CUTTING OLED SMARTPHONE DISPLAYS WITH A UV FEMTOSECOND LASER

In the last few years OLED (organic light-emitting diode) technology has revolutionized the display industry. As the technology advances and OLED displays continuously improve in contrast, resolution, color range, lifetime and power efficiency, older display technologies are rapidly being supplanted in devices ranging from TVs and laptops to smartphones and wearables. Moreover, as the demand for thinner, flexible, foldable and transparent screens continues, so too does the quest for new manufacturing tools. Because of the high resolution and sensitive circuitry in OLED displays, a key challenge in their manufacture is achieving narrow kerf widths with negligible heat-affected zones (HAZ).

OLED displays can be rigid type (where the OLED stack is on a glass substrate) or a non-rigid type (polymer substrate). Important applications include cutting the outline of the display, away for the emissive OLEDs themselves, as well as cutting a hole through the full OLED stack, which is comprised of numerous layers: substrate layer, OLED emission layers, polarizer layer, touch sensor layer and protective layer. Most of these consist of polymer materials, with polyethylene terephthalate (PET) and polyimide (PI) among the most common. Each layer is a few microns to 100 µm thick and the total thickness of the stack is typically 300-500 µm. Some layers are bonded together using an optically clear adhesive (OCA). Cutting the stack mechanically results in edge damage because of the brittle nature of some of the layers, a problem that is exacerbated by tooling wear. Similarly, cutting with longer pulse width lasers results in large HAZ or other quality issues. Moreover, because of the differing optical properties of layers within the stack, cutting with IR or green wavelength lasers—even in the ultrashort pulse (USP) width regime—can also be problematic.

Considering the case of both USP along with a shorter UV wavelength, we see the potential for an ideal choice for cutting these films. In addition to the benefits of low HAZ associated with ultrashort pulse durations, the short wavelength of UV lasers allows the pulses to be more readily absorbed by the diverse materials in the stack and, with smaller focus spot sizes, allowing for cleaner, narrower cut widths. In addition, the low divergence of focused UV beams is helpful for cutting thicker OLED stacks without the need for additional passes to widen the cutting kerf.

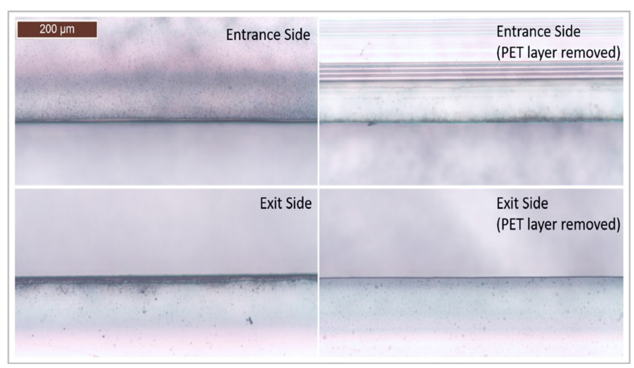

Figure 1. Microscope images of a ~375-µm-thick OLED film stack cut with a Spectra-Physics IceFyre FS UV50 femtosecond laser in multi-pass mode, resulting in a net (effective) cutting speed of ~133 mm/s.

To verify the benefits of using a femtosecond UV laser in cutting OLED films, engineers at MKS industrial applications lab have demonstrated the cutting of ~375-µm-thick, 6 inch non-rigid OLED displays for mobile phones using a Spectra-Physics IceFyre® FS™ UV50 high-power femtosecond UV laser. The OLED materials used in the tests were complete displays in pre-cut panel form with PET protective layers on both surfaces, allowing the tests to be performed in the intended cut path exactly as would be done for mobile device manufacturing. Figure 1 shows microscope images of the cut, demonstrating excellent surface quality.

In multi-pass cutting mode with >40 W power from the laser at 2 MHz, the film was cut with an effective speed of ~133 mm/s. It is noteworthy that even when operating at twice the laser's nominal operating frequency of 1 MHz, there is still ample power available, which is important for simultaneous optimization of both throughput and quality. The clean cuts, with a HAZ of just 5-10 µm (and even lower at the exit-side surface), demonstrate that IceFyre FS UV50 lasers are well suited for cutting these challenging multilayer film stacks.

Figure 2 shows the cross-section image of the cut. This view confirms the quality of the cutting process across all layers. The smooth sidewall and even cut of all layers with no indication of melting, delamination or seeping of OCA confirms that the IceFyre FS UV50 laser is an ideal choice for cutting OLED stacks.

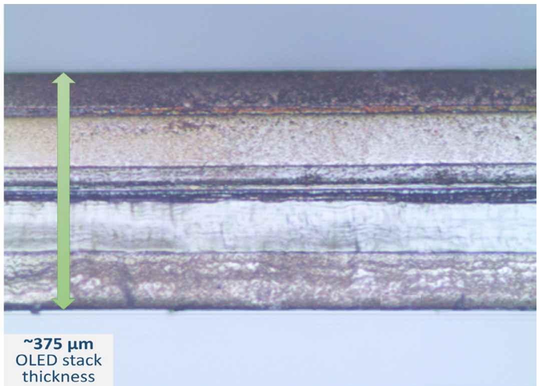

Figure 2. Cross-section microscope image of a ~375-µm-thick OLED film stack cut with a Spectra-Physics IceFyre FS UV50 femtosecond laser in multi-pass mode.

These initial tests, while limited to smaller cut lengths, were quite promising. Further testing was performed using a two-axis scanning galvanometer system with a longer focal length and large scanning field size capable of encompassing the entire cutting path. Therefore, the entire OLED display could be cut out with a high-speed, multi-pass process, thus taking advantage of the laser's high power at high PRFs. In addition, the cutting speed was determined for a range of fluences, which is useful for further throughput optimization from the perspective of system design, such as taking into account the possibility of beam splitting. In Figure 3, the cutting speed and surface HAZ are plotted over this fluence range.

