New process for cutting 4th generation OLED masks: Laser MicroJet® technology

T. A. Mai, B. Richerzhagen
Synova SA, Ch. de la Dent-d'Oche, Ecublens, Switzerland

Abstract

Display manufacturers are investing heavily into production lines for OLED (organic light-emitting diode) displays. For the manufacturing of OLEDs, shadow masks are employed for the deposition of the electroluminescent material onto the substrate of the OLED display. A typical mask is only 40 micron thick and has millions of tiny but lengthy apertures. The accuracy requirements are extremely high, as several different masks are used for each display. A new micro-machining technology - the water jet-guided laser, also called the Laser MicroJet® technology - has been developed for OLED mask cutting. By combining a hair-thin low-pressure water jet and a powerful short-pulsed Ytterbium fibre laser, the problem of heat damage has been completely solved. The Laser MicroJet® technology can produce small delicate openings with totally clean edges (no dross or slag). The cut apertures are free of contamination and thermal stress. Manufacturing precision (a few microns) and speed (25'000 - 30'000 apertures per hour) are so high that the production costs for OLED masks can be drastically reduced.

Keywords: OLED masks, OLED display manufacturing, laser cutting, water jet-guided laser, laser microjet.

1 Introduction

According to Display Search, a market research institute, the market for flat panel displays (FPD) is one of the fastest growing markets, with a projected annual growth rate exceeding 20% throughout the next few years. FPD can be found today in many electronic devices such as TV, computers, control panels, calculators, cellular phones and hand-held devices.

Organic LED (OLED) displays are relatively new amongst the various existing flat display technologies. It is foreseen, that OLED technology, which has only been commercially available for 5 years, will replace the present generation of liquid crystal displays (LCD) and plasma display panels (PDP) for small displays (cellular phones, digital camera, PDA). Other applications (e.g. computer and TV screens, flexible e-book, etc.) will also benefit from this technology in the near future.

OLED displays offer many advantages over LCD technologies such as greater efficiency, easier production, enhanced physical flexibility and lower production costs. Further advantages are high brightness, wider viewing angles, higher contrast, faster response time, lighter weight, lower power consumption, self emitting and therefore, requiring no backlighting. The OLED world market is expected to grow to $4.5 billion by 2008.

Despite important improvements achieved in the laboratory, sustainable series production of OLED displays has not yet been achieved. Present day producers of the displays are looking for new manufacturing techniques, able to meet the high requirements of this technology, whilst ensuring high productivity. This is especially the case for the manufacturing of OLED shadow masks, used for the deposition of the electroluminescent materials onto the substrate used for OLED displays.

The masks are made from thin Invar material. The apertures are obtained by electro-forming or micro photo etching. It is recognized that these methods are not applicable for new 3rd and 4th generation displays, due to the larger mask dimensions and resulting high fabrication costs. The lead times required for production of these masks, are also out of acceptable limits.

Conventional dry lasers are also not suitable for this sensitive application, due to the strong heating side effects. Since etching and conventional laser are not technically satisfying regarding the demands in precision, quality and speed, alternative solutions are required. The water jet-guided laser, which is presented in this paper, is a hybrid of laser and water jet technologies, and is a significant improvement for cutting shadow masks, as it combines high quality and speed with low costs.

2 OLED displays

OLED displays are based on the discovery that thin molecular films (polymers mainly) emit light. In an

OLED cell, multiple organic layers forming a p-n junction are interposed between a metallic cathode and a transparent anode and placed on a transparent substrate. A voltage – typically a few volts – is applied to the cell to generate the recombination of injected holes and electrons in the emissive layer, producing light. This phenomenon is called electroluminescence. The cell structure is depicted in **Fig. 1**.

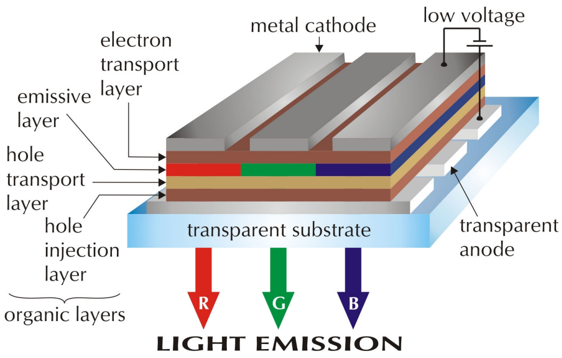

Fig. 1: *Basic structure of an OLED cell*

Due to the fact that OLED cells do not require backlighting, the resulting display is thinner than with other technologies. They are also brighter and have a wider viewing angle. The displays can also be produced on flexible substrates. The power consumption is 20 to 30% lower than LCD's, providing big improvements in efficiency, reducing heat dissipation and lowering electrical interference in devices.

3 OLED display mask manufacturing

Etching is currently the most widely used method for producing masks. It is, however, an expensive process and accuracy-related problems can arise as masks become larger. Lasers present several advantages compared to etching as they combine high flexibility and relatively low running costs. Dry laser cutting is, however, limited due to the presence of heat-affected zones and thermal influences. It is unsuitable for the manufacture of fine-pitch structures, as heating generates inaccuracies and warping. In addition, small particles and burrs remain after cutting, therefore post-processing steps are required [1], [2].

