

A NOVEL LASER TECHNIQUE FOR PATTERNING BLACK MATRIX IN LCD MANUFACTURE

Paper (M1107)

Jozef J. Wendland, Paul M. Harrison, Matt Henry

Powerlase Ltd., Imperial House, Link 10, Napier Way, Crawley, West Sussex. RH10 9RA

Abstract

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 so competition is fierce. In an attempt to reduce costs, manufacturers are always interested in new technology to gain a lead on their competition. In recent years laser use has been increasing in the manufacture of FPDs – most notably as a replacement for wet-etch lithography to pattern ITO thin films on the screens of Plasma Display Panels.

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 solves the problems experienced in previous attempts at laser processing of this material: edge taper, feature variation, residue and debris. This technique has the potential to displace wet-etch lithography for this process by offering both cost and quality advantages over the incumbent technology.

Introduction

A Black Matrix (BM) 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 ([1]). 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. Also, BM can act as a boundary to aid ink jet printing of colour filter cells.

Current technologies and their drawbacks

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 (Figure 2). A black matrix material

can be photoimageable, i.e. it is a photoresist itself [2,3], so the number of steps is reduced. However, some of those steps will involve chemicals, which pose a risk to environment. On the other hand as LCD panels become larger and larger, and contains smaller and smaller features, so 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.

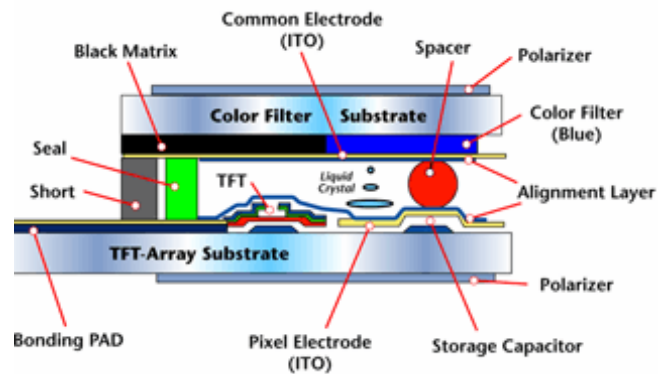


Figure 1. Simplified cross-section diagram of a TFT LCD display. BM-black matrix tracks are between all colour filter cells [1].

Table 1. Important requirements for black matrix patterning

Parameter	Target
Edge Resolution (Taper)	$\leq 1\mu\text{m}$
Edge Straightness	Best possible
Residue	98% optical transmission vs. glass

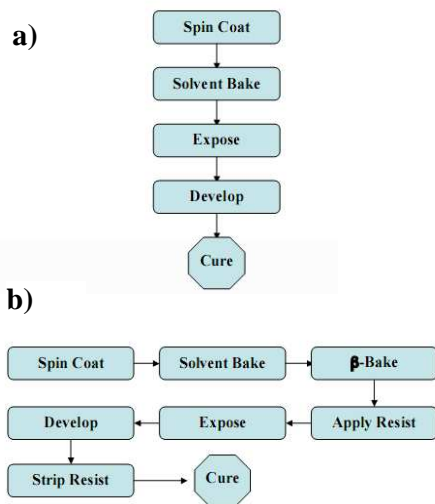


Figure 2. Processing steps required for directly imageable black matrix (a), and polyimide black matrix (b) [3].

Alternative laser based technology

An alternative method of producing black matrix is direct laser patterning. The main advantage of this method is the reduction of number of steps required to produce black matrix (see Figure 3), reduction in use of consumable chemicals, process flexibility, and also improved yield.

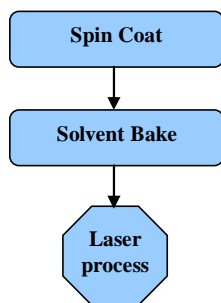


Figure 3. Processing steps for novel laser process.

Laser patterning 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.

Experimental setup

The system consists of a high power DPSS laser, beam delivery optics, and galvanometric scanner as shown below (Figure 4).

