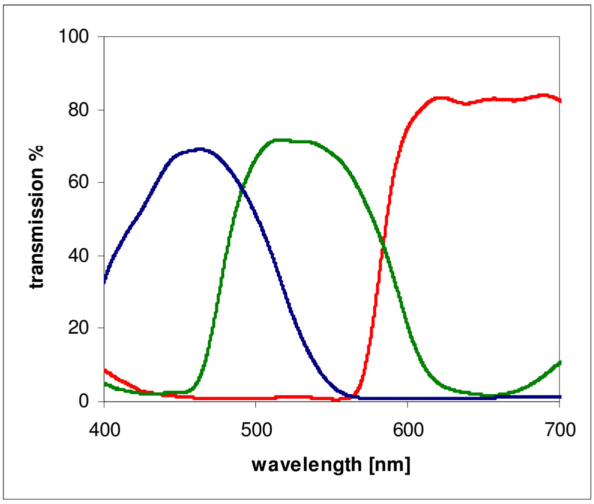


Fig. 9. RGB transmission for a sample LCD

7 Conclusions

This work presents a potential alternative to the use of wet-etch lithography for patterning BM. The Assist Liquid^{TM} laser process is a non-chemical technique offering possible cost savings as well as implicit environmental benefits. In combination with inkjet it could offer a path to replacing lithographic technology for the manufacture of colour filters.

There are a number of advantages of using this method over wet-etch techniques which include :

- it is a high quality process
- it is an energy efficient process
- it has the potential for high speed processing
- it is more environmentally friendly than alternative technologies.

8. References

[1] M. Henry, P. M. Harrison, J. Wendland, "Rapid Laser Patterning of ITO on Glass for Next Generation Plasma Display Panel Manufacture" SID Symposium Digest, vol. 38, pp 1209 – 1212 (2007).

[2] Plasma.com website. http://www.plasma.com/classroom/what_is_tft_lcd.htm

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[5] H. J. Booth, "Recent applications of pulsed lasers in advanced materials processing", Thin Solid Films, vol 453 – 454 (2004).