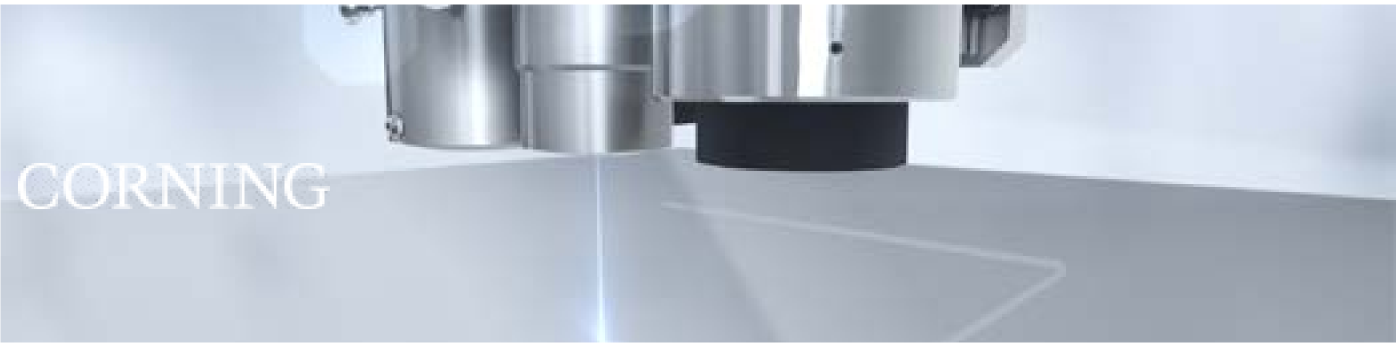

Enhanced Edge Strength Performance For Augmented Reality Waveguide Laser Singulation

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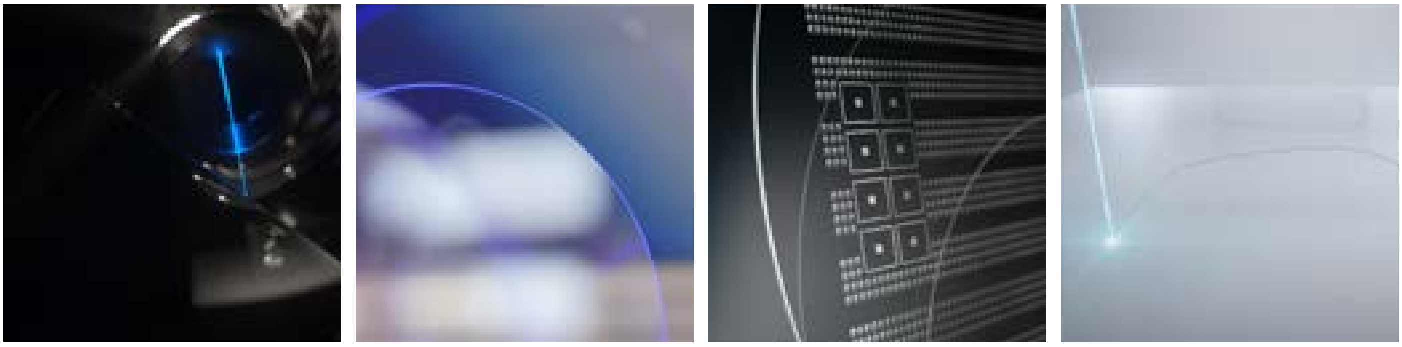
Abstract

Edge strength of a singulated glass product is a key metric to evaluate the performance of a cutting process. With the new Enhanced nanoPerforation (EnP) approach CLT can demonstrate an increase to 128 MPa B10 in ES for 1.8RI glasses applicable with an exceptional performance on free form contour designs.

These two aspects will help designer and manufacturers to meet the expectations of future AR applications.

Introduction

Augmented reality (AR) devices are designed to overlay the real-world image with an electronically generated image for human vision. One path to AR devices is based on diffractive waveguide technology. Herewith, light is guided from a projector through the eyepiece of a goggle into the viewing field of the observer. In order to extend the field of view and to reduce the thickness of the devices, the utilized glasses are designed to have a high refractive index to enable the required total reflection inside the waveguide.



These waveguides shall be utilized within a human portable device thus the form factor of the devices should be organic and shaped as typical glasses for goggles. Besides the shape, also the weight of devices is important, thus cutting close to functional areas (i.e. the imprinted grating for coupling the light in and out of the waveguide) is important. These two factors do lead to challenging processing requirements for singulation from a wafer to part, potentially having tight radii and even concave corners as seen in Figure 1.