For the manufacture of OLED displays, metal screens are used for the deposition of emitting layers onto the substrate of the panel.

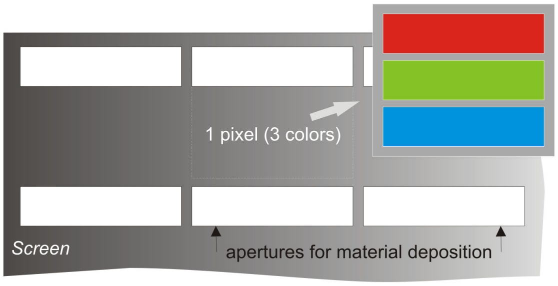

Fig. 2: *Example of mask design: a succession of rectangular openings results in a square pixel*

An OLED cell – corresponding to one pixel – contains all three colours (RGB). The mask openings are rectangular and at the end of the process a square containing the three colours is created. A simple example of a series of 100µm x 300µm opening masks is depicted in **Fig. 2**.

These masks are usually made from thin stainless steel or nickel/steel alloys. The thickness of the sheet metal typically ranges from 30 to 50µm.

4 Water jet-guided laser

The concept of the water jet-guided laser (also called Laser MicroJet®) is to guide a laser beam into a water jet. This is achieved by focusing a laser beam into a nozzle whilst passing it through a pressurized water chamber, as shown in **Fig. 3**.

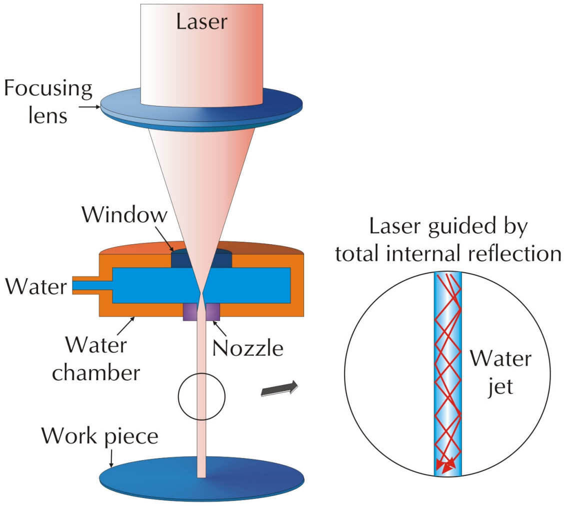

Fig. 3: *Laser MicroJet® principle: laser/water coupling and beam total reflection at water/air interface*

The primary function of the water jet is to guide the laser beam onto the work piece and more precisely, to the bottom of the groove, where ablation takes place. The extreme long working distances which are thus achievable, when compared to the few tens of microns depth of focus practical with dry laser processing, enables the cutting of thick material with small kerf widths and parallel cutting walls. The water jet also generates two other effects, which are very important for precision cutting.

First, the water jet prevents heat damage within the material, by constant cooling of the cut edges between laser pulses. The heat-affected zone, as a result, is negligible. Hence, the water jet-guided laser can be also called a "cold laser".

The second effect is the strong expulsion of the molten material out of the cut. Because of its high momentum, the water jet is much more efficient than any assist gas used in dry laser cutting. It also avoids surface contamination that may be caused by laser ablation. The water jet instantly cools all removed material, and remaining particles are contained in a thin water film covering the screen during cutting. This prevents particles from reattaching to the screen surface. An important point to note is that the mechanical force applied by the water jet to the screen is negligible (less than 0.1 N). As a comparison, the gas jet usually accompanying conventional laser cutting, creates a mechanical force typically in the range of 1 to 5 N.

5 Laser MicroJet® mask cutting

Because of its original features, the water jet-guided laser is well suited for screen cutting. The cutting width depends on the nozzle diameter, which can vary from 25 to 120µm. The cutting speed in turn, depends on the thickness and material composition of the screen, the thinner the piece, the higher the cutting speed.

In the following **Tab. 1,** some drilling rates in stainless-steel sheet are shown, as a function of the thickness, for two common forms of openings: circles and squares. It is three to five times faster than a conventional laser under similar conditions, and less expensive than etching.

Tab. 1: *Cutting rates for the water jet-guided laser*

	Mask thickness: 100 µm	
Type of opening	Opening size	Number of openings per hour (rate)
Round	ϕ 150 µm	8,000 / hour
Square	150 µm x 150 µm	6,000 / hour

	Mask thickness: 50 µm	
Type of opening	Opening size	Number of openings per hour (rate)
Round	ϕ 80 µm	30,000 / hour
Square	90 µm x 90 µm	25,000 / hour

As an example, rectangular 100µm x 300µm openings were drilled in trepanning mode with a 40µm nozzle and a drilling rate of 20’000 openings per hour. An infrared Ytterbium fibre laser was selected for this application. As can be see in the following microscopic image, **Fig. 4, t**he openings are very constant and cleanly cut.

