Manufacturing of 4th Generation OLED Masks with the Laser MicroJet® Technology

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Abstract

Display manufacturers are investing heavily into production lines for OLED (Organic Light-Emitting Diode) displays. Volume production of active-matrix OLED has already started. The production will increase through the TV mobile phones demand for high-resolution mobile displays as the AM OLED can switch pixels 1,000 times faster than TFT-LCD technology. A typical mask is only 40 micron thick and has millions of tiny but lengthy apertures. The requirement for accuracy is very high, since several masks are used for the same display. A new micro-machining technology, - a hybrid of laser and water jet technology, the water jet-guided laser, also called as 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 fiber 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. Precision (few microns) and speed (25,000 – 30,000 apertures per hour) is so high so that the manufacturing costs for OLED masks can be drastically reduced. The process is applicable for any mask dimension. Synova cutting systems, which have a cutting area of 1300 x 900 mm for producing 4th generation OLED masks are being used now at major mask manufacturers.

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, commercially available for only 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) 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 cost. Further advantages are high brightness, wider viewing angle, higher contrast, quicker response, lighter weight, low power consumption, self emitting and hence, no backlight required. The OLED world market is expected to grow to $4.5 billion by 2008. Despite important improvements achieved in the laboratory, a sustainable series production of OLED has not yet been obtained. Today's OLED producers are looking for new manufacturing techniques able to match the high requirements of this technology, while ensuring the productivity. This is the case for the manufacturing of OLED, shadow masks employed for the deposition of the electro-luminescent material onto the substrate of the OLED display.

The masks are made out of thin Invar material. The apertures are obtained by electro-forming or micro photo etching. It is recognized that these methods are not applicable for the new generations (3rd and 4th generation) due to the larger mask dimensions and high fabrication costs. The lead times are out of any acceptable limit. Conventional dry lasers are also not suitable for this sensitive application due to the strong heat effects. Since etching and conventional laser are not technically satisfying regarding the demand in precision, quality and speed, alternative solutions are required. The water jet-guided laser, a hybrid of laser and water jet technologies, is a significant improvement in mask cutting, as it combines high quality and speed at 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 and as a result light is produced. This phenomenon, is called electroluminescence, see Figure 1.

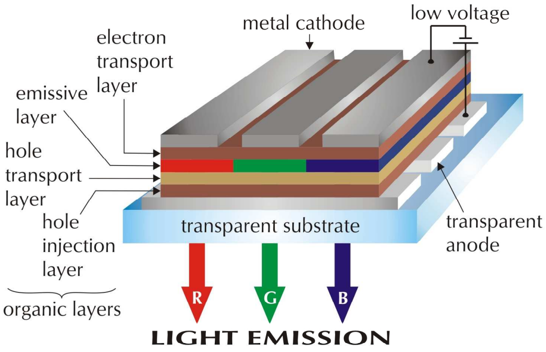


Figure 1 Basic structure of an OLED cell

Due to the fact that OLED cells do not require backlighting, the resulting display is thinner than with other technologies. It is also brighter, even from a side-viewing angle. OLEDs can be produced on flexible substrates. Their power consumption is 20 to 30% lower than LCD's providing maximum efficiency, thus minimizing heat and electrical interference in devices.

3. Metal Screens for Emittive Deposition

For the manufacture of OLED displays, metal screens are used for the deposition of emitting layers onto the substrate of the panel. An OLED cell – corresponding to one pixel – contains all three colors (RGB). The mask openings are rectangular and at the end of the process a square containing the three colors is created. A simple example of a series of 100µm x 300µm opening masks is depicted in Figure 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.

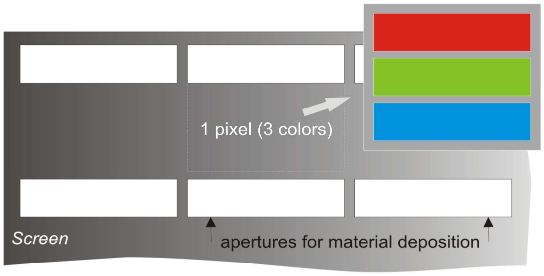


Figure 2 Example of mask design: a succession of rectangular openings results in a square pixel

Several small screens can be fabricated in parallel with a single mask. For example, as one cell-phone screen has more than 30,000 pixels, the total number of openings in the mask can reach 3 million. The cut quality is extremely critical, as very precise and constant shapes are required. Furthermore, in order to meet the productivity requirements, screens must be manufactured at high speed.

Etching is currently the most widely used method for producing these screens. It is however an expensive process and accuracy-related problems can arise as screens 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 damage. It is unsuitable for the manufacture of fine-pitch structures, as heating generates inaccuracies and bending. In addition, small particles and burrs remain, and thus post-processing steps are required. The water jet-guided laser cutting is a new cutting technology that provides both, high production rates and excellent quality in a single step process, permitting lower fabrication costs when compared to the other available processes. It has been recently adapted to screen cutting and already proves to be the best method for this application.