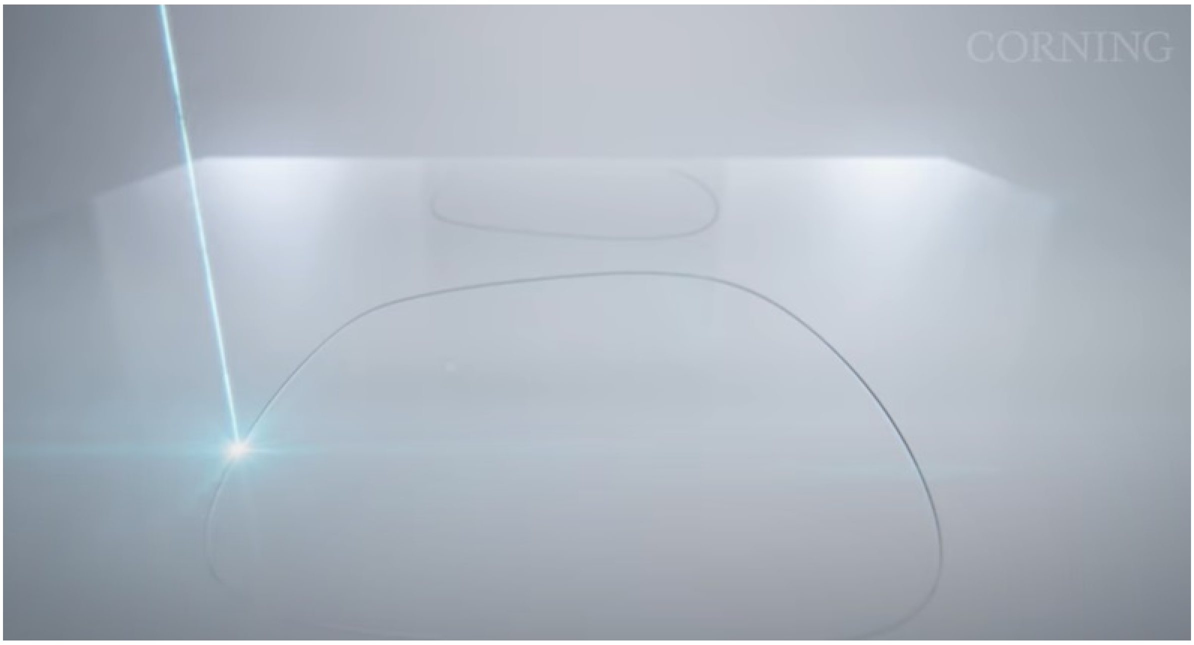


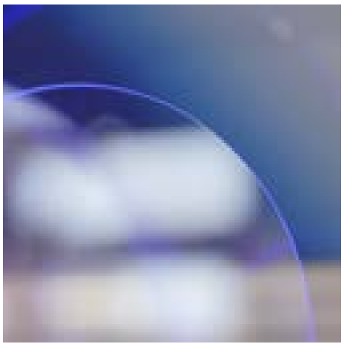
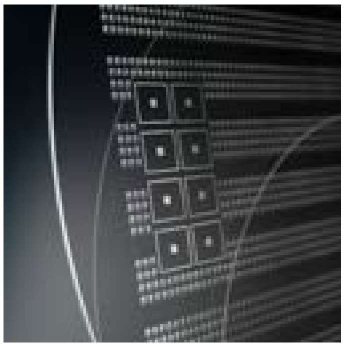
Fig 1: Typical shape for glasses utilized for AR goggles. Introductory Corning video on AR technology can be found here: https://www.youtube.com/watch?v=xcaU7kpGjpY

To add to this, the value of the processed wafers is high given the high precision of the micro-optical structures on the wafers. This leads to an elevated expectation on the cleanliness, yield and throughput of the process to singulate the parts from the wafers.

Laser cutting has been established as process of record over the past years for such parts and the Corning Laser Technologies nanoPerforation (nP) process combined with a thermal laser release process provides a proven solution for this application.

Details on the CLT nP Cutting Process

Utilizing the CLT laser cutting process for glass, a two-step laser based singulation process, a clean, qualitative and high-speed process can be shown on high index glass compositions.


The first step creates a micrometer-scale modification throughout the full thickness of the glass. This modification progresses less than 10µm into the glass sideways but is strong enough to steer the crack through the glass for rounded contours.

The second step is connecting the microcracks generated by the modification process, using a thermal stress induced by a second laser process, to a macroscopic crack, and thus enabling a force free picking of the singulated parts.

These processes can be implemented within a standalone operator-based laser system or, as shown in figure 2, within a fully automated processing solution to singulate the eyepieces from a wafer, from a cassette to a tray.

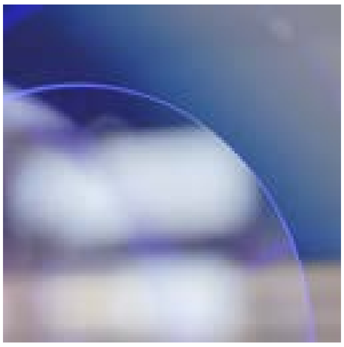
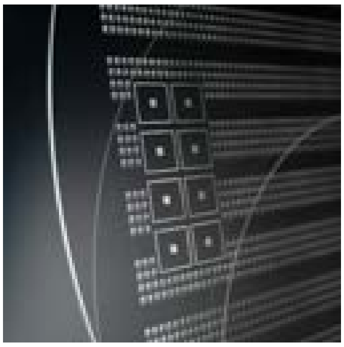
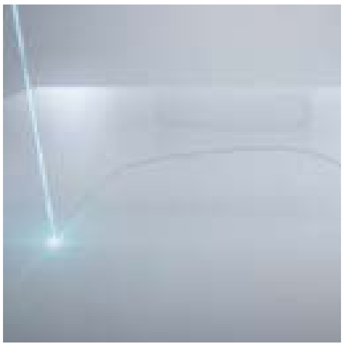
Figure 2: Fully automated process solution by CLT to singulate eyepieces from a wafer to a part.

