NEW FOLDABLE OLED DISPLAY MATERIALS CUT WITH PICOSECOND UV LASER

While advances in processing power and wireless data communication are clearly the primary drivers for continued growth in mobile device markets, the importance of display technology should not be overlooked. As the primary human interface component, touchscreen flat panel displays play a critical role in shaping the user's experience. In recent years, OLED (organic light-emitting diode) displays have risen to prominence in the mobile device market. They offer excellent image quality in a thin, flexible, lightweight and energy efficient package, which make them ideal for current and future generations of foldable mobile devices.

Figure 1. Left – Flexible displays enable foldable phones, a transformative development in mobile device technology. Right – Layer structure diagram of the material stack studied in this applications note.

The key challenge of a compact foldable phone is achieving a small bending radius of curvature in all of the display's components (OLED display, touch sensor, polarizer, cover window). For this purpose, manufacturers continue to develop materials such as ultrathin glass (UTG) and a relatively new type of polyimide—clear polyimide (clear PI)—that is highly transparent at visible wavelengths. While UTG is inherently more scratch resistant, it is also brittle and challenging to both manufacture and handle at the required thicknesses (~50-200 µm). Clear PI is inherently flexible and has manufacturability advantages, but it must be covered with a thin hard coat (HC) layer to improve its scratch resistance. This coating can also be engineered for anti-glare and anti-fingerprint properties. Both materials are expected to have a strong presence going forward in the foldable display market. For UTG glass cutting, Bessel beam processing with an IR picosecond laser is likely a viable option; for clear PI + HC, ablation cutting is required.

In this work, we present results using a high power picosecond 355 nm hybrid fiber laser (IceFyre® 355-50) for ablation cutting of a clear PI-based multi-layer stack for foldable display cover window application. The stack is comprised of 50 µm thick clear PI film with a 12 µm thick HC layer on one surface. Adhered to the HC layer is a protective layer (to be removed later) of 50 µm thick polyethylene terephthalate (PET). Additionally, the PET film has a pressure sensitive adhesive (PSA) coating (~4 µm) for adherence to the hard-coated surface of the clear PI. While high quality is imperative for the clear PI+HC layers, it is important but not as critical for the PET + PSA film.

Initial experiments were performed to independently characterize the ablation behavior of each of the three primary materials, clear PI film, HC layer, and PET protective sheet. Single pulse ablation thresholds were determined, with results displayed in Figure 2.

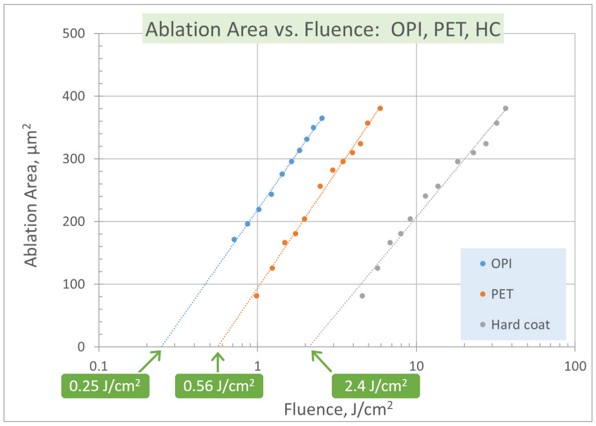

Figure 2. Plot of ablated area vs. laser fluence shows the disparity in thresholds for the three materials in the stack to be cut.

The thresholds were found to differ greatly. Clear PI has a very low 0.25 J/cm² threshold while HC is nearly 10× higher at 2.4 J/cm², and PET is intermediate at 0.56 J/cm². The low ablation threshold for clear PI is consistent with the observation of very clean, shallow ablation craters that were formed, likely due to strong absorption at the UV wavelength (as with conventional polyimide). The HC film's high threshold is similar to those found with various glasses. Likewise, the thin layer exhibits brittleness and is prone to cracking and chipping, as demonstrated by microscope photos for various process conditions in Figure 3 below.

The left-hand microscope image in Figure 3 shows a very clean scribe through the HC layer after parameters were carefully optimized for fluence and pulse overlap in the material. The middle image in Figure 3 shows a non-optimal result, with severe chipping along the entire scribe. Surprisingly, this poor quality result was generated with low pulse overlap at moderate fluence, which is typically considered to be a more gentle processing regime and hence better quality is expected. Indeed, the cracking apparent with just a single pulse irradiation (Figure 3, image at right) demonstrates the need for an unconventional approach.

With knowledge of the thresholds and overall ablation behavior of the three individual materials, a process was then developed for cutting through the full stack. The parameters for the various materials had to be fine-tuned, however, since the laser beam is directed at just one surface of the stack (clear PI) for a full cutting process. For each successive layer, a unique combination of pulse energy, PRF, and scan speed was applied. The ablation behavior was found to be very repeatable with the ps UV pulses, and therefore real-time monitoring of ablation depth, etc., was not necessary. Rather, the parameters such as laser pulse energy and PRF, number of repeated scans, etc., could be pre-programmed for a final cutting process, benefiting from

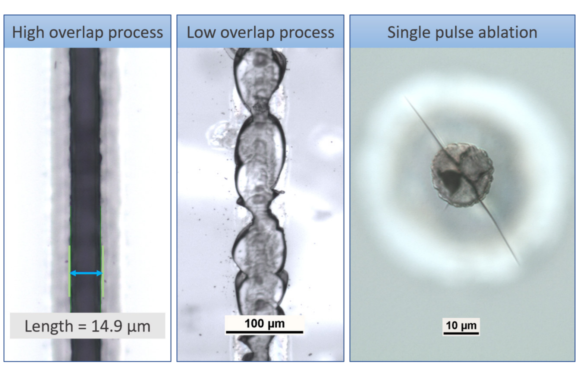

Figure 3. In the 12 µm hard coat film, high-overlap process with closely spaced pulses leads to dramatic quality improvement.