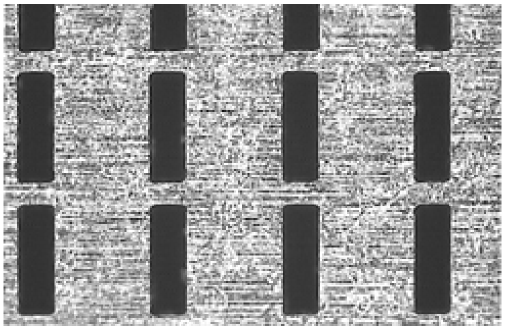

Fig. 4: *Microscopic front side image of rectangular openings, 100 * 300µm, cut in 50µm stainless steel*

The processed masks show no burrs and very few non-adhering particles, which, if present, are easily removed, with standard ultrasonic cleaning processes. The material also exhibits no visible signs of thermal damage.

The following microscope image, **Fig 5**, illustrates the high cutting quality obtained using the Laser-MicroJet® process, for the manufacture of very long narrow slots (aspect ratio of 1/1000) in 30µm thick Invar material. Due to the efficient cooling effects of the water jet, neither heating, nor warping effects are visible.

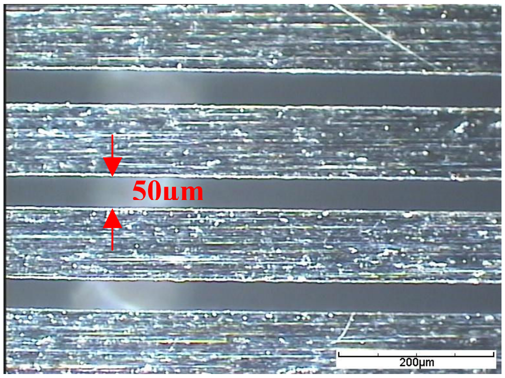

Fig. 5: *Microscopic rear side view of line type apertures, 55mm long, 50µm width on rear and 95µm on front side respectively*

Besides the high requirements on through-cut quality, a symmetrical and controlled wall taper of the cut is also essential, as shown in **Fig. 6**, for the optimal deposition of electroluminescent materials.

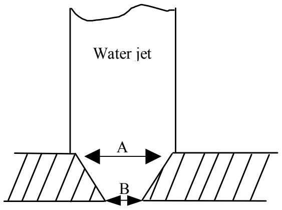

Fig. 6: *Cutting taper profile*

In **Tab. 2**, the variations of wall taper achieved as a function of laser power for a test carried out using a 120µm nozzle, are shown.

Tab. 2*: Wall taper angle as a function of laser power*

Laser Power (%)	A(µm)	B(µm)	Taper
65	71	36	60°
70	79	39	56°
75	81	41	56°
80	88	41	52°
85	93	46	52°
90	96	49	52°
95	96	54	55°

Because of the high cutting speed of 200mm/s, a mask sample with 60 cells and 14,520 total lines can be cut in only 110 minutes. Typical dimensions are as follows: 55mm line length, 95µm cut width on the front side and 50µm cut width on the rear side, and a 140µm pitch between lines. The taper angle and the slot width are controlled by adjusting the laser power and/or cutting speed. Due to the acceleration or deceleration of the x- or y movement at the start and end of each line, a widening at the slot ends could occur. To overcome this problem, a synchronous function can be introduced. When using this function, the laser is switched on and off while the axis is moving. All accelerations and decelerations are outside the slot and hence have no influence on the cutting results.

6 Conclusions

Within the fast-growing market for flat panel displays, the OLED technology offers many advantages. Today's producers are looking for new manufacturing techniques becoming available, to match the high requirements of this technology in terms of quality and productivity. This is especially the case for cutting screens used to deposit the emitting material onto the substrates.

Since etching and conventional lasers are not entirely satisfactory, alternative solutions are needed. The water jet-guided laser allows a significant improvement in screen cutting, as it combines high flexibility and high speed with low manufacturing costs. It is able to cut small openings with clean edges, avoids the problems of dross and slag and the screen is free of mechanical and thermal stress, as well as heat damage.

Fig. 7: *Synova LSS1200 Laser Stencil System*

Using the SYNOVA Laser Stencil System LSS1200 machine, shown in **Fig. 7**, the cutting of line aperture OLED masks, is repeatable and reliable, while the taper angle and slot width can be controlled by adjusting the laser power and/or cutting speed. The machine combines the advantages of a high energy pulsed infrared fibre laser, with a hair-thin water jet. Whilst the laser is used for material ablation, the water jet is used for guiding the laser light, cooling the material edges and protecting the sample from particle contamination, advantages that are essential for economically cutting high quality products.

Bibliography

[1] Sugimoto Akira; Ochi Hideo; Fujimura Soh; et. al, Flexible OLED displays using plastic substrates, IEEE Journal of selected topics in quantum electronics, 2004, Vol. 10, No1

[2] J. Kickelhain, LPKF Laser & Electronics AG, Mikroschneiden von SMD-Schablonen für den Lotpastendruck, LEF 2000 Symposium, Erlangen, Germany