Cutting glass with photons

Beam shaping allows latest technology leaps in laser material processing.

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all images: Trumpf

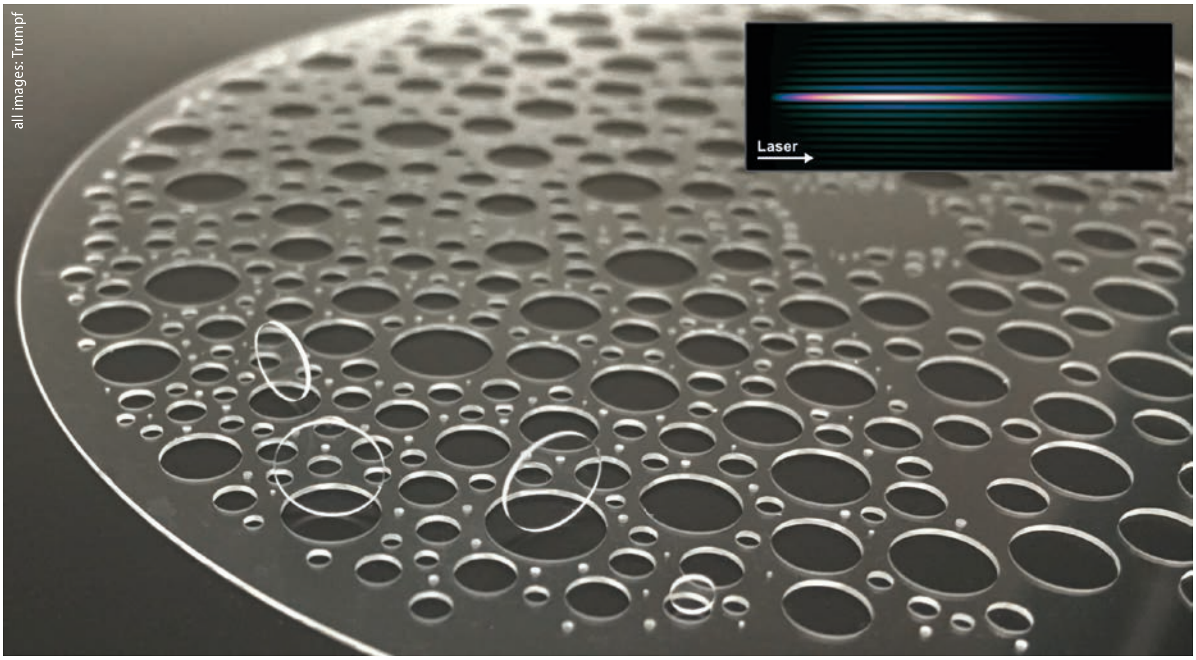

Fig. 1 The inner contours were cleaved using a TruMicro 2030 ultrashort pulse laser beam shaped into a Bessel-like intensity distribution with TRUMPF TOP Cleave-2 optics (inset) [4].

A comprehensive report is provided here about the state of the art and recent advances in cutting glass with ultrashort pulsed lasers. Several optical concepts are discussed that enable single-pass, full thickness modification of transparent articles in the most diverse geometries, such as architectural glass or glass tubes. We highlight the trend towards tailored glass edges for substrate protection with laser-fabricated chamfers. Here, a new beam shaping concept is used in which a large number of focal copies are distributed along any edge shape to combine cutting and beveling in a single laser process.

We use glass to decorate the façades of our buildings or the interior of our cars and touch it almost every minute when we control our smartphones. In addition to the obvious transparency, its frequent use is due to the outstanding mechanical and chemical properties – to name but two. Conventional processing of glass using the scribe and break method is cost-effective but has several disadvantages, such as the occurrence of internal cracks, chipping or time-consuming post-processing steps. This is exactly where the laser shows its strength as a subtle tool for efficient processing on a micro or nanometer scale. The extreme photon densities provided by ultrashort pulsed lasers allow energy to be selectively deposited in the volume of the transparent workpiece via non-linear absorption effects [1]. If suitable intensities are selected, the material can be specifically weakened and separated in a second processing step, for example by applying thermal or mechanical stress. Considering the laser modification process, reliable ultrafast laser platforms are equally available as adapted processing optics providing customized non-diffracting beams for single-pass operations with meters-per-second feed rates. The use of non-diffracting beams to process transparent materials can therefore be considered state-of-the-art (**Fig. 1**) [2].

