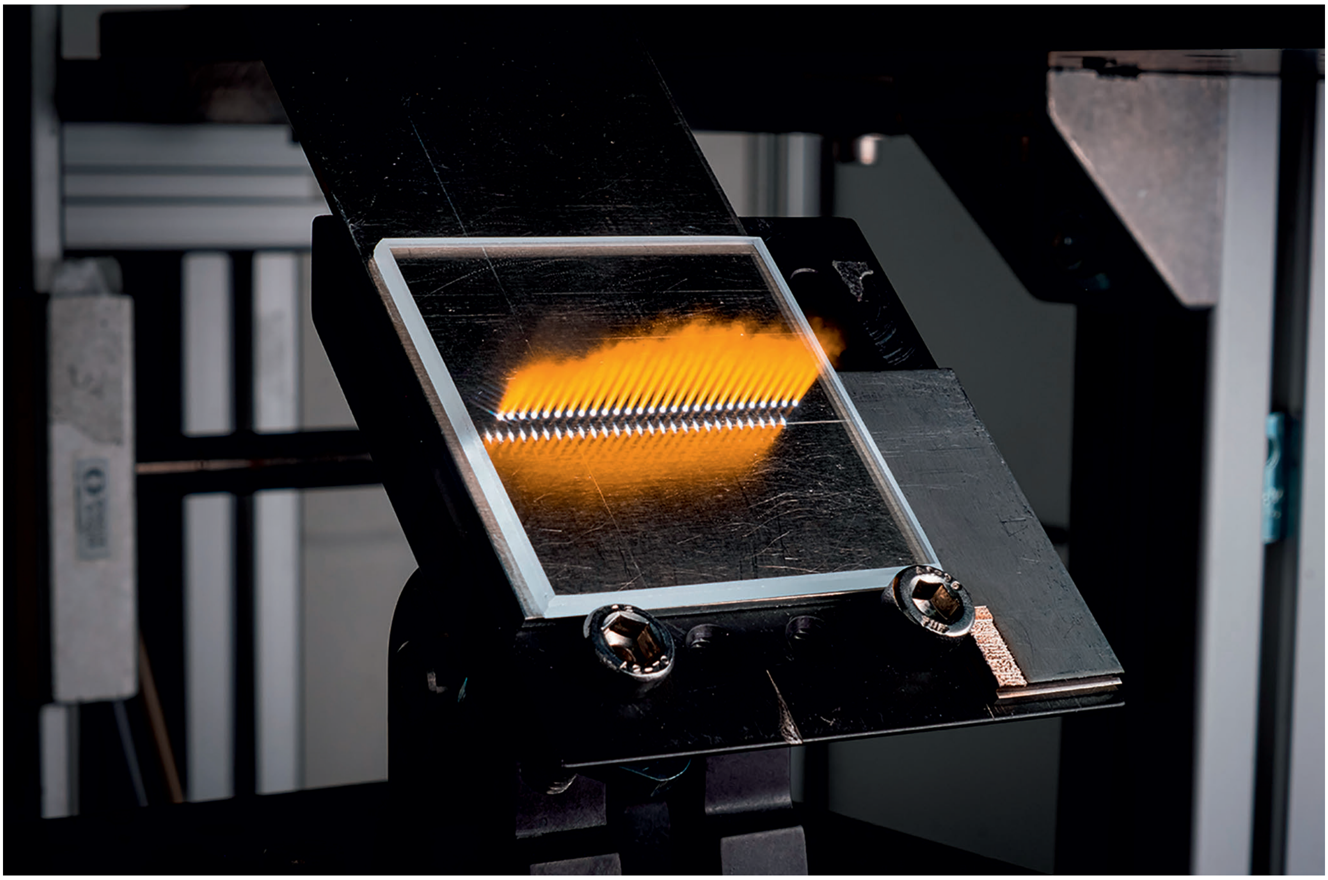
Uniting Glass and Plastic

Innovative Glass-Plastic Hybrid Combinations through Precise Laser Structuring

Transparent functional and design elements often consist of glass and plastic materials. But there may be problems in bonding them using adhesives or adhesion promoters, since adhesives only have limited aging resistance and glass is usually not easily wetted. High-strength hybrid connections are made possible with a two-step process, in which a laser first creates micro- and nanoscale structures in the glass, into which the plastic melt can subsequently penetrate.



Laser structuring of a glass sample by means of CO_2 laser radiation: the microstructures are introduced into a glass substrate with a thickness of 3 mm at spacings of 1 mm. This is performed by means of a scanner system, which guides the laser beam over the glass substrate in multiple passes at high speed. When the laser beam impinges on it, the material is vaporized; the ablated particles can be seen as a yellow jet of flame

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Bonding of glass to plastics is very important for producing functional components, which require high transparency combined with high shape flexibility. Typical applications include interior and outdoor lighting, such as car headlamps (**Fig. 1**) and touch-operation elements, such as in displays. While glass is limited in its range of possible forms, plastics are heat and scratch sensitive and permit only low service temperatures and temperature cycles. The specific disadvantages limit the use of the respective materials. These restrictions can be overcome with a combination of the specific advantages of these two material classes.