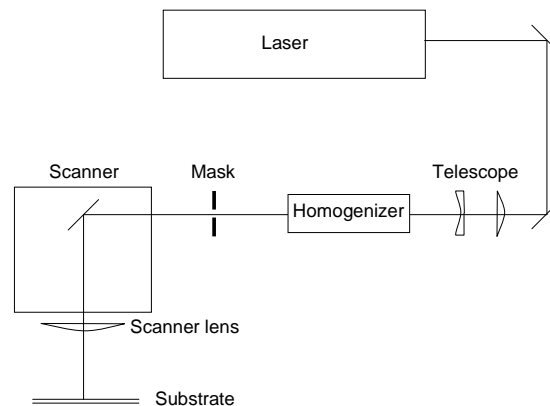


Figure 4. Workstation diagram

All substrates are LCD grade glass 0.8 mm thick with 1 μm thick black matrix resin. The laser used is a Starlase AO4 Q-switched DPSSL at the Nd:YAG fundamental wavelength of 1064 nm. At 6 kHz repetition rate, 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 collimated using a Galilean telescope and homogenized by a microlens array type homogenizer manufactured by LIMO GmbH. Figure 5 shows measured beam homogeneity from the unit.

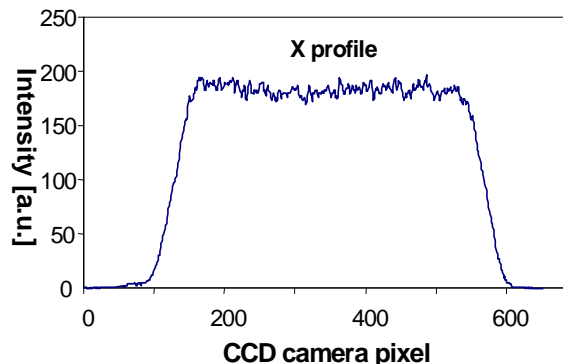


Figure 5. Measured homogenized intensity profile of the beam before mask.

The homogenized beam illuminates a rectangular test mask 0.4 mm \times 1.2 mm. This mask plane is relayed to the substrate and demagnified using an f-theta 163 mm focal length lens. The beam divergence after the mask is such that the beam fully fills a scanner input aperture of 25 mm. 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 \times 290 μm .

Power measurements are made at the workpiece using a Molectron power meter. Through the use of the external Powerlase attenuator the pulse energy reaching the workpiece is accurately controlled so that the process fluence could be carefully monitored.

The use of the homogenizer and mask creates a nominal flat top energy profile, therefore the fluence values measured are much more accurate and representative than in cases where Gaussian beam profiles with complex spatial energy profiles are approximated to uniform energy density.

BM ablation was assessed using a Nikon LM1500 optical microscope with a PC interface via a 12 Mega pixel camera into Lucia G software. This software allows microscopic measurements to be made against a Nikon calibrated standard.

Results and discussion

Several methods of BM patterning are considered, including top ablation, through glass ablation and through glass with water jet. These three methods are illustrated in Figure 6. All methods have advantages and disadvantages; those are briefly described in the sections below.

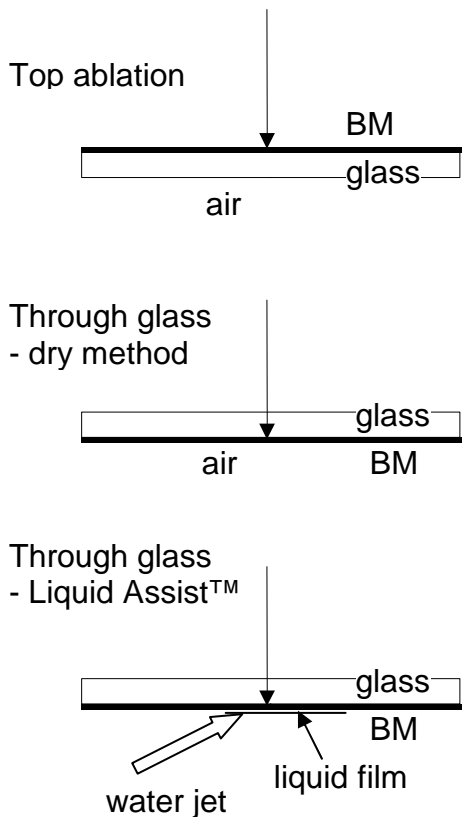


Figure 6. Illustration of BM processing methods.

Top ablation

The black matrix coating initially was ablated using a traditional method where the laser beam irradiates the top surface of the coating. This is a well known technique and is used for other thin film processes [4]. This method is very well suited for patterning partially transmissive thin films such as ITO. 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 due to the film thickness being less than optical absorption depth. In the case of black matrix resin, where its thickness is several times greater than optical absorption depth, 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 is an anisotropic process, which reduces resolution of material ablation.

The shape of the edge of 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:

$$d = 0.6 \cdot \frac{\lambda}{NA}$$

where NA is numerical aperture of projection system, and λ is wavelength of 1.064 μm .

