Lasers for a flexible future

Foldable and flexible displays are almost certainly the wave of the future. This article written by Coherent's Rainer Pätzel, director of strategic marketing, and Hatim Haloui, application senior manager, reviews the technology most likely to be adopted for foldable and flexible displays, and then examines how UV laser sources will support their production

Just a few months ago, the demand for OLED displays was rising, and it was completely reasonable to expect this growth to continue, if not even accelerate. In fact, OLED was foreseen to become the most popular display technology for mobile devices. And, foldable displays were predicted to comprise an increasing share of the OLED market.

Has all that changed? Possibly not – for two important reasons. First, despite the economic downturn and quarantines, people are actually streaming more content than ever before. Second, is the rollout of 5G technology. 5G provides a substantial increase (up to 20 times) in download speeds over existing 4G LTE technology, and the only way to get that benefit is with a new device.

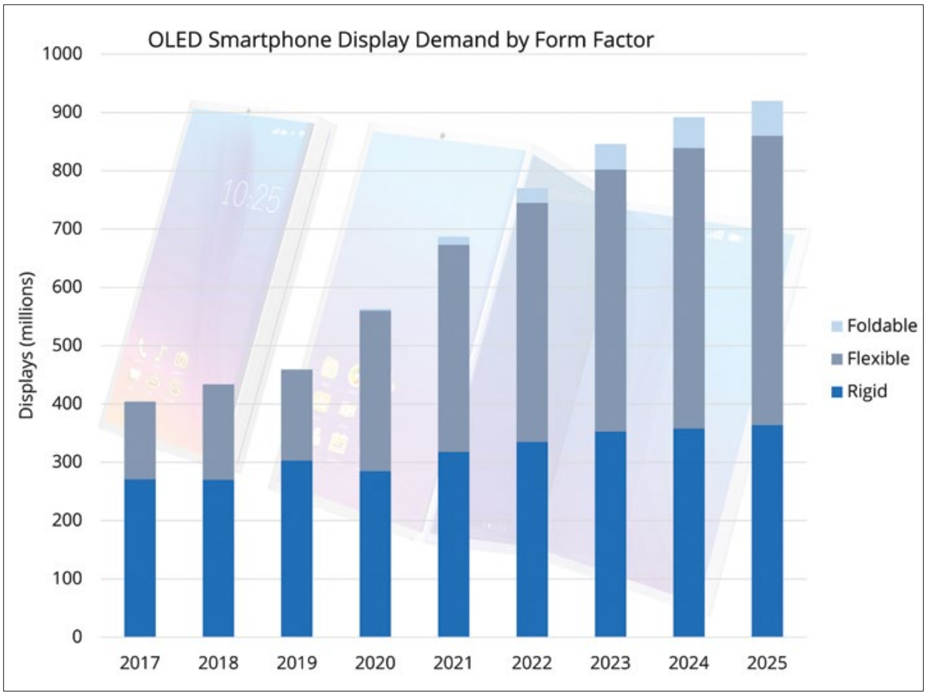

Figure 1: Market projection for various display types. Data from the "2019 Foldable Display Market Update and Outlook Report" courtesy of Display Supply Chain Consultants (DSCC)

The shape of displays to come

If there is reason to be hopeful about the near-term future of the display market, then it is logical to ask the question of which specific technologies are most likely to predominate in the market. Foldable displays are likely to become more popular because they offer the advantage of a larger screen size, but retain the small form factor of the device, especially for smartphones and tablets. This gives a better user experience for video streaming, and opens up new opportunities for mobile-productivity, such as the use of split screen and multiple windows. And, for foldable or flexible displays, in particular, OLED presents a number of distinct advantages.

One major reason for this can be understood immediately by looking at the simplified schematic of the construction of LCD, OLED and FlexOLED displays. OLED construction is inherently thinner than LCD, and OLED pixels are emissive (they emit light), so no backlight is required. This makes OLED displays thinner overall. Also, their output characteristics aren't affected by applied mechanical stress. And, most importantly, OLEDs can be produced on a flexible substrate. This makes the technology readily adaptable for use in flexible displays.