Glasses are usually combined with plastics by means of adhesives or adhesion promoters. However, this presupposes that the materials are compatible and that the coefficient of thermal expansion does not result in severe mechanical stresses at elevated temperatures. With adhesion promoters, the number of material combinations is also restricted since most types of glass only have limited wettability. This requires special part designs and

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Fig. 1. Glass-plastic hybrid bonds combine the specific advantages of the two material classes. A typical application is a car headlamp, which requires high transparency and shape flexibility © Hella

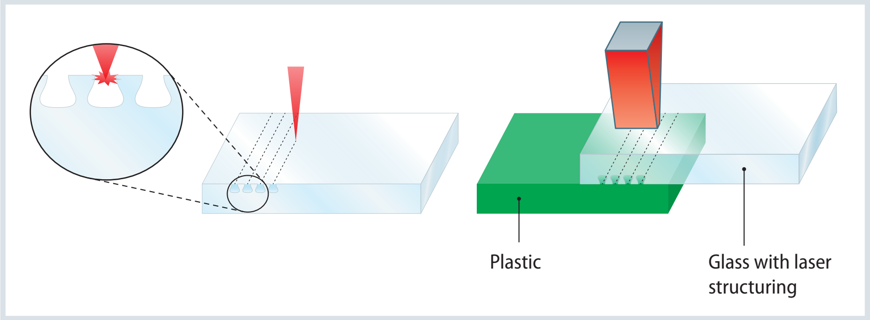

Fig. 2. Laser-based manufacture of a glass-plastic bond in two steps: left, laser structuring, right laser joining Source: ILT, graphic: © Hanser

a complicated process technology. Furthermore, adhesives only have limited aging resistance.

In NRW's HyTraM research project (NRW for North Rhine-Westphalia, Germany) , with three industry partners, a hybrid manufacturing process was developed that uses a precise laser beam to create a hybrid connection between glass and plastics. The process does not use additives, so the restrictions mentioned above are not applicable. In this two-step process, micro- and nanoscale structures are first introduced into the glass. Then the plastic is heated by means of a thulium fiber laser, so that the melt penetrates into the cavities, creating a bond between the two materials. The advantages of laser-based machining are the contactless and precise energy introduction, high flexibility of the structural geometries and high degree of automation that is possible.

Laser-Structuring of Glass Materials

Undercuts are generated in the glass by structuring the samples at a defined angle of incidence. Two different laser sources can be used for this step. With a CO_2 laser, a scanner system is used to guide the laser beam over the glass sample at high speed in several passes (**Title figure**). Thanks to the galvanometric scanner mirrors, speeds of several m/s can be achieved here. Each laser pulse ablates material; the structural depth and density can be flexibly adjusted via the number of passes or the scanning velocity. To increase the bond strength, multiple structures can be introduced on a glass sample. The advantages of the process are the short process times of a few seconds. However, it must be noted that, during the structuring process, the glass sample heats up. If the structural density is too high, thermally induced stresses can cause cracking in the part.

These disadvantages can be avoided by using ultrashort pulsed (USP) laser sources. The strong focusing of the laser beam and its short pulse times of 15 ps ($15 * 10^{-12}$ s) generate locally high intensity peaks $> 10^{13}$ W/cm^2, which instantaneously ablate the material. Because of the short pulse duration and the sublimation of the material, only virtually imperceptible heating of the part takes place, so that the technique is colloquially

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Hytram Project Partners

- Fraunhofer Institute for Laser Technology ILT, Aachen, Germany
- Hella KGaA Hueck & Co., Lippstadt, Germany
- Krallmann Pilot-Werkzeug GmbH, Hiddenhausen, Germany
- Simcon kunststofftechnische Software GmbH, Würselen, Germany

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↘ Read the German version of the article in our magazine ***Kunststoffe*** or at *www.kunststoffe.de* known as "cold ablation." This avoids micro-cracks and spalling at the bore hole and achieves a homogeneous roughness of the bore wall, so that the workpiece can be processed with hardly any damage.

The advantage of USP structuring, additionally, is the high precision of the process. With each pass, layer thicknesses of 1 µm are ablated, so that almost any arbitrary structures can be generated in the glass. The process has been improved in the course of the project to provide the extremely high reproducibility that is necessary for a secure plastic-glass bond. Due to the low ablation rate per laser pulse, the processing times are significantly longer compared to CO_2 structuring, reaching the order of 20 to 30 s.