The NA is defined as

$$NA = \sin(\theta)$$

where θ is acceptance angle, and is a ratio of lens aperture and working distance.

For the experimental system, the optical resolution is $\sim 8 \mu\text{m}$, and test results show an edge width of that order, which is not good enough for a LCD production process. The edge width can be improved by using a multipulse ablation approach, where 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 positioning of each pulse must be achieved with μm accuracy.

Another disadvantage of this process is residue. The vaporized material is partially deposited back onto the irradiated zone and onto the surrounding area.

For multipulse ablation the residue is removed with successive pulses from the irradiated area, 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 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 this method.

The fluence range for this process is 1.0–5.5 J/cm² for each pulse, and the number of pulses is 1 or 2. As can be seen in Figure 7 and Figure 8, which represent optimum performance, 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.

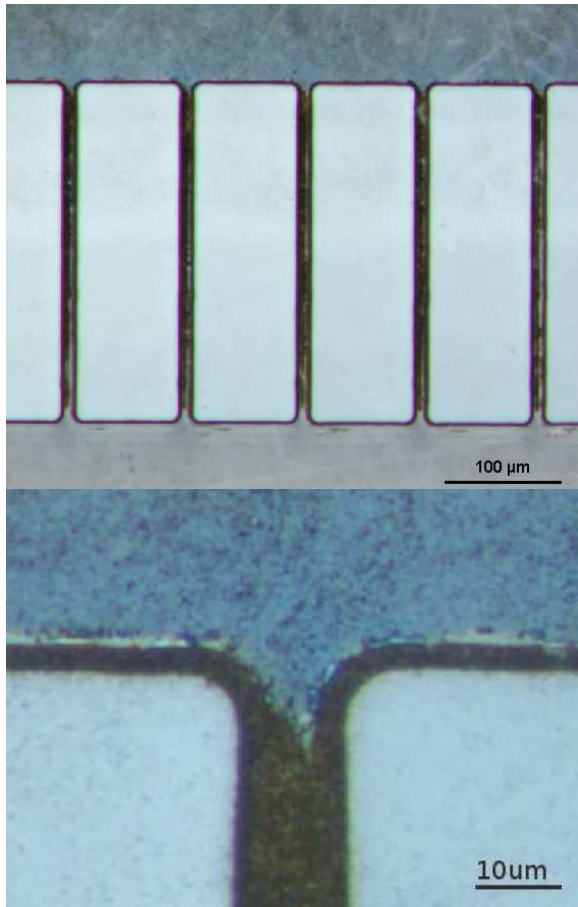


Figure 7. Top ablation, single pulse at 5.5 J/cm².

Moreover, the zone surrounding irradiated area is contaminated with a deposit.

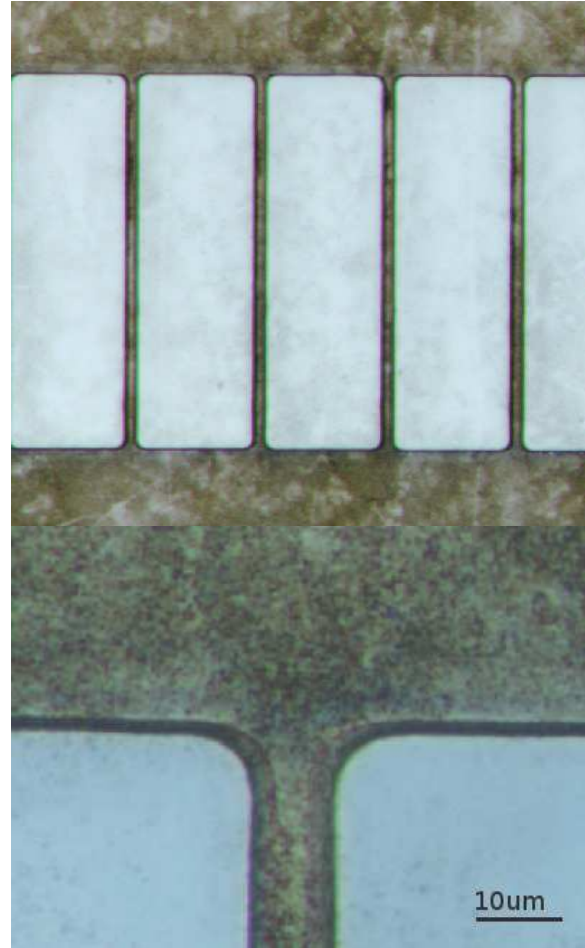


Figure 8. Top ablation, two pulses at 3.0 J/cm² each.

