Ultra-Short Pulse Lasers Enable Precision Flexible OLED Cutting

FLORENT THIBAULT, PRODUCT LINE MANAGER, HATIM HALOUI, APPLICATION MANAGER, **JORIS VAN NUNEN,** PRODUCT MARKETING MANAGER, INDUSTRIAL PICOSECOND LASERS, COHERENT

Organic light emitting diode (OLED) displays have become a dominant technology over the past few years, in products ranging from smartphones to large screen televisions. The unique construction of OLED displays, together with the level of precision at which they are fabricated, present many practical challenges for the manufacturer, with device cutting being a standout example. Ultra-short pulse lasers have emerged as an ideal solution to this challenge, and this article examines their advantages and use in flexible OLED production.

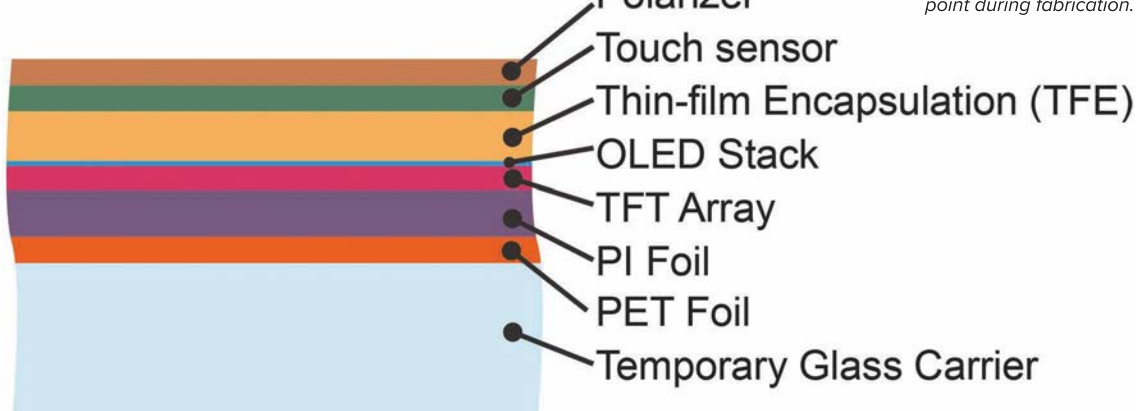
▶ *Figure: Modern flexible display concept with touch interface produced using plastic electronics.* ▶

Flexible OLED Cutting Requirements

OLED displays comprise a relatively thin, but complex stack of heterogeneous materials, all deposited on highly heat-sensitive polymer substrate. Specifically, this may include a silicon based thin film transistor (TFT) layer, several layers of active organic materials, a conductive transparent indium tin oxide (ITO) layer, and other semiconductor and polymer materials like PET or polyimide.

Flexible OLED displays that have become popular for smartphones and smart watches, present unique fabrication requirements and are produced in a different manner than rigid glass-based displays. In particular, while flexible OLEDs are also produced on glass substrates, at some point in the process flow the OLED display is removed from the temporary glass carrier.

▶ *Figure 1: Simplified schematic (not to scale) of typical flexible-OLED structure. The glass carrier is removed at some point during fabrication.* ▶



Typically, this is accomplished using an excimer laser-based technique called Laser Lift-Off.

While the details of where and how the OLED display is separated from the carrier vary among manufacturers, all flexible OLEDs must eventually be precision trimmed to their final shape. Furthermore, their final shape increasingly includes rounded cuts and contours, and even cutouts.

Typically, these requirements translate into a cutting kerf width of only 25 µm, and a process affected zone in the tens of microns range. This level of precision precludes virtually all traditional mechanical cutting methods. Moreover, from a practical standpoint, economics requires that any cutting method deliver 24/7 reliability, with high throughput and a targeted yield above 99.99%. Laser cutting has emerged as the only method for flexible OLED trimming that can meet all these requirements.

To implement laser cutting, the laser is directed through a pair of galvanometer scan mirrors and then a scan lens which focuses it to a spot size in the 10 to 20 microns range on the surface of the OLED. Because the field of view of the scan lens is relatively limited – typically a few hundred millimeters – a motorised xy stage can provide additional part motion in conjunction with this beam scanning.