Facilitating glass separation

After introducing the laser-based changes in the volume of the glass article, the actual separation is performed in a second processing step. If the substrates are particularly

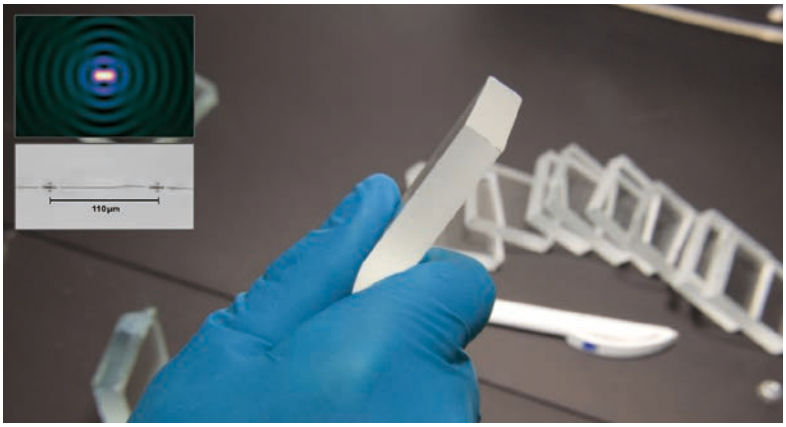

Fig. 2 The architectural glass is 12 mm thick and is separated by several non-diffracting beams. The samples were fabricated with TruMicro series ultrashort pulse lasers delivering pulse energies in the mJ range. The top inset shows the lateral intensity distribution for several Bessel-like beams. The lower inset is a reflecting light microscope picture top view of two laser modifications and demonstrates a continuous crack for spatial pulse distances of 110 µm. The resulting intensity distribution allows the modification distance to be increased up to 110 µm [4].

thick (> 2 mm) or thin (< 0.1 mm), difficulties like chipping or uncontrolled cracking [3] often occur during controlled separation. To counteract this, multiple non-diffracting beams are used to create asymmetric material modifications. If those align with each other during processing, a controlled crack discharge is initiated, resulting in the separation of the material.

Figure 2 shows the process results with a multispot Bessel-like beam, which enables the mechanical separation of glass with extreme dimensions. For profiles with cracks aligned along the splitting path, a continuous crack can be detected regardless of the spatial pulse spacing used. Therefore, by increasing the characteristic pulse spacing, which still allows for a proper splitting process, the feed rate and thus the throughput can be significantly improved. The maximum spot distance that was demonstrated was > 100 µm [4] (for symmetric Bessel-like beams the typical distance is < 10 µm).

Figure 3 depicts the successful separation of a laser-modified ultrathin glass subtrate of ~50 µm thickness. Here, too, the key for a controlled separation is the crack control which is confirmed by the surface micrograph, where the crack orientation follows the rotation of the focus shape generated by the TRUMPF TOP Cleave-2 optics.

A microscopic image of the entrance surface of a laser-modified ultrathin glass sample (50 µm) demonstrates the ability. Thus, in addition to the improved quality, the theoretical feed rate can be improved to the next level [3, 4].

Phase for curved surfaces

When non-diffracting beams are applied to a curved surface (e.g. tubes), the resulting energy distribution prevents proper material processing. This negative effect can be overcome by a correction, comparable to glasses for myopic eyes. In our case, the ideal on-axis constructive interference is disturbed such that strong intensity modulations occur (**Fig. 4**). Microscope images of the resulting laser-induced material changes in the cross section of the glass show that the elongated modifications are too short due to the disturbed interference and extend only from the curved surface entrance to about half of the wall thickness.

To correct these aberrations, it can be assumed that the surface acts as a cylindrical lens. The first approach to correct this is by inverting an additional cylindrical lens. The resultant aberration-compensated, elongated intensity profile is close to an ideal Bessel-like beam shape in the case of a flat surface. The corresponding laser-induced material modification in the cross-section of the glass (**Fig. 4** lower inset) now covers the entire material thickness and enables a clean cleaving process.

Tailored edges

We have to break new ground to make use of the laser literally as a

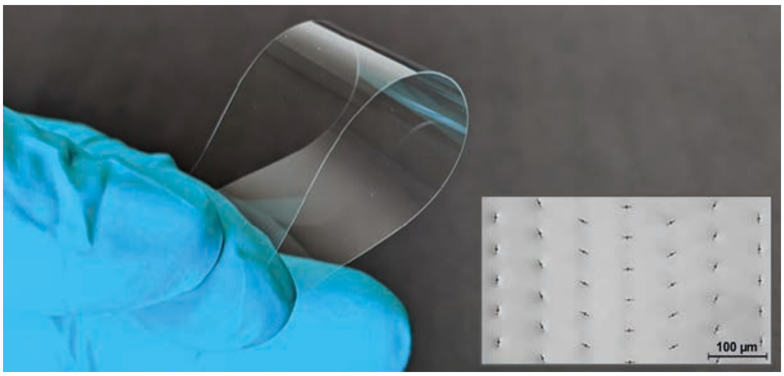

Fig. 3 The ultrathin glass, separated by an optical concept generating multiple Bessel-like beams. The inset shows a reflected light microscope image of the laser-induced changes/cracks from above. From left to right, the orientation of the beam profile was changed in 30° steps. It shows that the alignment of the applied cracks can be controlled by aligning a Bessel-like beam with two local intensity maxima [3].

