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Optimized laser cutting processes and system solutions for separation of ultra-thin glass for OLED lighting and display applications

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Abstract

For some years now, laser cutting processes based on filament technology with ultrashort pulse (USP) lasers have been increasingly adopted in industrial applications. The main reasons for this are the good edge quality that can be achieved with simultaneous easy automation and free-form capability. This ability to be automated is of critical importance, especially for applications that target the mass market with their end products. However, the real advantage of the technology comes from its almost unlimited free-form capability. In addition to established manufacturing processes for glasses of medium thickness from 0.2-2 mm, an increasing number of applications with ultra-thin glasses of 30-100 µm are entering the market. These applications also require further development of the process and fab technology.
This presentation covers the possibilities of laser technology based on applications for OLED-based lighting and glass components in the display area.

Keywords: Ultrashort pulse Laser; glass cutting; OLED lighting; Display

1. Industry background

1.1. OLED lighting applications

The motivation for using ultra-thin glass as an OLED substrate lies in its strong barrier effect compared to the previously common plastic barrier films. Due to the lack of defects in the glass film (pinhole-free), defect-free, homogeneous OLED luminous surfaces with significantly longer lifetimes on flexible, cost-effective substrates are possible. However, new winding concepts for the careful handling of ultra-thin glass for productive roll-to-roll (R2R) manufacturing processes and especially gentle technologies for the final separation of the substrates have to be created.

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In order to decisively expand the applications and thus the economic potential of OLED as a lighting element, in addition to the homogeneous, opaque (bottom-emitting) OLED luminous surfaces on ultra-thin glass that have already been implemented over a large area, the development of transparent OLED components on ultra-thin glass is desired. If the top electrode succeeds in increasing its transparency from 20-30% to at least 50% and can be produced in a cost-efficient R2R production technology, the economic potential is obvious. Ultimately, the production chain requires a cutting or singulation process that provides free-form capability as well as process stability to prevent premature failure of the OLED components.

For this purpose, 3D-Micromac AG researches and develops within the framework of the project LAOLA (Large Area OLED Lighting Applications on ultra-thin flexible substrates, FKZ: 03INT509AF) funded by the German Federal Ministry of Education and Research (BMBF) together with partners such as Fraunhofer FEP and TESA SE on industrial solutions for the production of the OLED components. The structuring by means of screen printing in the R2R process is done by Yamagata University on glass substrates from Nippon Electric Glass (NEG).

1.2. Display applications

Another application area for ultra-thin glasses is the display industry. The trend in this segment is strongly influenced by the desire for flexible, malleable and portable electronic devices. Clear innovation drivers here are above all “foldables” or portable “smart devices”, for example with augmented reality (AR) or virtual reality (VR) functionality. In the automotive sector, too, there is a strong demand for very thin, and therefore flexible, large displays. These can only be attached to the required positions if all components such as cover glasses and touch units are correspondingly flexible or bendable. Only through the use of heavy-duty cover glasses are there significantly more options for placing displays in the car interior. The display technology itself offers further possibilities for new applications in the future, which at the moment cannot be fully exploited due to limited production technologies.

In these applications, too, glass has the enormous advantage of its barrier effect and higher mechanical resistance compared to the more flexible plastic substrates. However, the requirements for bending strength and long-term stability of the cut edges pose a major challenge for the cutting processes. High production yield is particularly important here. The production costs and thus the sales price of the consumer products play an essential role in the acceptance of the end products among potential consumers. Only when the required target costs can be achieved will products such as foldable telephones or OLED lighting devices gain acceptance in the mass market.

2. Manufacturing challenges

When looking for suitable manufacturing technologies, it is of course obvious to consider established techniques such as diamond scribing (in connection with mechanical separation) or laser-based stress cracking (known as Thermal Laser Separation, or “TLS”). However, both techniques have decisive disadvantages. On the one hand, a mechanical scribing process never works completely free of particles and has the disadvantage of requiring the application of force. This can be especially detrimental with ultra-thin glasses. The right underlay plays an important role due to its good deformability and the pressure introduces undesirable stresses into the material, which can lead to crack propagation. Furthermore, the free-form ability is limited and the cut edge may require mechanical finishing depending on the application. Thermal Laser Separation provides a very high bending strength but is not sufficiently contourable and not sufficiently stable in the crack guidance, since ultra-thin glass is strained by deformation.