Influences on Cutability of Wafers

The key properties of the source wafers are determined by its glass composition, which is designed to provide a high refractive index as well as a good transparency. As summarized in table 1, the typical properties of the glasses result of the glass composition and will also influence the laser processability.

	1.7 AR	1.8 AR	1.9 AR	2.0 AR
RI	1.70	1.80	1.91	2.0
CTE [ppm / °C]	8	9.1	7.5	8.4
Density [g/cm3]	3.23	3.65	4	5
Youngs Modulus [GPa]	91.2	115.8	119.5	127

Table 1: Overview on the PGS products relevant for AR high refractive index waveguides. Please refer to the current specification sheets for details.

In addition to these glass properties, also the finishing and the additional processes for the glass wafers will influence the ability to apply laser cutting. Besides surface quality of the wafers, which is typically at an optical grade, additional surface coatings to improve the optical performance of the device need to be mentioned here. As example, the anti-reflection coating (ARC) might inhibit the laser process and should be designed to allow later laser singulation. The ARC supplied by Corning are designed to be compatible with this singulation approach.

Established Performance of Laser Cutting

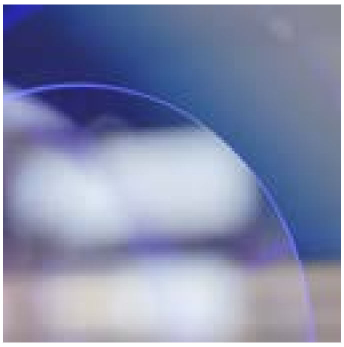
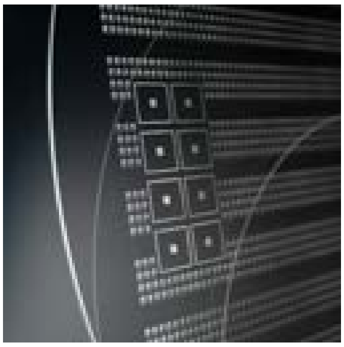
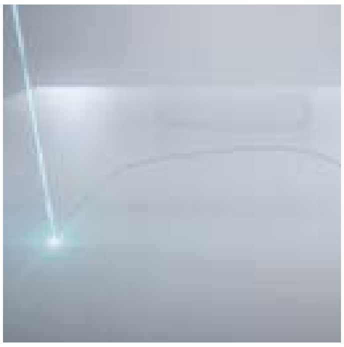
The requirements for the singulation process of augmented reality glasses is a clean process with a high-quality edge. Since the active layers are already applied onto the wafer prior to the singulation process, no additional finishing processes can be applied after singulation. All the requirements for the singulation process are fulfilled by the CLT cutting process. The CLT cutting process provides a homogeneous, non-dangerous, and high-quality edge without any additional edge finishing steps. Herewith the typical processable thicknesses of the glasses is currently up to 1.0 mm for the legacy nP and up to 0.6mm for the EnP.

Compared to mechanical cutting technologies, the CLT cutting process is clean, dry and can be operated in a clean environment, since it does not require any wet finishing processes like grinding and polishing.

Edge Performance of Laser Cutting

A key metric for the edge quality is the Edge Strength (ES). This performance is measured in a destructive test and this test described later in greater detail.

The CLT laser cutting technology achieves B10 edge strength values of typically 60 – 90 MPa with different glass compositions and suppliers (see Figure 3). Currently this performance is within the customer expectations and few concerns are voiced on this performance. This might be due to the fact that the current designs of AR devices will have the waveguide plates mounted solidly in a frame, making edge strength and impact strength not an important factor so far. In future, edge strength will become more and more important and will be a major differentiator for competitive laser singulation technologies and laser process suppliers.