Laser Ablation

Lasers can process material photothermally or photoablatively. Traditional industrial lasers produce either continuous output, or pulsed output with pulsewidths in the tens of nanoseconds range. For these lasers, material removal occurs through a photothermal interaction, i.e., intense spatially confined heating. This allows relatively high material removal rates; however, for the most demanding tasks, peripheral heat affected zone (HAZ) damage can be a significant problem. For multilayer

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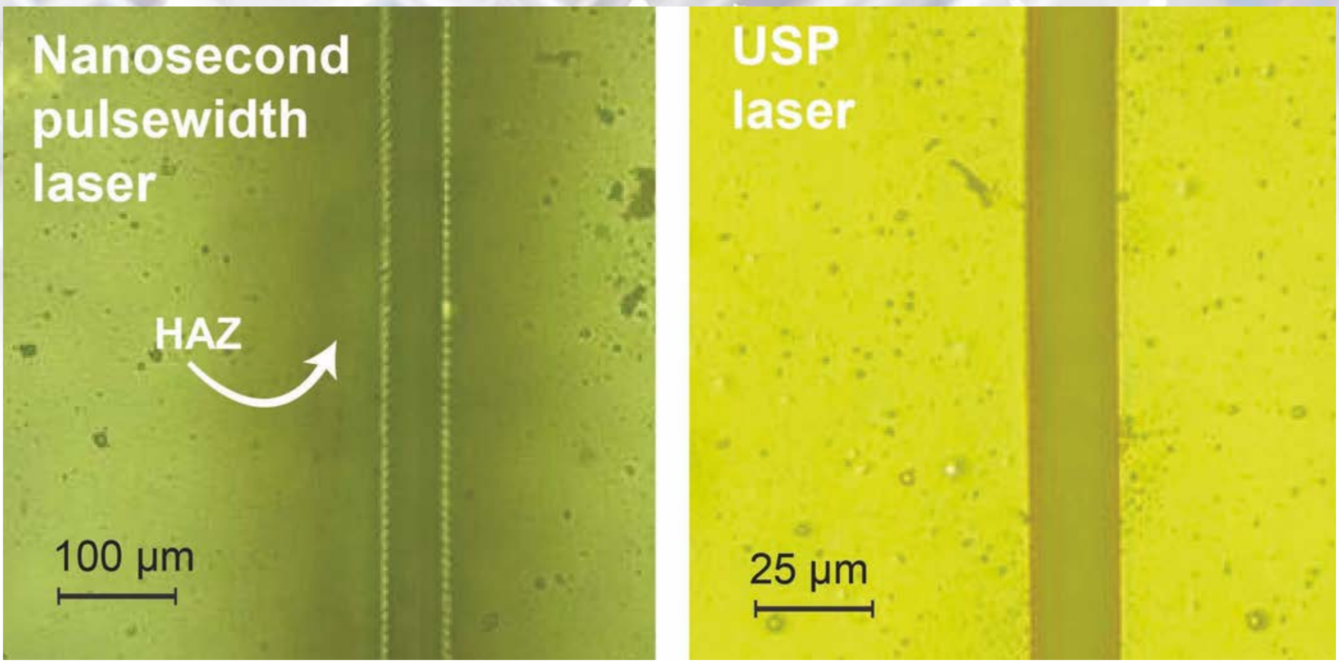
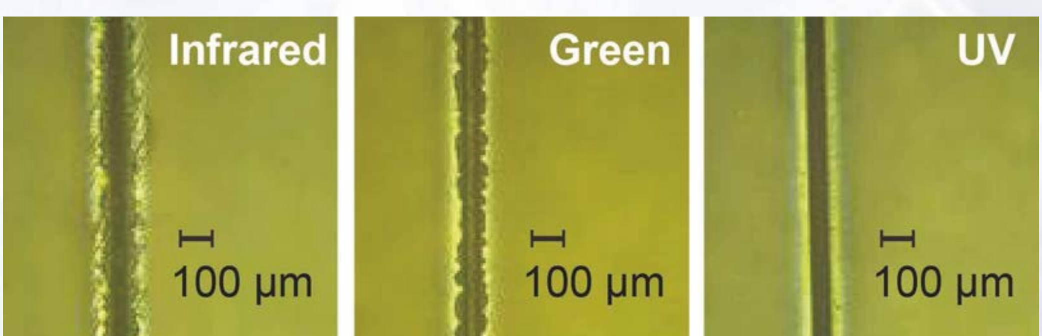


▶ *Figure 2: "Dark Yellow," 30 µm thick polyimide sheets scribed with a nanosecond and USP laser (in the UV). The nanosecond laser processed at 66 mm/sec, while the USP laser cut at 193 mm/sec. The nanosecond laser produced a substantial HAZ – seen as a darkening in this image – while the USP laser produced none, and also delivered a substantially smaller cut width. Note the difference in scale between the two images.* ▶

targets such as OLEDs, this undesirable damage can include delamination of surface coatings, microcracking, changes in the bulk material properties, and/or the presence of recast material.

The second mechanism for laser material removal is based on photoablation, typically accomplished using ultra-short pulse (USP) lasers with very high peak powers. This power is sufficient to directly break the molecular or atomic bonds which hold the material together, rather than simply heating it, resulting in inherently "cold" material removal. Plus, the material is exposed to the laser light for such a short time that the energy isn't carried beyond the area of impact. This minimises the heat affected zone, and leaves no recast material that could require post-processing.