There are also some other specific trends in mobile devices, particularly cell phones and tablets, for which OLED technology offers

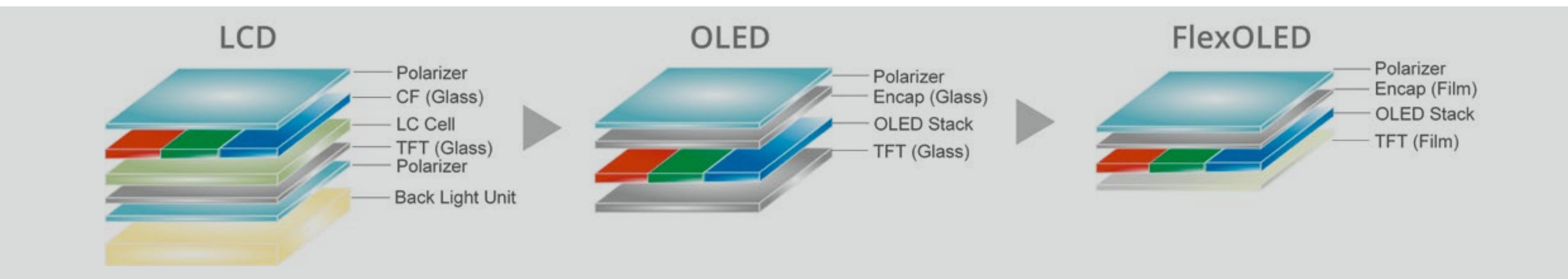

Figure 2: Simplified schematic of the construction of various display types

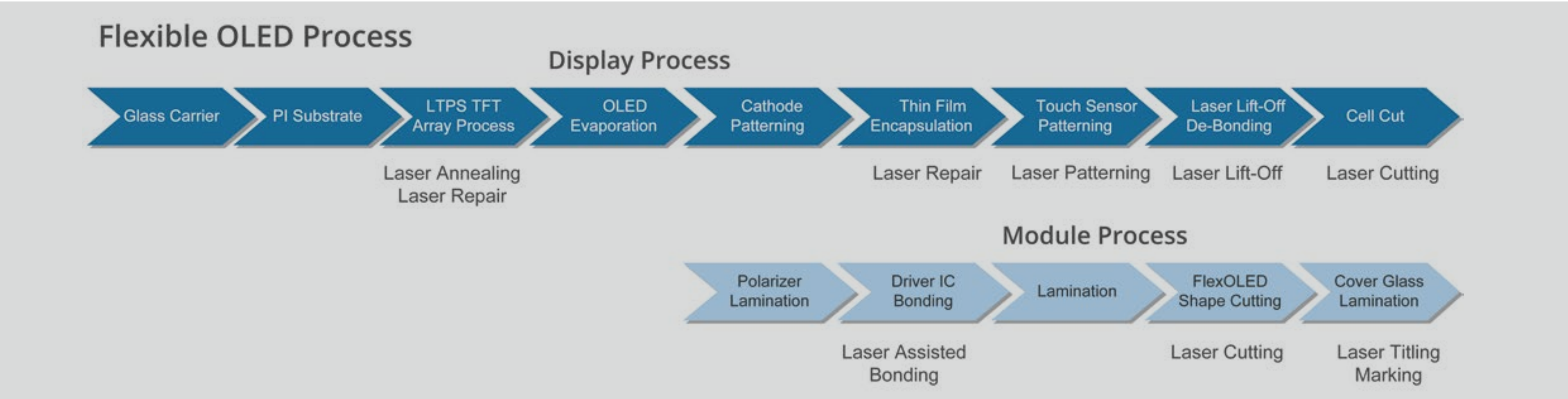

Figure 3: Production steps in flexible display fabrication, with laser processes indicated

distinct advantages. One of these is the use of under display fingerprint (UDF) readers. It is easier to implement UDF functionality with an OLED because the display itself is thinner, and the fingerprint can be readily sensed through the display. This is more difficult on a thicker display, and particularly one incorporating a backlight.