4. Water Jet-Guided Laser

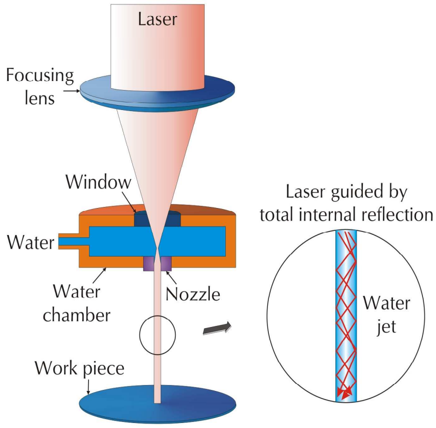


Figure 3 Laser MicroJet® principle: laser/water coupling and beam reflection at water/air interface

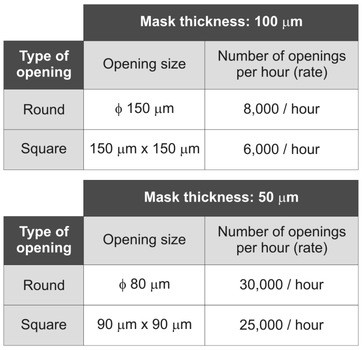
The concept of the water jet-guided laser (also called Laser MicroJet®) is to guide a laser beam into a water jet. This is achieved by focusing a laser beam into a nozzle while passing through a pressurized water chamber. The water jet emitted from the nozzle guides the laser beam by means of total internal reflection that takes place at the water/air interface, in a manner similar to conventional glass fibers. The water jet can thus be referred to as a fluid optical wave-guide of variable length as shown in Figure 3.

The primary function of the water jet is to guide the laser beam onto the work piece, more precisely to the bottom of the groove, where the ablation takes place. The extreme long working distance if compared to the few tens of microns depth of focus achieved by dry laser process enables the cutting of thick material with small kerf widths and parallel cutting walls. The water jet generates also 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 the 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 from 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 maintained 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® screen 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, ranging from 25 to 120µm. The cutting speed depends on the thickness and the material of the screen, the thinner the pieces, the higher the speed. Table 1 shows some drilling rates in stainless-steel sheets, in function of the thickness, for two common shapes of openings: rounds and squares. It is three to five times faster than conventional laser in similar conditions, and less expensive than etching.

Table 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

In the example presented in Figure 4, rectangular 100µm x 300µm openings were drilled in trepanning mode with a 40-µm nozzle and a drilling rate of 20,000 openings per hour. An infrared Ytterbium fiber laser has been selected for this application. Openings are very constant and clean. The processed screens show no burrs and very few non-adhering particles, which are easy to remove with a standard ultrasonic cleaning process. The material has no visible thermal damage, as shown in Figure 5.

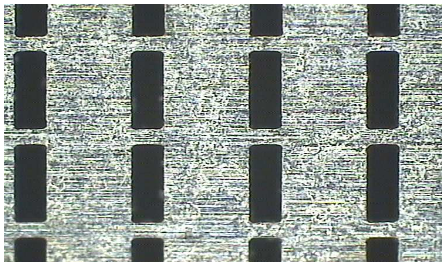


Figure 4 Front view of rectangular openings, 100 x 300µm in 50µm stainless steel

The following microscope picture illustrates the high cutting quality results obtained using the Laser MicroJet® technology for the manufacture of very long narrow slots (aspect ratio of 1/1000) in 30µm thick Invar material. Due to the efficient cooling effect of the water jet, neither heat nor warping effects exist.

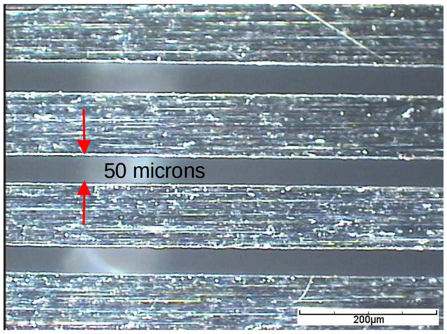


Figure 5 Rear view of line type aperture, 55mm length, 50µm and 95µm width front and back side respectively

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

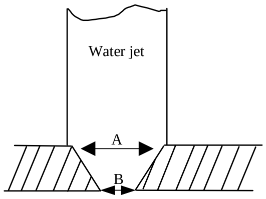


Figure 6 Taper Profile

Table 2 shows the variation of wall taper as a function of laser power for a test using a 120µm nozzle.

Table 2 Wall taper angle, as a function of laser power

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

Because of a high speed of 200mm/s, a mask sample with 60 cells and 14,520 total lines was cut in only 110 minutes. Typical dimensions are as follows: 55 mm line length, 95µm cut width on the front side, 50µm cut width on the backside and 140µm pitch between lines. Due to the acceleration or deceleration of the x- or y movement at the start and end of the line, a widening at the slot ends could occur. To overcome this, a synchronous function was introduced. When using this synchronous 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 of flat panel displays, the OLED technology offers many advantages. Today's producers are looking for new manufacturing techniques available to match the high requirements of this technology in terms of quality and productivity. This is the case for cutting screens used to deposit the emitting material onto substrates.

Since etching and conventional laser 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 at low manufacturing costs. It is able to cut small openings with clean edges, avoiding dross and slag; the screen is free of mechanical and thermal stress, as well as heat damage. Furthermore, the cutting of line aperture OLED masks on SYNOVA LSS1200 machine is repeatable and reliable; while the taper angle and the slot width can be controlled by adjusting laser power and/or cutting speed. The machine combines the advantages of a high energy pulsed infrared fiber laser with a hair-thin water jet. While the laser is used for material ablation, the water jet is used for guiding the laser light, cooling the edges and preventing the sample from particle contamination, advantages that are essential for cutting with high quality.

7. References

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