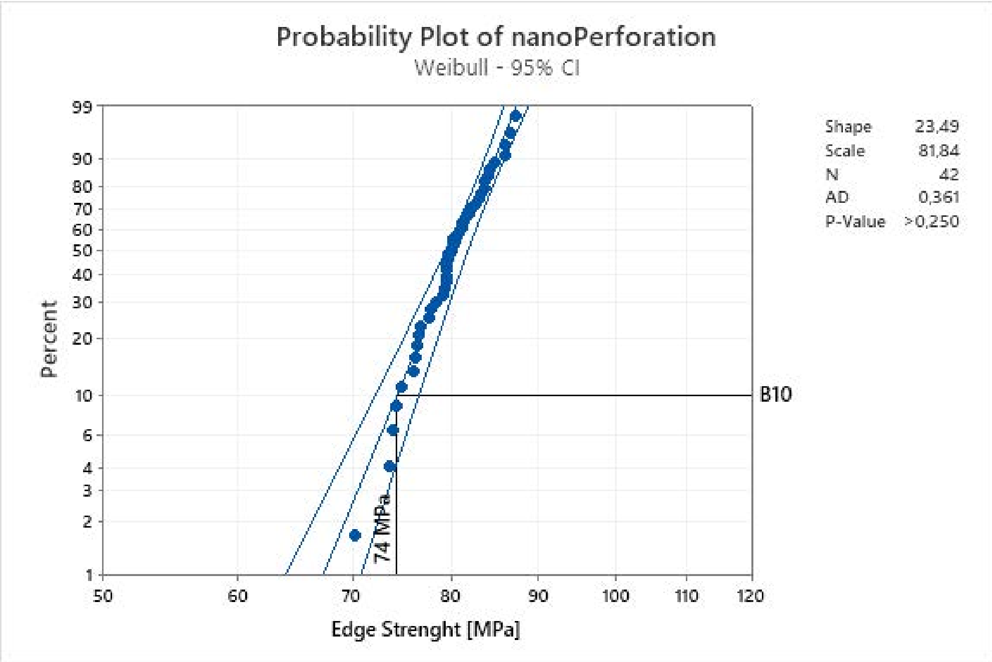


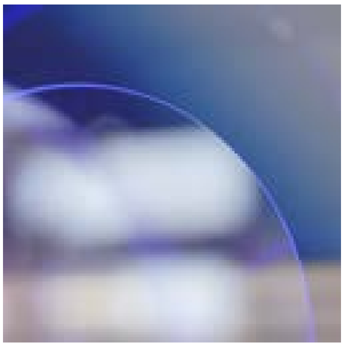
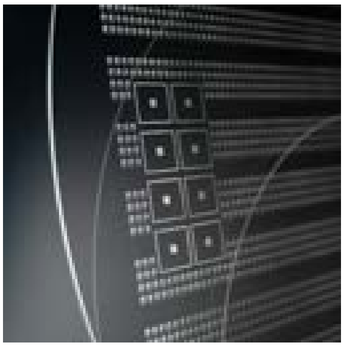
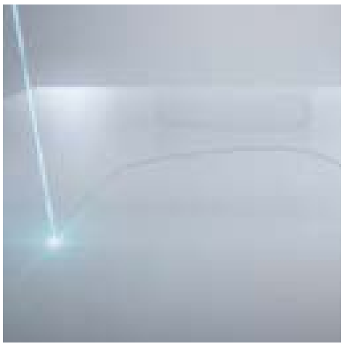
Figure 3: Weibull plot for demonstration of standard performance of 1.8 HI Glasses with legacy nP. This is an exemplary dataset on bare glass and might not apply to a custom design.

Edge Strength Measurement Background

The test method for the edge strength is a destructive test, where a force is applied to a glass specimen under bending stress. The maximum force required to break the glass is recorded and the specimen is evaluated, if the break did occur at the edge of the specimen. In case the break did occur at the surface of the glass, the measurement can be discarded as it mainly shows the surface quality of the wafer and not the edge performance.

For glasses in the range of 0.4-0.7mm thickness and the Youngs Modulus of the AR glass compositions, a 4-point bend setup with a span width of 36/18 mm is typically used. The procedure is described in greater detail in [ASTMC1161].

As the currently utilized wafers are mainly 200mmD sized, a test specimen geometry of 45x22mm is used. Statistically reasonable evaluations of a 4PB test can only be realized, when more than 30 samples are measured per evaluation.

In order to reduce the data from the failure stress distribution, a Weibull distribution is utilized and to compare datasets, typically the B10 value is used. The B10 value means, that 10% of the samples did break with a lower ES value as the B10 stress value. In order to compare the performance of different test runs or of different singulation techniques, in addition the slope and the confidence intervals of the Weibull distribution have to be taken into account when comparing ES performances. Thus, it is always helpful to compare full datasets against each other and not to rely only on a single B10 value comparison.

For specific customer requirements, the relevant failure rates to be analyzed will be much lower than the 10% value. But given the confidence level of the typically used sample amounts, the B10 values are established to compare datasets against each other reliably. For lifetime considerations for real products larger datasets are required to evaluate B-values at low percentages and these should be analyzed customer specific with the relevant coatings and structure on the glass. Corning can support here with more technical background on the theory of glass reliability.

Edge Strength Improvements by Laser Cutting utilizing EnP

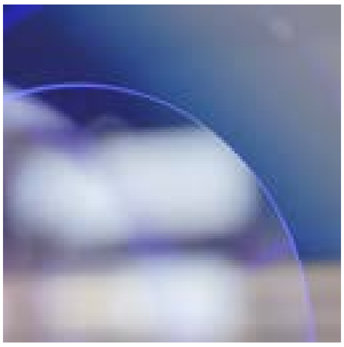
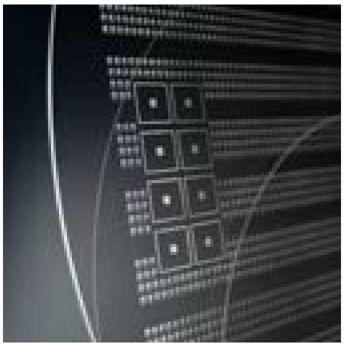
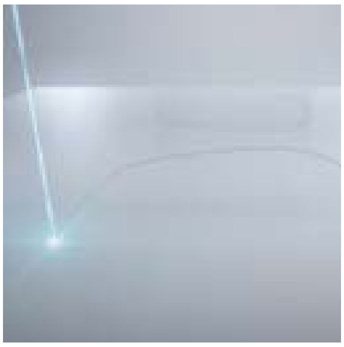
Investigated Samples

For this study the 0.6 mm thick Corning 1.8RI 200mmD glass wafers were used. These are established in the AR community for diffractive holographic displays and further details can be found on Corning's Website (www.corning.com). The wafers were non-coated or further processed in order to establish a good understanding of the baseline performance.