Through glass ablation – dry

A different ablation technique is where the laser beam comes from the glass substrate side [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: the laser energy causes vaporization of the BM resin at the interface. The rapid pressure build up causes explosive ejection of the BM material above. Although this process is also prone to re-deposition of BM material, the edge taper is much smaller. However, due to explosive removal mechanism the edge of processed material becomes irregular, and is sensitive to focal position. This suggests weakening of the BM film at the edges where there is some laser energy, but not enough to vaporize material.

Due to the fact that only part of the film must be vaporized, the energy requirements for this method are lower. Full removal of the coating can be

achieved at 0.75 J/cm^2 . However, to make sure that the process is consistent and repeatable the fluence was increased to 1.0 J/cm^2 to produce a sample as in Figure 9.

The results show that there is significant improvement comparing to the top ablation method, especially in terms of edge taper. However, there is some deposit around irradiated area, so unless the substrate is post-processed, this method is not suitable for production.

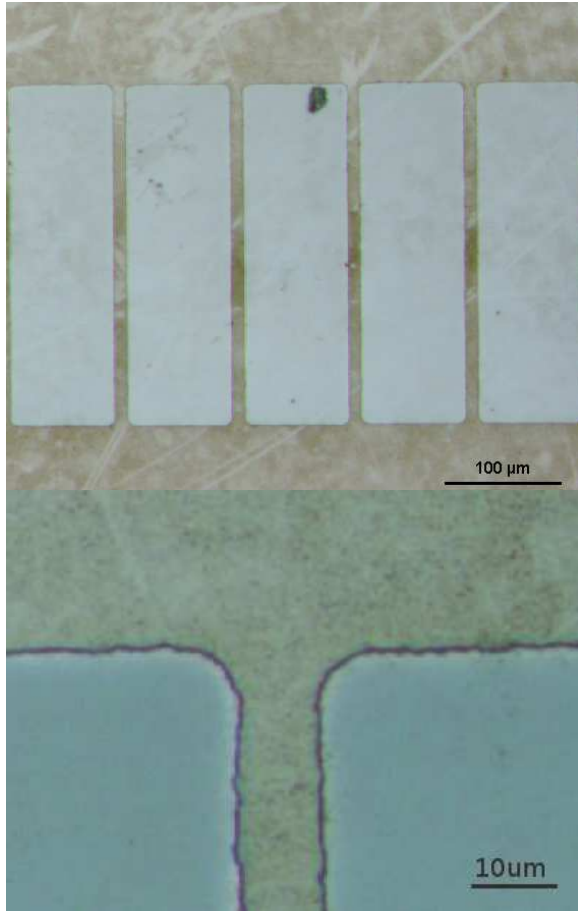


Figure 9. Ablation through glass, no assist, 1.0 J/cm^2 .

Through glass ablation – with water jet

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 was produced by a small water pump with a 1 mm round nozzle. The water pressure was about 1.4 bar, and the flow rate 0.4 l/min. The nozzle was positioned under the sample at $\sim 10^\circ$ angle to the

surface. The water jet after hitting the sample was flowing on the surface as a uniform film. The estimated water film velocity was 2 m/s.

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 10 below.