A glass-glass stack with an organic intermediate layer is used in OLED lighting applications. In the case of display components, the glass is also used with polyimide, anti-reflective or anti-glare coatings. These coated glasses are either very sensitive to contamination by particles, or conventionally limited or impossible to separate in the required quality. With the OLED stacks in particular, the limits of the classic techniques are clearly evident.

2.1. Cutting technology development

For Filament or modification cutting is a process that uses USP lasers to cut glass substrates. The process has numerous advantages, including the ability to create curved shapes and cutouts. A high-end edge quality is achieved at cutting speeds of up to 1500 mm/s without the introduction of tension. There is no need for post-processing.

The possibilities of introducing the necessary modification for the subsequent separation in the glass are varied. For this purpose, special optics have been developed in recent years, which typically deliver good results with picosecond lasers.

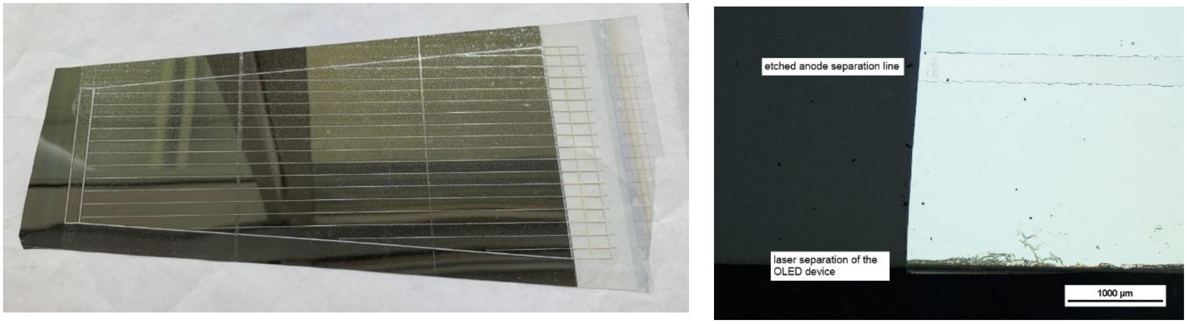

Fig. 1. Laser cut OLED-lighting device, full cutting of glass-OLED-glass stack

In the first process step, specific damage is required along the cutting contour over the entire thickness of the glass. The damage occurs either through self-focusing of the laser beam through the non-linear optical Kerr effect or, alternatively, by means of a Bessel beam, which is generated with the help of suitable specially designed optics. For this purpose, various systems were evaluated at 3D-Micromac for the aforementioned application. In the case of ultra-thin glasses with coatings, there are advantages in focusing with the help of Bessel optics.

In general, soda lime glass, borosilicates or chemically strengthened glasses can be cut very well and reliably. Ultra-thin glasses, especially if they are used as a stack or coated, however, require fine-tuning of the energy input and the substrate handling.

Three main factors contribute to the result:

- Precise adjustment of the required pulse duration to the layer stack
- Exact position of the modification relative to each interlayer
- A subsequent separation process precisely matched to modification process step

In the OLED lighting application example, the stack consists of 2 x 50 µm thick “GLeaf” ultra-thin glasses from NEG. In between there is a specially developed adhesive and the actual OLED layer. In order to protect the glasses in the R2R process, a PET carrier film is applied to both sides of the stack. This prevents the glass from splintering during transportation. At the time of the separation, this carrier has already been removed.