Flexible OLED cutting represents an excellent example of where the reduced kerf width and smaller HAZ of USP lasers delivers a unique advantage. Even nanosecond pulsewidth lasers with ultraviolet (UV) output, which are widely employed in challenging applications throughout microelectronics manufacturing (e.g., for high precision wafer cutting, scribing and marking) cannot reach the required level of accuracy for this application (see figure 2).



▶ *Figure 3: A 220 µm thick simulated display layer on glass scribed with a Coherent HyperRapid NX laser with output in the infrared, green and ultraviolet. This clearly demonstrates the improvement in cut quality with decreasing wavelength.* ▶

Optimising Process Parameters

USP lasers are commercially available with spectral output in the near infrared, green and UV. In the case of OLEDs, operation in the UV is particularly advantageous because virtually all of the materials used (both semiconductors and polymers) absorb well in this part of the spectrum. UV limits the penetration depth of the light into the material, providing fine process control and further minimising the HAZ. Furthermore, since process quality (specifically kerf width) generally improves in virtually all materials as wavelength decreases (see figure 3), the USP ultraviolet laser is the ideal choice for this application.

However, it should be noted that ultraviolet lasers are not a panacea. For example, shorter wavelength lasers have lower material removal rates than longer wavelength sources (all other factors being equal), so processing speed also decreases with wavelength.

Additional factors may affect the choice of laser for a specific application. For example, process speed scales with higher laser power or pulse repetition rates. However, laser cost scales directly with these parameters, so increasing them raises cost. Determining the optimum laser characteristics for a given process typically requires some practical testing from an experienced laser supplier offering applications development services and a wide range of technologies and techniques. Thus, the user often effectively buys a process rather than just a laser.

Testing and practical experience have shown that a USP laser delivering 30 W of UV achieves the desired throughput with adequate process headroom for flexible OLED cutting. Additionally, the laser must produce a high quality, Gaussian beam in order to yield a sharp and clean cut, as well as exhibit industrial-grade stability and reliability to maintain the expected yield over 24/7 operation.

Practical USP Lasers

Manufacturers have responded to these needs with a new generation of USP products specifically engineered to deliver in all these areas. For example, Coherent's HyperRapid NX series of USP lasers incorporate a number of output control options that enable a high degree of process optimisation and process flexibility, therefore maximising customers' return on their capital investment.

Particularly important features in this context are pulse gating, continuous energy control of individual pulses, and the ability to alter repetition rate on the fly. These are necessary to support a high degree of synchronisation between the scanner, motion stage, and the laser pulses. Specifically, when cutting curves or contours, the laser beam travels slower around the curves than it does when cutting straight lines (because the stage or galvanometer mirrors must decelerate/ accelerate). So, the time spacing between pulses must be varied on the fly in order to maintain constant laser power delivery at any given

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point, and therefore a consistent laser/material interaction. The alternative is to work at a constant speed, equal to the minimum speed imposed by the shape of the display. This is becoming an increasingly critical requirement for maximising throughput for next generation displays which often have complex shape contours. The architecture of Coherent HyperRapid lasers, which feature a pulse jitter of ~10 ns, supports this functionality well.

USP laser technology is more complex than older laser technologies. With complexity comes potential failure modes. Coherent has successfully mitigated this complexity downside by focusing on product reliability and lifetime, which is critical in cost-sensitive consumer product manufacturing. The application of Highly Accelerated Life Testing (HALT) and Highly Accelerated Stress Screening (HASS) protocols is novel– Coherent is currently the only company in the laser industry to invest in this. HALT is a proven approach that takes initial component and system designs and makes them better through pushing components and systems to failure, analysing the failure mechanism(s), designing out the failure cause, and then iteratively repeating the harsh testing until all identifiable failure mechanisms are eliminated. HASS is a complementary screening protocol that identifies product manufacturing weaknesses or errors before delivery, therefore dramatically improving the product reliability on the shop floor.

Another important trend driven by OLED production is a move to operation at a higher laser repetition rates. This is because extensive application evidence now shows that both higher quality (reduced HAZ) and higher throughput results when applying processing strategies involving repetition rates in the 1MHz region or even higher, provided output power stays in the 20 W to 30 W range.

▶ *Figure 4: The Coherent HyperRapid NX represents the new generation of USP lasers that deliver the performance and reliability necessary for cost sensitive, high throughput manufacturing applications.* ▶

Finally, operational flexibility is important because OLEDs are still an emerging technology, and device structure is both diverse and fast evolving. Operational flexibility enables display manufacturers to adapt seamlessly as device structure changes, as well as to address different market segments. A laser which supports a wide range of operating modes can more readily deliver the right process recipes for these various needs.

To summarise, next generation displays based on OLEDs require advanced manufacturing methods to deliver on the technology's promise. Even laser methods from just five years ago cannot fully deliver this new level of sophistication. Fortunately, a new generation of USP lasers with state-of-the-art features and unprecedented reliability is now delivering the requisite performance. ●