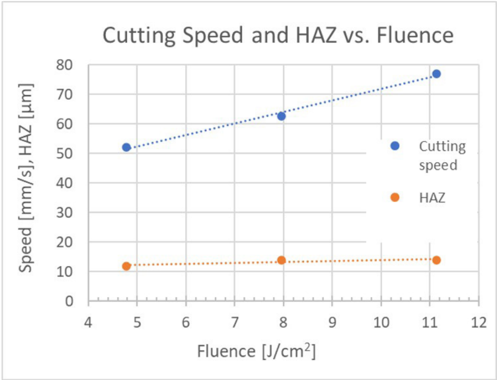

Figure 3. OLED stack cutting speed and HAZ change with UV beam fluence.

The data shows that, while higher fluence results in higher cutting speeds, it is not proportionally higher. Indeed, the cutting speed increases by just ~1.5× with a fluence increase of 2.3×. Therefore, operating at the reduced fluence is more efficient and it is clear that using a beam splitting system design will allow for highest overall throughputs. In addition, the quality in terms of measured HAZ trends lower with reduced fluence, further making the case for processing with multiple low-power beams. Based on the data generated in these tests, using multiple lower-power beams allows throughput to be dramatically improved, as seen in Figure 4.

We see from Figure 4 that the overall cutting speed approaches 160 mm/s when changing from a single high-power beam to a three-beam configuration. It is also imperative to maintain good cut quality throughout the entire cut. As shown in Figure 5, the surface HAZ is uniformly small around the cutting perimeter, particularly for the final display surface after the PET protective layer is removed.

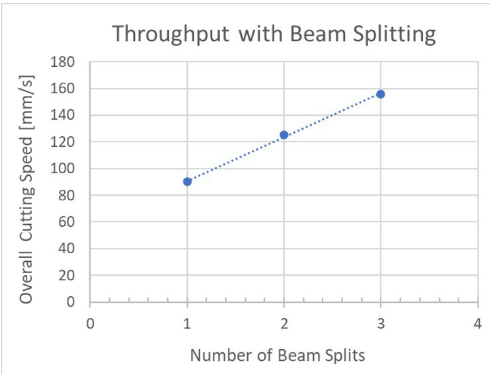

Figure 4. Beam splitting allows for higher overall throughput with a large-field scanning galvanometer-based cutting system.

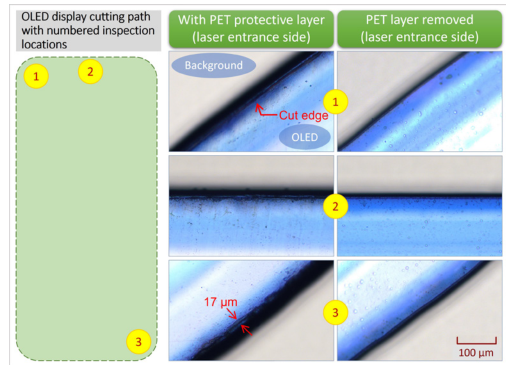

Figure 5: Excellent quality is achieved around the entire perimeter of the OLED display cutting path.

Inspection of both the corners and straight segments show that the excellent quality first demonstrated in short cutting lengths is replicated in the larger, full size OLED cut out. On the outer PET protective layer, HAZ is typically in the range of 10-20 µm. After the PET layer is removed, we see HAZ uniformly in the range of 5-10 µm or less on the display's outer surface itself. These measurements are for the laser entrance side where we typically see greatest amount of HAZ, and the exit surface HAZ is significantly lower.

OLED displays are comprised of numerous materials having widely varying thermal, optical, and mechanical properties, thus presenting a challenge for cutting them with both high speed and high quality. Lasers, however, have a remarkable history of providing solutions for even the greatest of manufacturing challenges, and we find no exception here. With the IceFyre FS UV50 laser's combination of both an ultrashort pulse width and a short UV wavelength, we have shown that it is highly capable of cutting full-sized smartphone OLED display panels with both high throughput and excellent quality.

PRODUCT

IceFyre® FS™ UV50

The IceFyre FS UV50 laser is an extraordinary leap forward in industrial femtosecond UV laser technology, delivering industry-leading performance, versatility, reliability and cost of ownership. IceFyre FS UV50 is the highest performing UV femtosecond laser on the market, providing >50 W of UV output power at 1 MHz and pulse widths of <500 fs. The laser offers exceptional versatility for optimal process performance with adjustable repetition rates from single shot to 3 MHz, pulse-on-demand (POD) and position-synchronized output (PSO) triggering, and TimeShift™ programmable pulse capability for flexible burst-mode operation. Customers benefit from the ultrashort pulse duration and superior beam quality at the UV wavelength, enabling micromachining of complex and challenging parts with highest precision and quality with negligible heat affected zone (HAZ) at the highest throughput. The IceFyre FS UV50 laser is designed for industrial use and offers reliable and robust 24/7 operation at industry leading cost-performance. Based on Spectra-Physics' *It's in the Box*™ design, IceFyre FS UV50 integrates laser and controller into the industry's smallest package.

	IceFyre FS UV50
Wavelength	343 ±2 nm
Power	>50 W @ 1 MHz and 1.25 MHz
Maximum Pulse Energy	>50 µJ @ 1 MHz
Repetition Rate Range	Single shot to 3 MHz
Pulse Width, FWHM	<500 fs
Pulse-to-Pulse Energy Stability	<2.0% rms
Power Stability (after warm-up)	<1% rms over 8 hours

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Application Note_64_01/23/23