Fraunhofer ILT

FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY ILT

MODELLING AND SIMULATION OF THE LASER PROCESSING OF GLASS

Fraunhofer Institute for Laser Technology ILT

The Fraunhofer Institute for Laser Technology ILT is one of the most important development and contract research institutes in laser development and application worldwide. Its activities encompass a wide range of areas such as developing new laser beam sources and components, laser-based metrology, testing technology and industrial laser processes. This includes laser cutting, ablation, drilling, welding and soldering as well as surface treatment, micro processing and additive manufacturing. Furthermore, Fraunhofer ILT develops photonic components and beam sources for quantum technology.

Overall, Fraunhofer ILT is active in the fields of laser plant technology, digitalization, process monitoring and control, simulation and modeling, AI in laser technology and in the entire system technology. We offer feasibility studies, process qualification and laser integration in customized manufacturing lines. The institute focuses on research and development for industrial and societal challenges in the areas of health, safety, communication, production, mobility, energy and environment. Fraunhofer ILT is integrated into the Fraunhofer-Gesellschaft.

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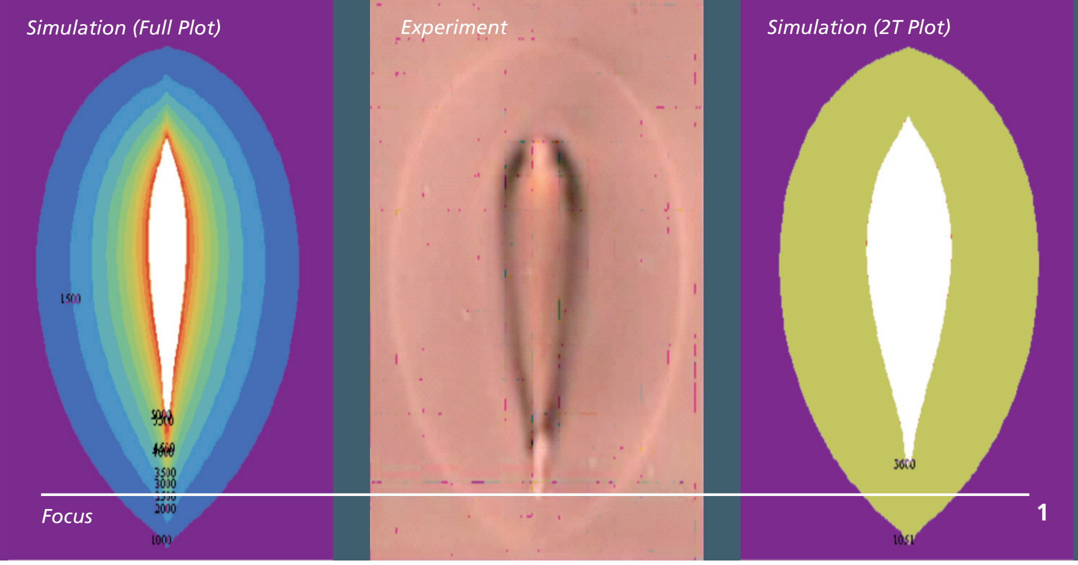
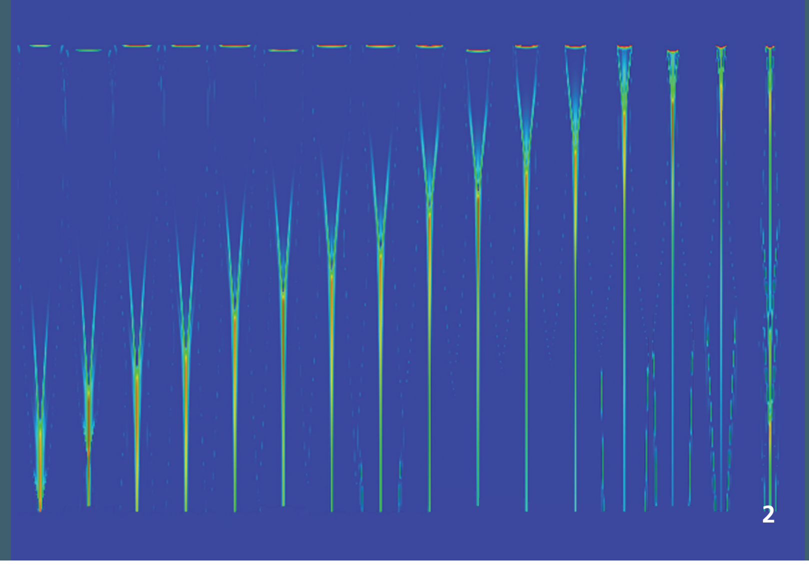
Fraunhofer Institute
for Laser Technology ILT