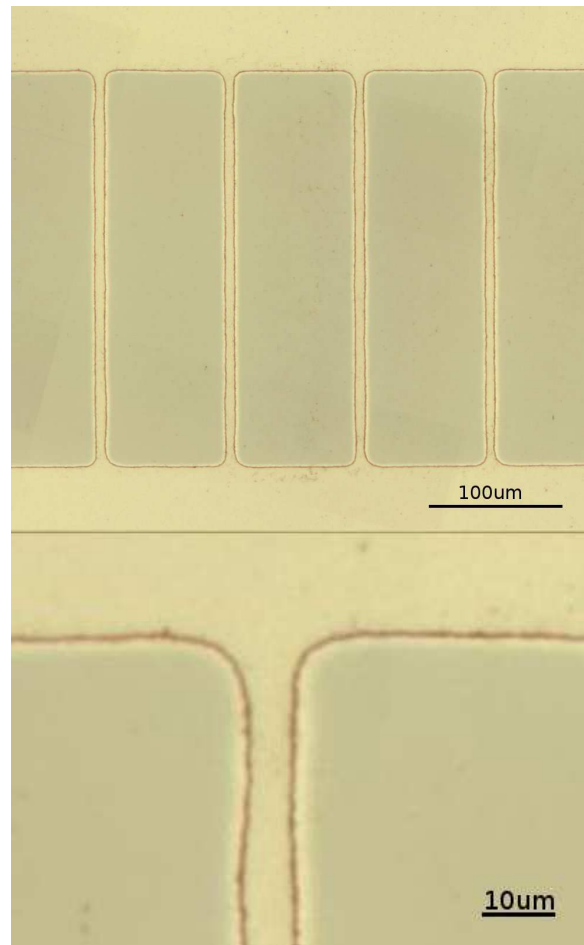


Figure 10. Ablation through glass with Liquid Assist™, 1.0 J/cm^2 .

The influence of water jet pressure was also tested. When the pressure was reduced to 0.5 bar at the nozzle, there was some deposit on the BM surface. The deposit creation mechanism is similar to those in the previously described techniques: deposition from BM vapour. But in this case the vapour is enclosed in a bubble, so the area affected is smaller. To avoid redeposition of the ablation products, the water flow must exceed a threshold value. The exact mechanism

is under investigation and further experimental trials are scheduled to explain this effect.

Nonetheless, a set of parameters have been found that allows clean patterning of black matrix film. Figure 11 shows a larger area of black matrix patterned with this novel laser process. The two images show a sample photographed with diascopic and episcopic illumination. The size of the BM track between each pixel is $10\ \mu\text{m}$.

It can be seen that the edges of each pixel are very well defined. A typical edge width (taper) is $< 1\ \mu\text{m}$, a cross-section of a processed sample is shown in Figure 12.

The resulting edge of each pixel is very straight; the straightness was assessed by digitising a microscope picture, extracting the edge profile, and performing statistical analysis over the full length of the long

edge: the standard deviation from a straight line is $\pm 0.3\ \mu\text{m}$, and the maximum variation $\pm 0.7\ \mu\text{m}$.

Summary: results vs. requirements.

The main process requirements are summarized at the beginning of this paper, here they are compared with achieved results (Table 2). As can be seen all parameters exceed targets. Process throughput is not included here because it depends on patterning machine design, in particular on laser beam delivery and substrate positioning systems. However, taking into account only required fluence and available laser power, a single Starlase AO4 laser can theoretically process up to $150\ \text{cm}^2/\text{s}$ assuming 50% efficiency in beam delivery. That corresponds to 32 s per standard 42" display.