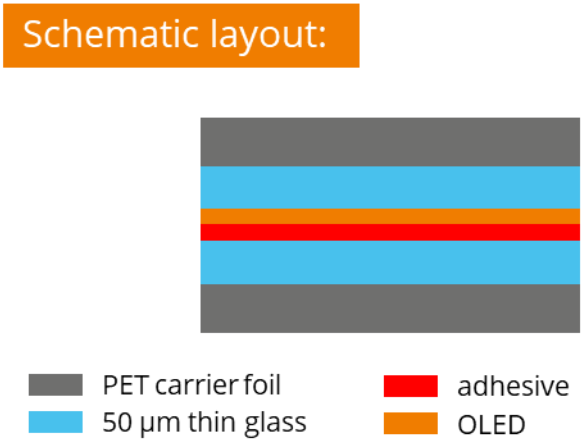

Fig. 2. Schematic layout of an OLED-lighting device

Extensive optimizations to the three bullet points listed above led to a stable process result. It is necessary to reduce the pulse duration of the laser to less than a picosecond and to adapt the length of the modification precisely to the thickness of the glass. The duration of laser-beam-material interaction and homogeneous energy distribution in the direction of beam propagation plays an important role. The coordination of the spatial and temporal energy distribution in the laser pulse (burst processing) was found to be important for ensuring the least possible damage to the glass edge. In order to minimize damage to the adhesive and the OLED layer, it is also necessary to keep the position of the laser focus sufficiently constant. Required values are significantly below single glass thickness itself. This is achieved with process reliability within the technology developed.

The current state of development requires a mechanical separation process, which can be easily automated due to the good stability with regard to crack guidance and low breaking force.

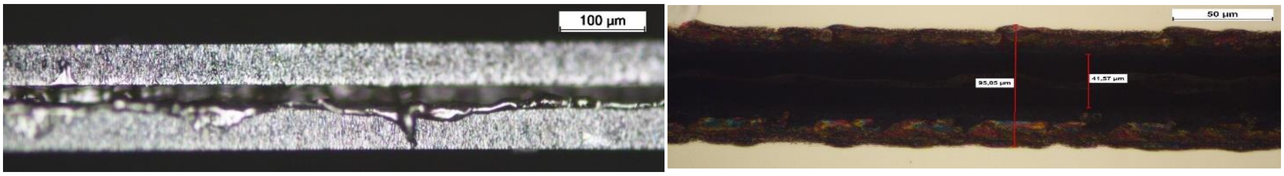

Fig. 3. Process results glass-adhesive-glass stack: left: side view after the separation process; right: top view, damaged area of the organic intermediate layer

An essential criterion for this specific application is the bending strength of the entire stack. This was already rated as good in the project based on the achievable bending radii, and will be further optimized and statistically evaluated.

Furthermore, the roughness of the cut surface and breakouts on the glass edge were evaluated. The roughness of the cut edge is typically around 1 µm (Ra) or even below. Broken glass edges (edge chipping) typically remain below 10 µm even over longer distances. Damage to the OLED and the adhesive intermediate layer is in the range of approx. 100 µm, which is acceptable for the application.

The technology for subsequently separating the glass stack has been proven on a laboratory scale. 3D-Micromac is currently working on process stability when transferring to larger substrates.

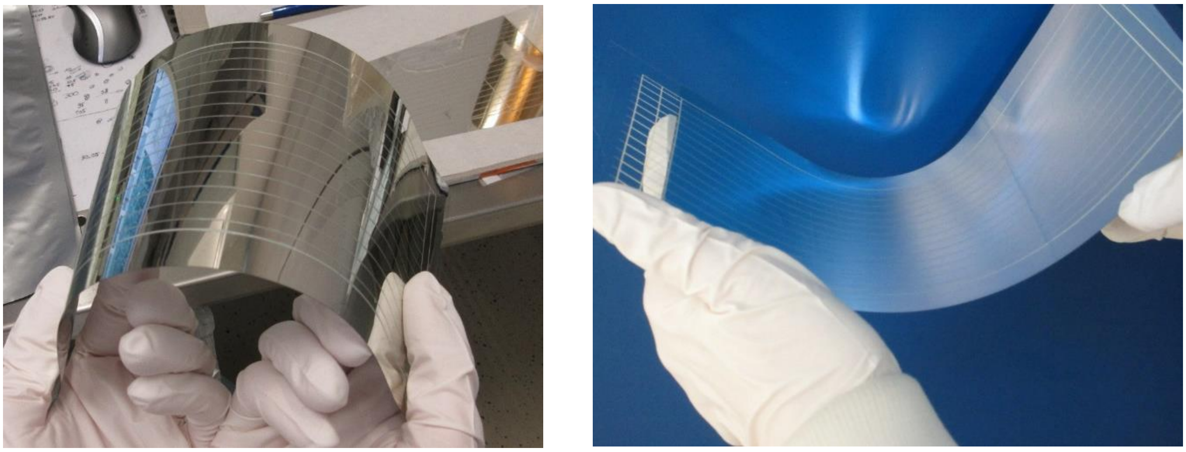

Fig. 4. Evaluation of behavior of laser cut OLEDS by manual bending and torsion tests