Similarly, some manufacturers are exploring the idea of having the front facing camera lens underneath the display, because this allows the display area to be maximised for a given size device. Once again, a thinner, backlight free display technology facilitates accomplishing this.

Another way to minimise overall device thickness is to utilise touch on encapsulation (TOE) construction. Specifically, this means incorporating the touch panel circuitry on the top layer of the display, rather than on a separate (glass or film) substrate. This construction is again supported by OLED display technology.

Lasers for flexible display fabrication

Lasers are utilised for numerous processes in flexible OLED production, just as they are in the manufacture of other display technologies. In fact, it can be reasonably claimed that lasers are a key enabling technology in the fabrication of modern, flat panel displays. And it is likely that they will continue to perform essential fabrication steps as flexible and foldable displays become more commonplace.

One main reason for the widespread use of lasers is because virtually all smartphone displays types are based on polycrystalline silicon, which delivers higher resolution and brightness, greater angle of view, lower power consumption, and higher pixel refresh rates than amorphous silicon. However, the deposition techniques used to first form the thin layer silicon onto the glass substrates on which displays are fabricated produces a layer of amorphous silicon.

Excimer laser-based low temperature polysilicon (LTPS) annealing is the preferred approach for converting this amorphous silicon layer into poly-silicon during display fabrication. And, the method can be physically scaled up in size, enabling its use on large glass panels (from which many smaller, individual displays are eventually produced). This has made excimer laser annealing (ELA) a critical enabler in achieving the economy of scale allowed by the use of larger glass substrates, and thus key to lowering the cost of individual displays.

For the production of flexible OLED displays, another laser process has become important. Specifically, this is laser lift-off (LLO), which is performed to separate display circuitry from the rigid glass carrier on which it is fabricated. This separation is one of the final steps in production, where the circuitry already has substantial value, so high yield is essential. LLO has become preferred over

other, non-laser based (chemical, thermal or mechanical) techniques because it delivers better results and is more cost effective.

In LLO, the output of a high pulse energy UV laser is formed into a long, thin line beam that is focused through the bottom side of the transparent carrier, and then scanned across the substrate. This light is strongly absorbed at the interface between the polymer and the glass, ablating a very thin layer, and thus releasing the patterned circuitry from the carrier. Since the laser is absorbed strongly at the interface, and the UV light doesn't penetrate far into the polymer, this causes minimal heating of the surrounding material. Thus, display circuitry is virtually unaffected.

Both solid state and excimer lasers are currently employed for LLO. But, recent trends, particularly in China, indicate that the excimer laser-based solution may predominate in the long run. This is, in part due to the output characteristics of the excimer laser, which are a particularly good match for LLO. Specifically, the flat-top (uniform) beam profile of the excimer maximises process efficiency over a source with a Gaussian intensity distribution. Additionally, the wide, uniform intensity line produced by the excimer laser yields a significantly larger process window, and makes it less susceptible to slight changes in the precise focus of the laser, carrier dimensional variations, or carrier warping. Finally, the "pulse on demand" operational characteristic of excimer lasers lowers cost-of-ownership as compared to solid-state lasers which must essentially be run continuously.

Singulation advances

Another key step in the production of flexible OLED displays is singulation. The increasing sophistication and functionality (cameras, fingerprint readers, etc.) of handheld devices, together with the complex foldable shapes previously mentioned, can often translate into the need to produce rounded corners and other contours, and even cut-outs, during the singulation process.

These complex shaping requirements, together with the need for a narrow cutting kerf width (e.g. 25µm) and a minimal process affected zone, have made laser cutting the only realistic option for flexible display singulation. Ultraviolet (UV) output, ultrashort pulse (USP) industrial lasers are quickly becoming established as the laser technology of choice for accomplishing this.