For the ES measurement rectangular parts must be cut from the wafer and one wafer can be populated with 24 parts. Thus, for one data set 2-3 wafers needed to be utilized.

Key Drivers of Breaking Performance and CLT Solution for a Better ES Performance

As discussed, the 4PB test does show, what are main drivers to weaken the break resistance of a glass. First, surface defects must be mentioned as influences here. These can be identified utilizing the appearance of the break and these measurements can be discarded. Secondly, mechanical impacts on the edge can reduce the achievable edge strength and care must be taken during sample handling and shipping. At last, the performance of the singulation technology will determine

the strength of cut parts. This strength is related to the flaws and the sub-surface damage that is introduced into the glass by the cutting technology and a reduction of these will increase the strength.

One key driver for higher ES is to reduce the subsurface damages of the cutting process. From the established laser cutting process, CLT has developed an enhanced laser setup, that results in higher ES.

Figure 4 shows a typical perforation for (a) the legacy nanoPerforation as well as (b) the Enhanced nanoPerforation. The Enhanced nanoPerforation setup creates a perforation that allows to use different laser parameter regimes compared to the legacy nanoPerforation, especially the pitch of the laser interaction. Those laser parameter regimes result in less subsurface damage thus increasing the edge strength. The combination of this enhanced setup together with the optimal parametrization of the overall process can lead to unprecedented edge performance for laser singulation and shall be discussed in the following in greater detail.

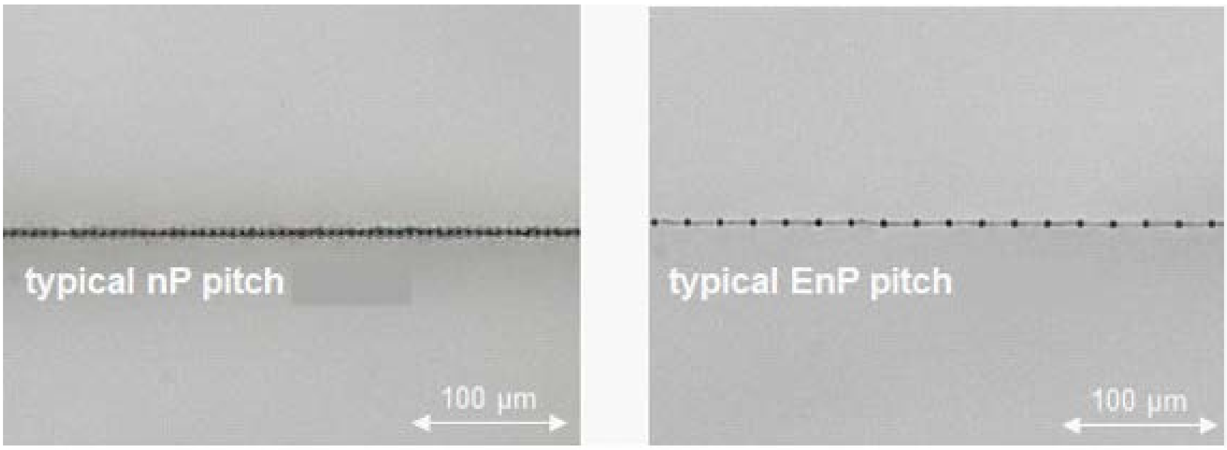
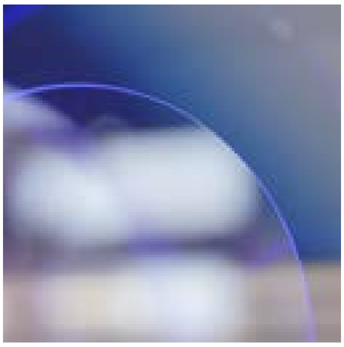
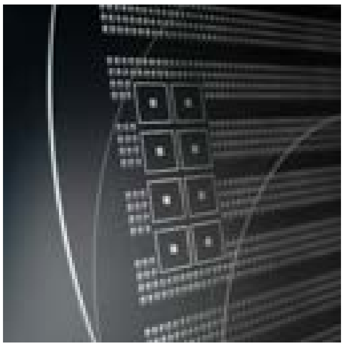
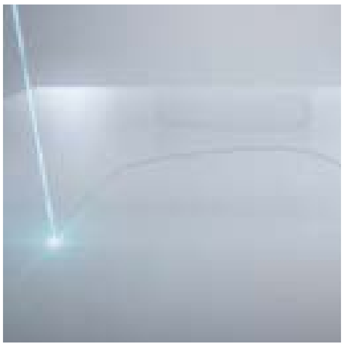


Figure 4: Typical image of the laser influence on the glass before the separation. Legacy nP shown on the left-hand side with a smaller pitch, on the right-hand side the EnP process can be utilized with a larger pitch. Utilizing the EnP, an increased parameter range is addressable, and this can e.g. be used to optimize for a better performance with respect to edge strength (ES).