The basic optimization was carried out on uncoated glasses. Pure thin glasses achieve very good strength values with a high Weibull modulus at the same time. The Weibull modulus is an indication of a stable process without major deviations in the breaking force. Figure 5 shows Weibull distribution of 2 laser cut sample series, bare 30 µm AF 32 and a laminate 50 µm AF32 + TESA 69401. The edge strength of the 30 µm AF32 glass samples is higher than the edge strength of the thin glass laminates. The highest edge strength of the laminate is 80 MPa according to FEM simulation. The highest edge strength of the 30 µm thick AF32 is 111 MPa.The strength values were determined with edge tensile test patented by SCHOTT. Other display glass at thickness of 30 µm shows possible values of up to 150 Mpa.

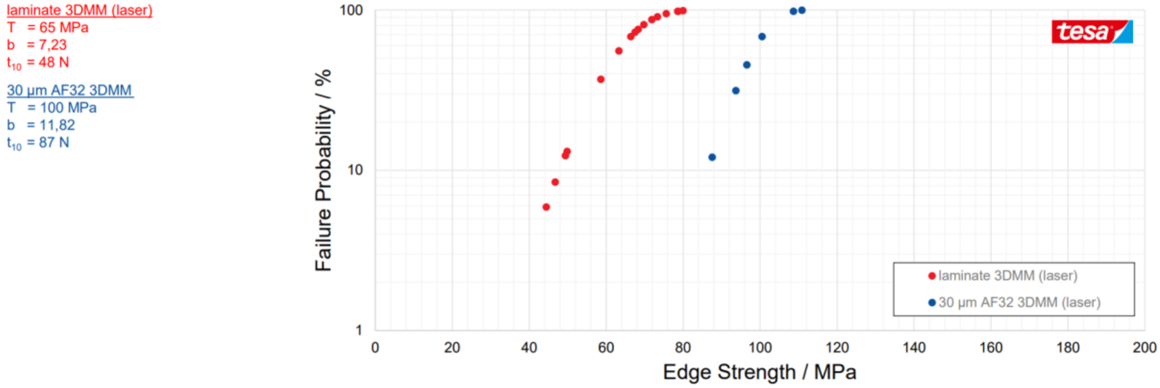

Fig. 5. Evaluation of edge strength after laser cutting (1)

With this bending strength of about 150 MPa, the bare glass can be bent up to a radius of around 7 mm without damage. This means that glass substrates for display applications can also be produced in good quality.

Full stack (50µm glass-OLED-50 µm glass) was initially tested by 2 point bending setup. Minimum achieved bending radius was 14 mm. Further statistical evaluation of the achievable flexural strength is the subject of ongoing tests within LAOLA project.

Looking at bare glass still mechanical cut samples have comparable or even higher values. Nevertheless, due to the advantages mentioned above, the aim is to use laser technologies instead of mechanical processes for the applications mentioned. For this reason, process developments are concentrating on further improving the strength values and process stability.

3. System Solutions

The laser micromachining system technology used for cutting is based on the proven microSHAPE machine concept of 3D-Micromac. The system is modularly adaptable to the application. The technology modules required for the end application are combined in such a way that an overall system suitable for production is created. The open concept of the system allows process configuration for sheet to sheet or roll to sheet process flows. Even a multi head setup is part of the platform. For customers, the advantages of modularity are short delivery times and a low cost of ownership for the respective end application.

Fig. 6. Example of Laser System microSHAPE SE, dedicated for manual loading or line integration in sheet-to-sheet or roll-to sheet process flows

References

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