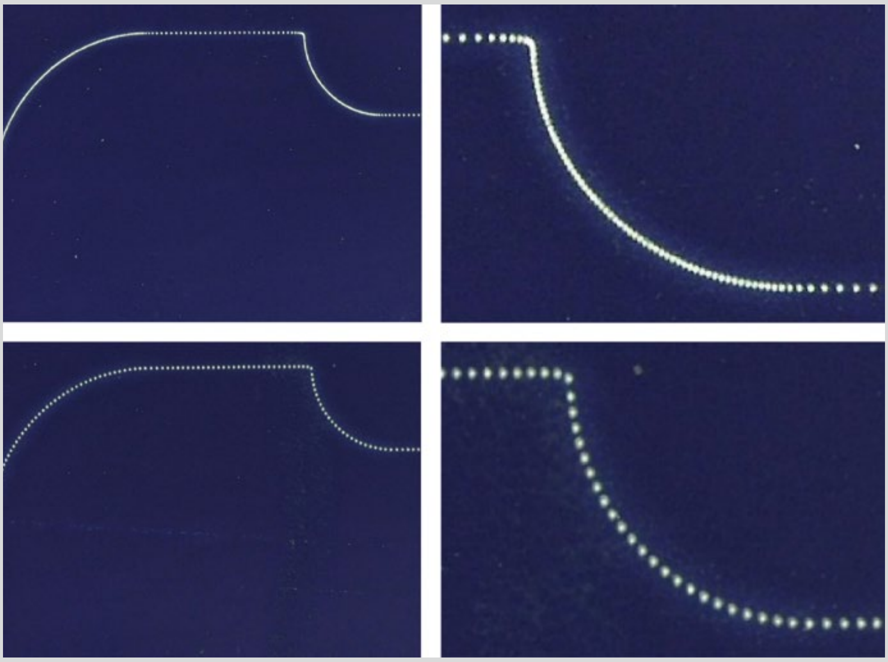

Figure 4: The top two photos show scribing of a Si on SiN sample using a UV USP laser without pulse control. Pulse overlap increases in curves because the laser beam must slow down when producing these features. The bottom two photos show the same shape scribed using the PulseEQ feature. Pulse overlap is constant regardless of laser beam speed relative to the workpiece

The next photos show how pulse control affects HAZ in a scribed material. In this case, slower beam movement in the curves has produced some charring there, but not in the straight line cuts. When PulseEQ is enabled, cut edge quality is uniform throughout and no thermal damage whatsoever is visible.