Joining with New Laser Wavelengths

A thulium fiber laser is used for the subsequent joining, which, with an emission wavelength of 1940 nm, emits a laser beam that is in the natural absorption range of most engineering polymers. Such a laser is usually used for the transmission welding of transparent plastics, since the plastic can be melted without the addition of absorption enhancers such as carbon black. The applications typically include medtech or biotech components, such as microfluidic chips. In a pneumatically operated chuck, the plastic is clamped below the structured glass sample and the two are pressed together at high pressure. The beam of the joining laser penetrates the glass sample and melts the plastic over a large area (**Fig. 2**). The applied bonding pressure causes the plastic melt to flow into the micro- and nanostructures and fill them.

The solidification of the plastic leads to a strong connection (**Fig. 3**). Via the structures, a high adhesion force is created solely by virtue of the molten plastic and its surface wetting. This generates the positive connection due to the structures and the resulting interlocking bonding. This approach does not require additional materials such as adhesion promoters or adhesives. Besides transparent plastics, any desired color combinations can be joined, giving designers a great deal of freedom.

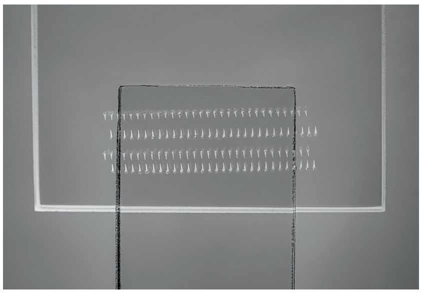

Fig. 3. Glass-plastic hybrid bond after joining: the structured glass sample (top) forms a firm bond with the planar sample of polycarbonate (bottom). The plastic was irradiated in the region of the microstructures (center) on an area of 10 mm x 20 mm. Due to the high transparency of the two joint parts, the molten region can hardly be seen with the naked eye © Fraunhofer ILT

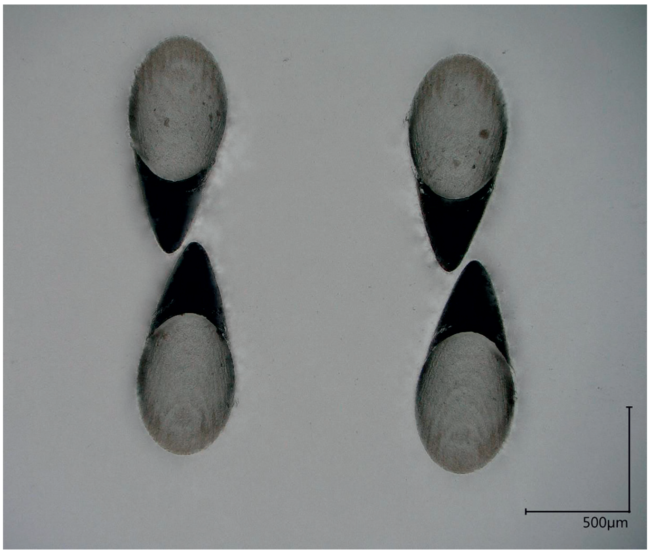

Fig. 4. Micrograph of the microstructures (top view): the glass is ablated layer by layer by means of a USP laser beam. Compared to machining by CO_2 laser beam, the high-precision ablation can generate structures with hardly any damage © Fraunhofer ILT

Factors Influencing the Bond Strength

The obtained mechanical strength of the joint depends not only on the mechanical properties of the plastic, but also crucially on the structural density and orientation. With greater structural density and orientation, more interlocking points are created, so that the bond strength is increased, but the residual material density is also reduced, which weakens the structure again.

The strength also depends on the orientation of the structures. By machining the glass material at a work angle relative to the angle of incidence, it was possible to generate undercuts in the glass (**Fig. 4**). Because of the high viscosity of the plastic melt, the melt flow is aided by a bore geometry with comparatively large diameters of approx. 500 µm. If the undercuts are aligned in opposite directions, this results in resistance to shearing and tensile forces when the plastic-glass bond is under load.

Conclusion

The two-step laser-based glass-plastic connection permits a simplification of the process chain compared to other joining processes. The direct connection reduces the weight and opens up new design opportunities. The generation of microstructures in the glass permits an interlocking connection between the two materials. The orientation of the microstructures can be flexibly adjusted to meet the loads in the part in order to obtain optimum strengths. While a CO_2 laser is used for rapid machining, ultrashort pulsed laser sources are suitable due to their precise ablation if high bond strengths are required.

In future, a demonstrator part is to be produced in order to illustrate the suitability of the new process for use in an industrial environment. To be able to establish this process in the long term, the ablation rates during laser structuring will need to be further increased. In addition, the overmolding of the samples and demonstrator, including filling of the microstructures, should be simulated. Simulation at a micro level is already possible with Cadmould, and the prediction accuracy should be further increased within the scope of the project if it is to be usable in an industrial environment. ■