In addition to the enhanced ES performance, the EnP also provides better contour control and enables tighter radii and more complex outlines compared to standard laser cutting offerings.

Parameter Influences on ES performance

Besides the enhanced optical setup to distribute the laser energy into the glass, parameter settings of the laser processes need to be understood to establish an optimal process. Both laser processes, the Enhanced nanoPerforation and the CO2 release, influence the edge strength. Therefore, the laser parameters must be carefully selected to achieve a robust CO2 release, high edge strength and minimal chipping.

Enhanced nanoPerforation
The key influences of the EnP laser process on ES are:

- Pulse energy Ep of the modification process
- Impact of the pulses
- Distance between the perforation dots

A design of experiment (DoE) is utilized to identify the best combination between high edge strength and good CO2 releaseability. With the DoE approach a parameter range is defined and tested at distinct combinations. The evaluation can be visualized using a multidimensional map (Figure 5) and the optimum combination of parameter settings for the Enhanced nanoPerforation can be identified.

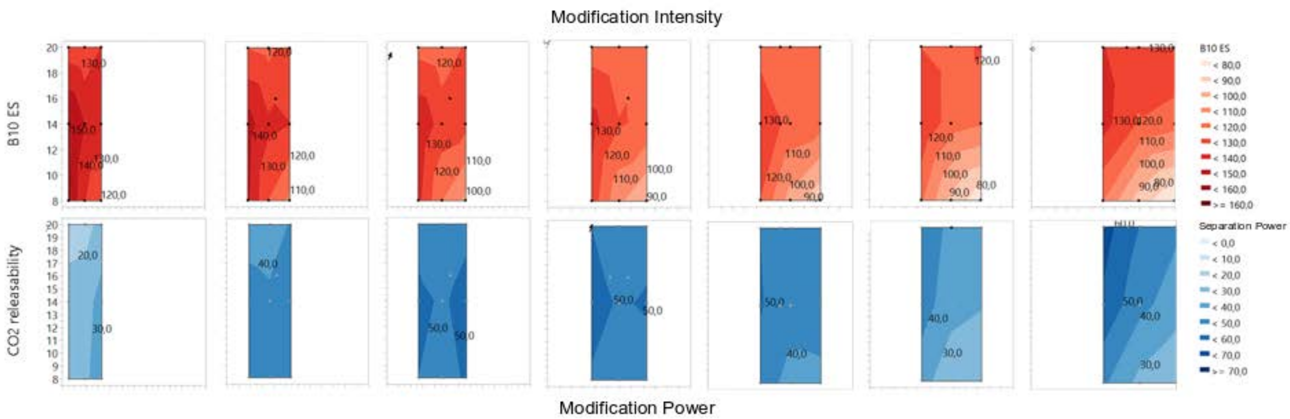


Figure 5: Influence of the Enhanced nanoPerforation parameters on edge strength as well as the CO2 releaseability. These edge strength values are measured prior to CO2 release. The influence of the combination of these processes on the achievable edge strength can be clearly seen.

CO2 release process
The key influences of the EnP laser process on ES are:

- Pulse energy Ep of the separation process
- Spot size

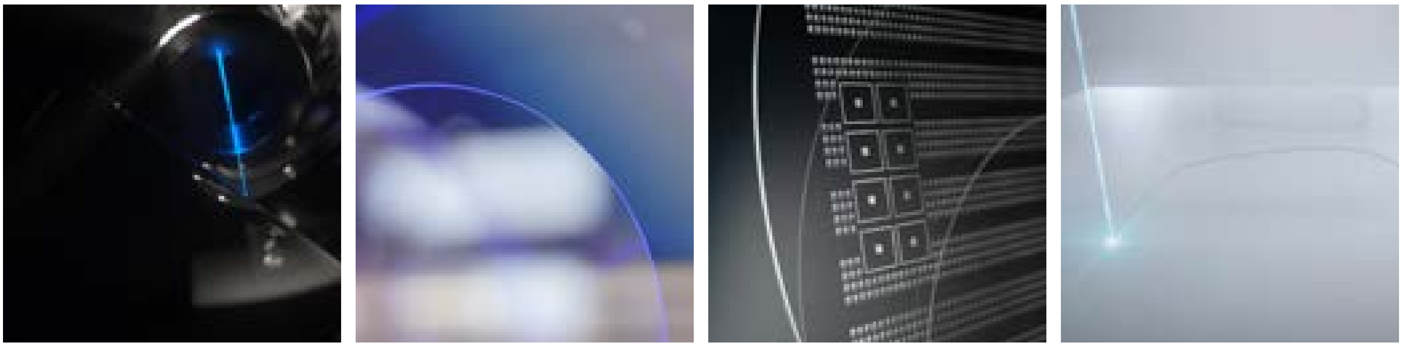


Figure 6 presents the influence of the CO_2 release process on edge strength as well as the CO_2 separation process. The full release of the parts is achieved at a CO_2 pulse energy of $E_p \geq 4.5$ mJ. To ensure a process stability and a stable release yield a slightly higher pulse energy ($EP = 5.2$ mJ) is used for these investigations. The required CO_2 laser pulse energy will change with glass thicknesses and type, but also with part geometry and part packaging densities on the wafers. Therefore, the achievable edge strength has to be evaluated for each custom design in detail.