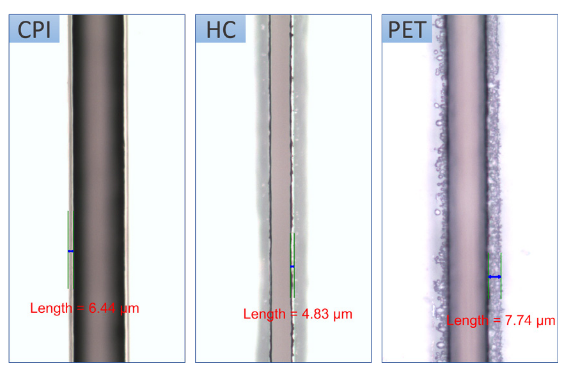

Figure 4. Microscope photos show ps UV laser cuts in clear PI (left), HC (middle), and PET (right) for a layer-specific cutting process with an overall (net) cutting speed of >400 mm/s.

the laser's capability of accepting "on-the-fly" pulse energy and PRF adjustments. Using individual scan speeds ranging from 3-10 m/s, and laser PRFs as high as 3 MHz, high-quality full cutting was achieved with a net speed of >400 mm/s. Figure 4 shows the cuts in the clear PI, HC, and PET layers.

The high quality of the cutting is clear, with all heat affected zones (HAZ) below 10 μm. Notably, the more challenging HC layer has edge chipping/roughness below 5 μm. The somewhat larger HAZ of the PET film is largely inconsequential since it is merely a protective cover film that is eventually removed, exposing the functional, scratch resistant HC layer. The sidewall edge quality of the cut is also important, as this may be an interface surface when mounting the completed display to a device. A microscope image showing a cross-section view of the sidewall can be seen in Figure 5.

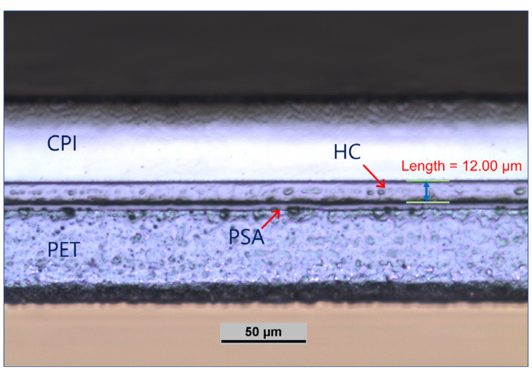

Figure 5. Cross section view of high quality cut in 50 μm clear PI and PET, 12 μm HC, and ~4 μm PSA.

The cross-section view confirms the quality of the cutting process is maintained through the entirety of the material stack. The individual layers are clearly distinguishable (including the very thin PSA), with no indication of melting, smearing, or delamination of the layers within the stack.

New technologies often require new materials and processing thereof. For foldable displays, the challenge of cutting a single compact stack of materials with widely varying optical, thermal, and mechanical properties is not trivial. For the case of a hard-coated clear PI with a protective PET film, a layer-specific optimization technique combined with the high power, highly flexible IceFyre ps UV laser has yielded very promising results in terms of both throughput and quality.

PRODUCT

IceFyre Industrial Picosecond Lasers

The IceFyre 355-50 is the highest performing UV ps laser on the market, providing >50 W of UV output power at 1.25 MHz (>40 µJ) with 100's µJ pulse energies in burst mode, and pulsewidths of 10 ps. The IceFyre 355-50 sets new standards in power and repetition rates from single shot to 10 MHz. The IceFyre 355-30 offers >30 W of typical UV output power with pulse energy >60 µJ (greater pulse energies in burst mode) and delivers exceptional performance from single shot to 10 MHz. The IceFyre 1064-50 provides >50 W of IR output power at 400 kHz single pulse and delivers exceptional performance from single shot to 10 MHz.

IceFyre laser's unique design exploits fiber laser flexibility and Spectra-Physics' exclusive power amplifier capability to enable TimeShift™ ps programmable burst-mode technology for the highest versatility in the industry. A standard set of waveforms is provided with each laser; an optional TimeShift ps GUI is available for creating custom waveforms. The laser design enables true pulse-on-demand (POD) and position synchronized output (PSO) triggering with the lowest timing jitter in its class for high quality processing at high scan speeds, e.g. when using a polygon scanner.

	IceFyre 1064-50	IceFyre 355-30	IceFyre 355-50
Wavelength	1064 nm	355 nm	
Power	>50 W @ 400 kHz	>30 W typical @ 500 kHz >25 W @ 800 kHz >20 W typical @ 1 MHz	>50 W @ 1250 kHz
Maximum Pulse Energy, typical (greater pulse energy per burst possible with TimeShift ps)	>200 µJ single pulse @ 200 kHz	>60 µJ typical @ 500 kHz >31 µJ @ 800 kHz >20 µJ typical @ 1 MHz	>40 µJ @ 1250 kHz
Repetition Rate Range	Single shot to 10 MHz		
Pulse Width, FWHM	<20 ps (15 ps typical)		<12 ps (10 ps typical)
TimeShift ps	yes		
Pulse-to-Pulse Energy Stability	<1.5% rms, 1 σ	<2.0% rms, 1 σ	
Power Stability (after warm-up)	<1%, 1 σ, over 8 hours		

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