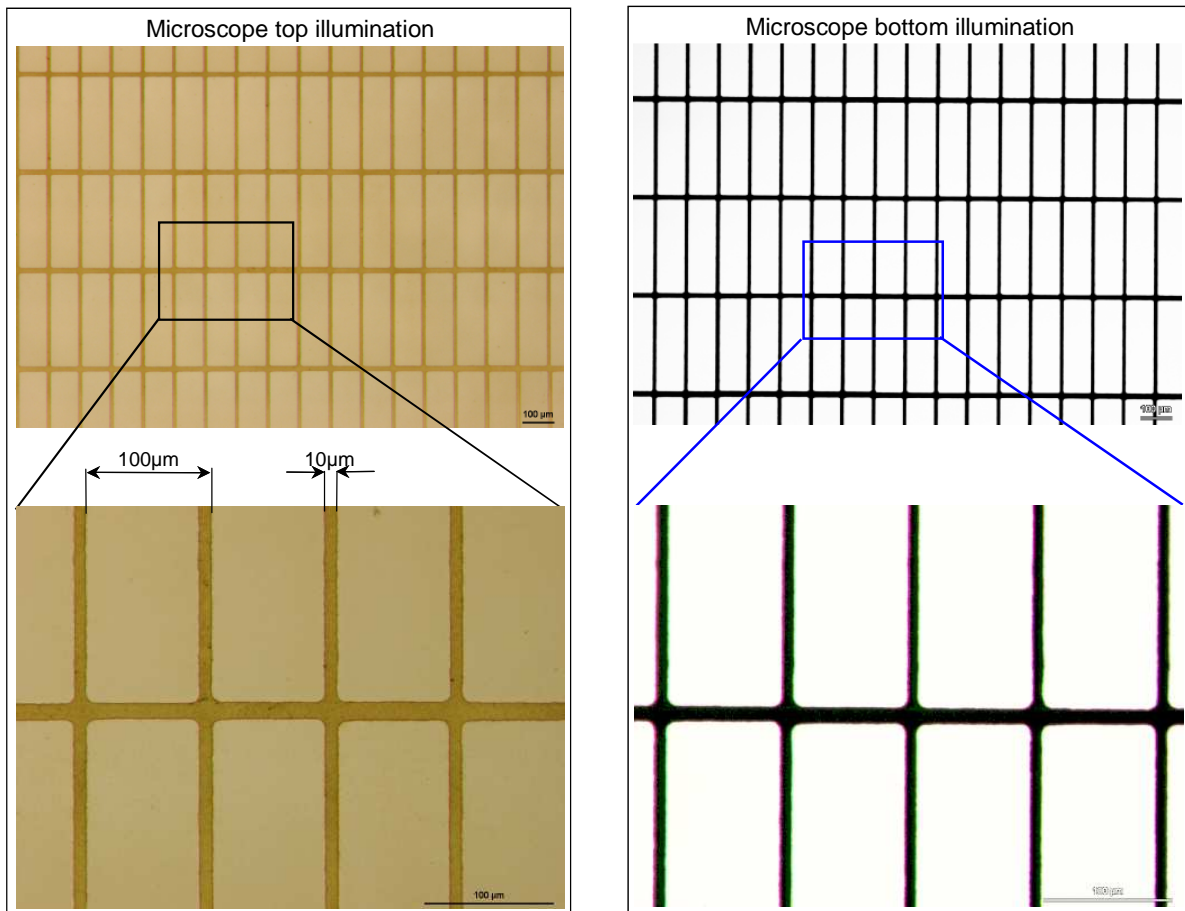


Figure 11. Black Matrix patterning using innovative laser-based Liquid Assist™ technique. The cell size is $90\ \mu\text{m} \times 290\ \mu\text{m}$, and the track width is $10\ \mu\text{m}$.

Table 2. Summary of requirements and achieved results.

	Customer Targets	Through glass with water
Edge Resolution (Taper)	$\leq 1\mu\text{m}$	0.6 μm
Edge Straightness	Best possible	$\pm 0.3\mu\text{m}$ (std dev) Over 290 μm
Residue	98% optical transmission vs. glass	Negligible

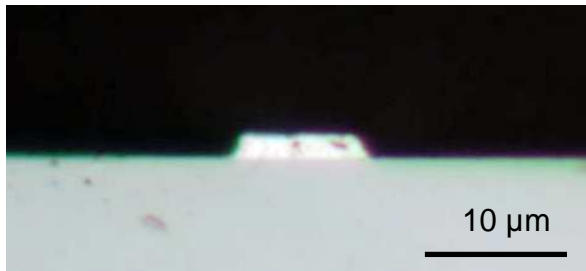


Figure 12. Typical cross section of a laser processed BM.

Conclusions

In this paper the authors describe an innovative laser-based technique for direct patterning of BM resin using industry-proven nanosecond pulsed diode pumped solid state (DPSS) lasers. The Liquid Assist™ method employs a laser beam and a water jet. The laser beam irradiates BM coating through the substrate and is absorbed at the coating-glass interface. On the surface of the coating there is a fast-flowing liquid film, which can be produced by a water jet directed at near-parallel angle to the surface.

The new method allows for very accurate and clean ablation of black matrix resins. This process is potentially very competitive to the industry standard: photolithography.

This process has a number of advantages versus lithography:

- Liquid Assist™ method is an innovative laser processing solution
- It achieves stringent customer specifications for BM patterning

- It is an energy efficient process
- It offers the potential for high speed BM patterning
- It employs only water – environmentally benign

The Liquid Assist™ technique can also be applied to other coatings. Also, laser beams of other wavelengths can be used, as long as the substrate is transparent at this wavelength, and the coating is absorbing.

References

- [1] Yuan-Tsung Chang, Chun-Hung Liou, Chun-Bin Wen. Inkjet revolution. *Circuits and Devices Magazine, IEEE* (2005) 21: pp. 8-11.
- [2] LG Chem webpage. <http://www.lgchem.com/>.
- [3] Brewer Science webpage. <http://www.brewerscience.com/products/sm/product-information/optoelectronics/>.
- [4] Matt Henry, Paul M Harrison, Jozef Wendland. Rapid Laser Patterning of ITO on Glass for Next Generation Plasma Display Panel Manufacture. *SID Digest of Technical Papers*. 2007.
- [5] H.J. Booth. Recent Applications of Pulsed Lasers in Advanced Materials Processing. *Thin Solid Films* (2004)