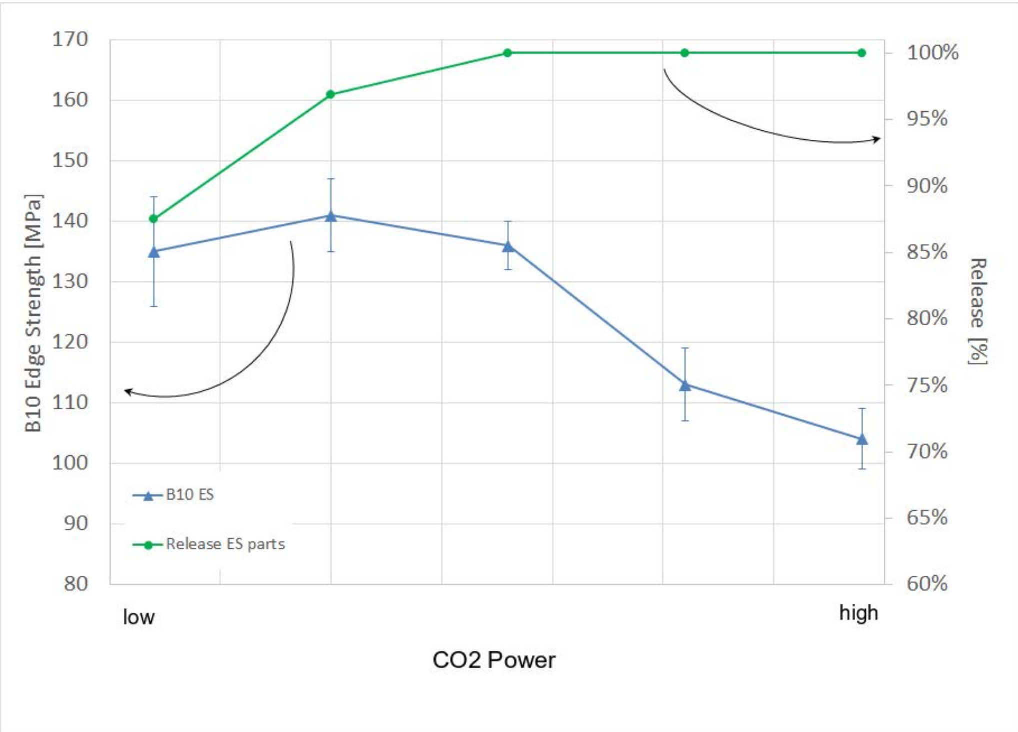
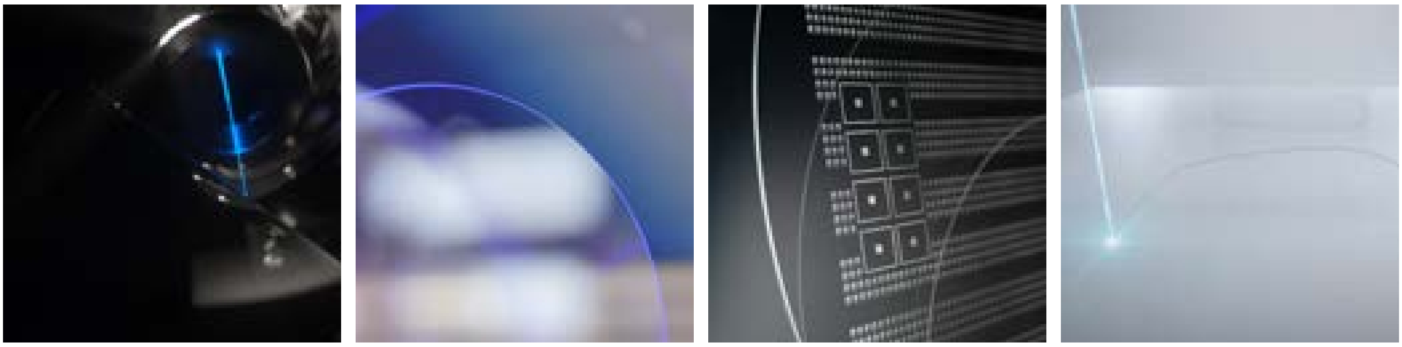


Figure 6: Influence of the CO_2 laser process on edge strength and part release. CO_2 pulse energies > 5 mJ result in a full release (100%).

This in-depth investigation of the Enhanced nanoPerforation for Corning 1.8RI glasses will help to find the optimal laser parameters for each customer product in a reliable and fast way.

This baseline performance and parametrization can be used to understand the influences of custom design and production expectation and to find the best fit for the given customer expectation.
The key influences to mention here are the custom designs for part size, thickness and shape, part packaging density and orientation on a wafer, coatings and layers for the functionalization of the parts. All of these will influence the achievable performance for throughput and cutting quality of the final products.



Results for Edge Strength of Enhanced nanoPerforation

The achieved edge strength in this study proves to be much higher than typical achieved edge strength values for the standard nanoPerforation. Figure 7 compares the achieved edge strength of standard nanoPerforation utilizing an established parametrization for these glasses and the optimized Enhanced nanoPerforation parametrization evaluated within this study.