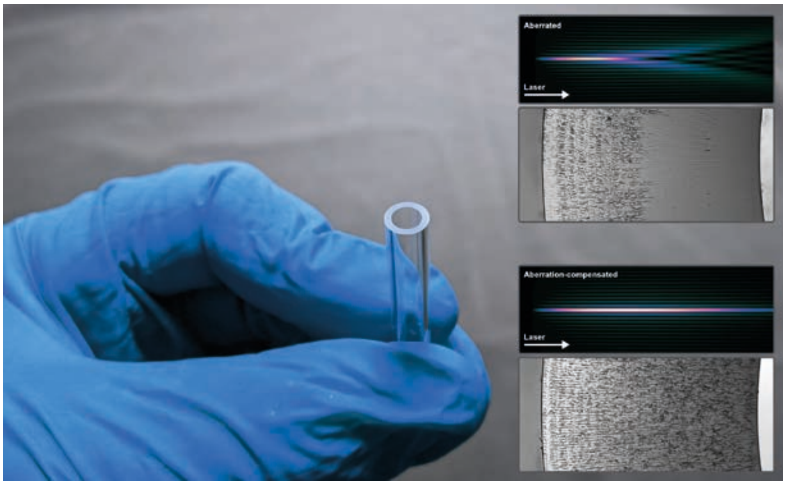

Fig. 4 The glass tube is cut by an aberration-corrected laser beam. The upper inset shows the longitudinal intensity distribution aberrated by the curved surface and corresponding material modification. In the lower inset the aberration is corrected [5].

universal shaping tool. So the goal is to distribute copies of nearly ideal focus along an arbitrary trajectory or, even more enhanced, in a well-defined three-dimensional volume. Diffractive beam splitters are well established for material processing today to parallelize processing and scale throughput. The foci are usually placed in a single plane, hence in two dimensions. The expansion into the third dimension is already in use, for example for optical data storage. Here we transfer this 3D holographic approach into laser glass processing for a fully flexible, single pass, three-dimensional modification in transparent material. After separation, this enables almost freely-configurable edge geometries of cleaved glass samples.

An exemplary distribution of several dozen nearly ideal single foci can be aligned to form a 45° beveled edge with constant point spacing on both sides (**Fig. 5**). The total height of this geometry is adapted to the thickness (and optical density) of the glass sample.

The holographic approach enables almost any imaginable edge geometry to be created in a single-pass laser process that cannot be realized by conventional mechanical approaches. It therefore paves the way to a broad bandwidth of novel, laser-based material processing applications from the improved impact resistance of displays to new mounting concepts for optical components [6, 7].

Conclusion

Using various selected process results, we have demonstrated how the laser can replace established tools in the machining of glass, or even enable completely new processing strategies. While the demonstrated applications for controlled crack orientation and glass tubes are available or close to available industrial systems (TruMicro series lasers and TOP Cleave optics), the example of holography for tailored edges heralds a paradigm shift for ultrafast laser processing and is still under development. Ultrafast lasers then pave the way toward new applications and approaches, for example in the display industry. Its potential as a universal photonic shaping tool is obviously far from being exhausted.

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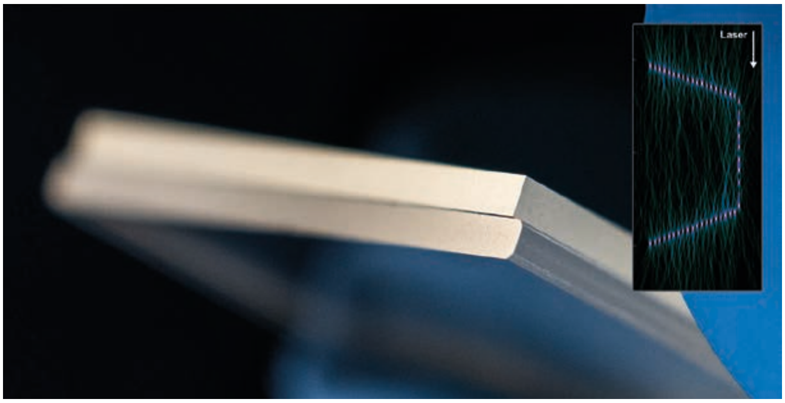

Fig. 5 The 550 µm thick Gorilla glass sample has a modified 45° edge geometry generated with a single laser pass. The inset shows the holographic intensity distribution of several dozen nearly ideal single spots in a plane perpendicular to the glass surface and to the feed direction [6].