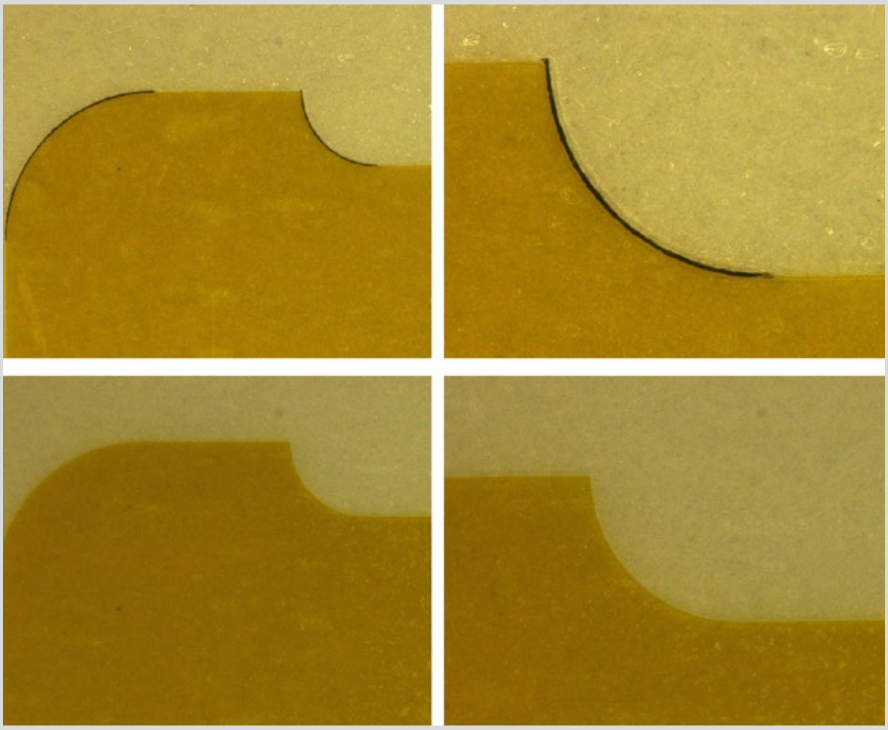

Figure 5: The top two photos show cuts to a laminate sample (copper on LCP on a paper carrier).Heat accumulation is clearly evident in the form of charring in the curved parts of the cut. The bottom two photos show the same cuts produced in the same material, but with PulseEQ enabled. Charring is absent

The reasons driving the adoption of UV, USP lasers for OLED singulation have been presented here previously (see Ultra-fast laser processing, Rainer Pätzel, OPE Journal, July, 2017, and Lasers drive flexible display production, Rainer Pätzel, OPE Journal, June, 2019). In short, UV light is strongly absorbed by virtually all the materials in the heterogeneous stack that makes up an OLED display. This means that UV light can efficiently ablate of all the layers simultaneously and doesn't penetrate far into the substrate (thus minimising heat affected zone). The short wavelength also allows a small focused spot which yields a small kerf width.

The ultrashort pulse length also helps to minimise heat affected zone (HAZ). This is because when laser energy is delivered into a material on a very short timeframe, it does not have time to spread far into the substrate (through thermal conduction), and, is instead, mostly ejected with the vaporised material. This combination of narrow cutting kerf and minimal HAZ, which is essentially unique to USP lasers, allows cutting to occur right to the edge of the display, which is also important in the newest device designs.

One of the most important recent developments in UV USP lasers for OLED singulation applications is the ability to synchronise laser pulsing with the motion of the beam relative to the workpiece. Specifically, whether the workpiece is moved relative to a stationary focused laser beam, or galvanometer scanners are used to sweep the beam across the work surface, there is always some acceleration and deceleration of the beam around curves and corners.

This is potentially problematic since excessive pulse-to-pulse overlap can lead to a thermal accumulation and the production of some HAZ, even with the small thermal load created by UV USP lasers. The only way to ensure consistent edge quality throughout all the cuts is to deliver a constant pulse-to-pulse overlap that has been optimised for a particular material target. Features like the Coherent PulseEQ enable laser repetition rate to be directly controlled, in real time. For example, repetition rate can be slaved to the position/velocity feedback signals from encoders on motion stages, or from scanner mirrors. This ensures that the pulse-to-pulse overlap stays at the constant amount that has been determined to be optimum.

The efficacy of this approach is seen in the photos. These show the results of a single pass with a 30 W UV USP laser (Coherent HyperRapid NXT) scribing a Si on SiN sample. The first scan was performed without the pulse control feature engaged, and shows increased pulse overlap at curves and corners. The next scan was performed with the pulse control feature engaged. The uniformity of pulse spacing is clearly seen in the enlarged view.

Conclusion

The near term future of the global economy, and the display market, in particular, are anyone's guess at this time. But, preliminary indications are that the demand to stream high quality content on to mobile devices will continue, and that this will drive a steady need, and maybe even an increase, in the market for displays including foldable. Lasers have already proven their value as a manufacturing tool in several key display production steps. The development of more cost effective laser sources and new techniques, such as advanced pulse control, will continue to improve their value proposition for display manufacturers and increase their use.

Image sources: Coherent