Utilizing the Enhanced nanoPerforation the edge strength might get increased from ~70MPa to 128 ± 10 MPa for a comparable product without change of the product details.

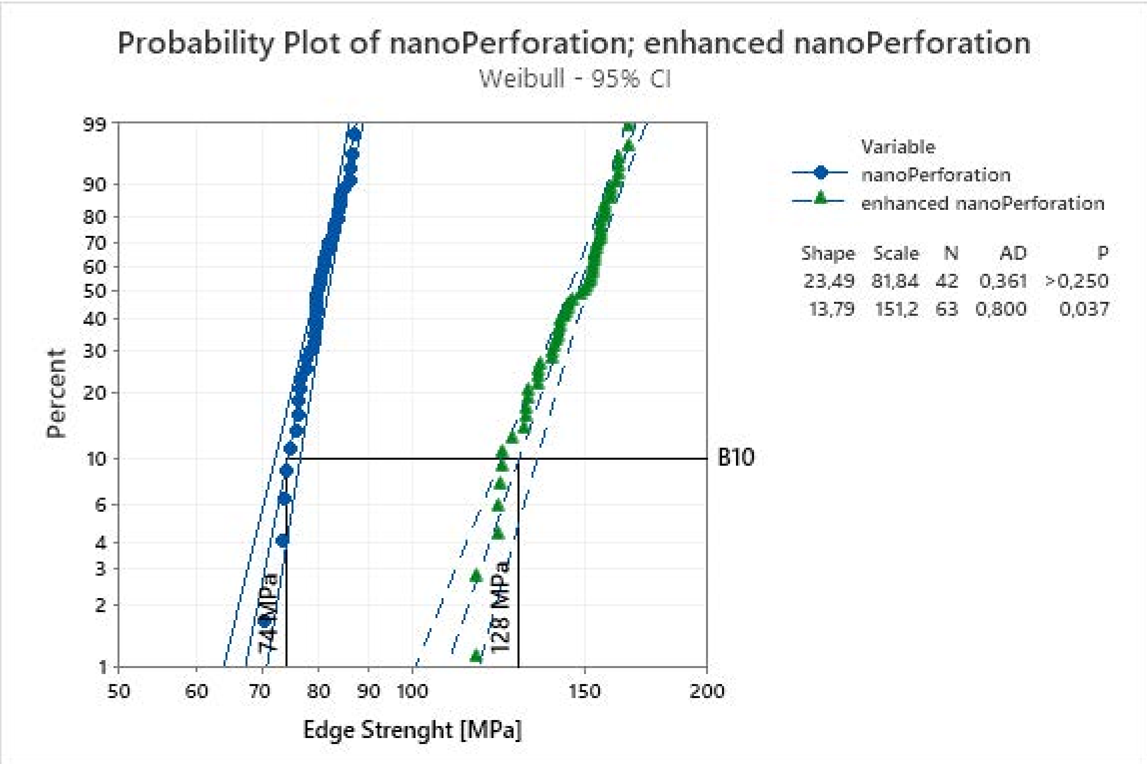
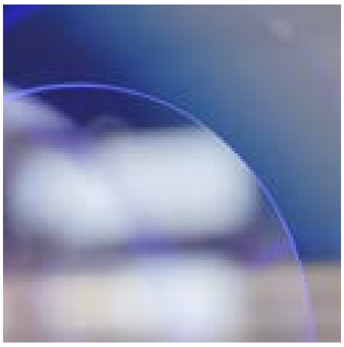
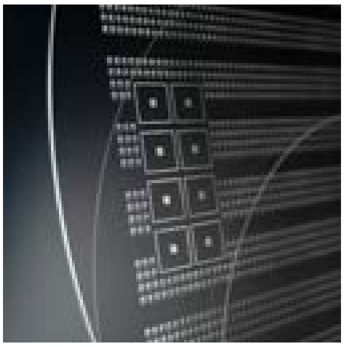
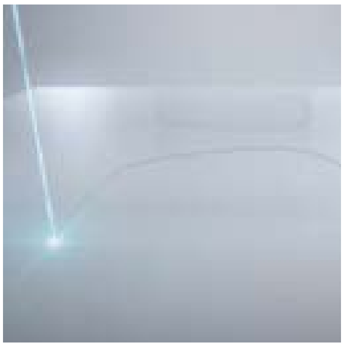


Figure 7: Achieved edge strength improvement when utilizing the EnP technology compared with the standard nP technology with confidence bands on 0.6mmt 1.8RI Corning glasses

Conclusion

By utilizing a DoE (Design-of-experiment) approach the influences of the laser parametrization with respect to ES has been investigated for 0.6 mm thick 1.8RI Corning glasses. By utilizing the EnP approach an unprecedented performance of 128 ± 10 MPa; B10) has been establish by the full process flow for automated laser singulation. These results show that the Enhanced nanoPerforation can increases the ES over 50% compared to established laser processing. Besides this benefit in ES increase, this EnP technology also provides an unmet performance for contour accuracy and edge surface quality.

Acknowledgements

We would like to thank all the involved people who support this project. Special thanks go to Ralf Terbrueggen, Director Technology and Dr. Sandra Hoehm, Head of Application & Laserprocess Development at Corning Laser Technologies.

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