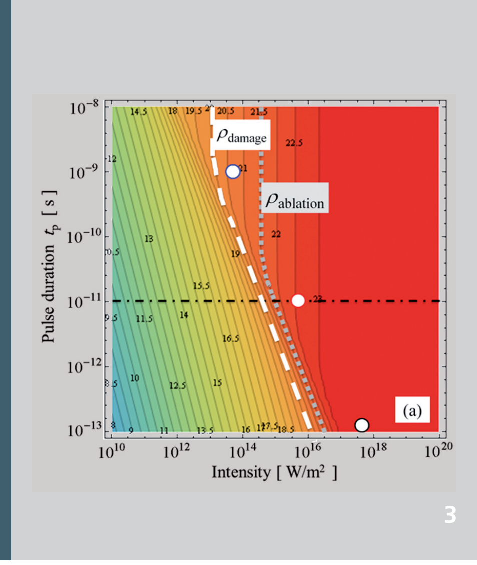
Director
Prof. Constantin Häfner

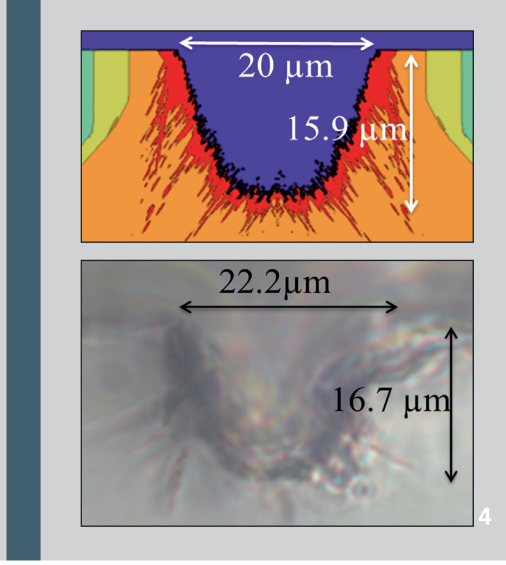
Steinbachstraße 15
52074 Aachen, Germany
Telephone +49 241 8906-0
Fax +49 241 8906-121

info@ilt.fraunhofer.de
www.ilt.fraunhofer.de









MODELLING AND SIMULATION OF THE LASER PROCESSING OF GLASS

The high demand for smartphones and other devices incorporating flat-panel displays has given rise to substantial market potential for the processing of transparent dielectric materials (e.g. glass) using ultrashort pulse (USP) lasers. However, the current state of research as described in literature does not provide a full understanding of the ablation mechanisms involved, of beam propagation effects inside the glass volume, as well as of possible damage to the material from the laser process. Modelling and simulation techniques enable us to expand this understanding and identify ways of improving process speed and quality.

Lasers are particularly well suited to the processing of glass and other transparent materials, because they allow both surface and in-volume modifications. However, the use of USP lasers in the glass processing industry and their technological advancement is being held back because the knowledge about interaction mechanisms between high-intensity laser beams and the glass material is not provided to the users of such technologies so far. Fraunhofer ILT has developed a simulation code based on the continuous mathematical and physical modelling of the processes. The code can, for example, calculate the effect of nonlinear mechanisms on the absorption and beam propagation properties of dielectrics, and the way they interact. With this information, it is possible to predict the ablation geometry and intended (filamentation and modifications) as well as unintended (cracking and delamination) alterations in the material. The simulation tool is already being used to obtain a better understanding of the physical processes and to predict or optimize the results of different glass processing methods.

Possible optimization measures include:

- Increasing the degree of light absorption by means of pulse shaping or wavelength mixing
- Adapting the ablation profile (for instance increasing the perpendicularity of cutting kerfs)
- Avoiding or minimizing patterns of surface or in-volume damage in the glass material by adapting the spatial light distribution
- Designing in-volume modification structures
- Creating optical filaments by means of beam and pulse shaping

Absorption and Beam Propagation

In dielectrics, light energy is absorbed through nonlinear mechanisms (multi-photon ionization, cascade ionization, [multi-body] recombination) because the band gap is relatively wide compared with the energy of a single photon. Consequently, in order to increase absorption, free electrons must be produced by these nonlinear mechanisms before dielectrics can be processed, whereas they are already present when processing metals. The process description for dielectric materials is therefore more complex than that for metals, because the intensity of the laser light has a significant effect on the material's optical characteristics.

The aim of modelling is to provide a spatially resolved description of beam propagation and energy deposition in dielectric materials and of the way they are modified or ablated when exposed to ultrashort, high-intensity laser pulses. This involves calculating the dynamic behavior of the electrons in the glass as well as the resulting feedback effect on the propagating light beam, which is determined by the gradual increase in local absorption and in refractive index of the glass. As a result, it is possible to predict the modification, damage and ablation based on the density of the free electrons in the material.

Laser Welding of Glass

Precise knowledge of the effective heat source plays an essential role in predicting the range of temperatures developed in the workpiece when welding glass using a USP laser. Thanks to the high precision of the laser absorption models developed by Fraunhofer ILT for glass materials, this heat source can be calculated very accurately, enabling the scientists to make targeted improvements to the thermodynamic (melting) and thermo mechanical (modification, stress, crack formation) aspects of glass processing.

Laser Ablation of Glass

An essential step in predicting the laser ablation process in glass is calculating the density of locally produced free electrons, both on and below the surface of the material. The model developed by Fraunhofer ILT enables the precise description of the subprocesses of nonlinear absorption and beam propagation. The resulting information makes it possible to determine the expected ablation geometry and damage patterns, which can be extremely useful for assessing the breaking strength of the final component with a view to its intended improvement. The simulation tool provides a reliable way to predict and analyze the mechanisms involved.

Ceation of Optical Filaments

The ability to tailor modifications inside the glass volume to specific requirements (filamentation, material modification, melt zone) means that the laser of fers significant potential for developing efficient, high-quality glass cutting methods. In filamentation, the laser creates defined structures inside the glass volume in which the laser light is strongly focused by nonlinear phenomena. This enables the material to be modified within a tightly restricted area. Local damage effects are used in glass cutting, for example, while structural modifications are used among other things to alter the refractive index in order to generate waveguides. Researchers at Fraunhofer ILT have developed a simulation tool capable of predicting the formation of filaments in glass depending on the process and material parameters. Various properties of the filaments, including their stability and length, can be adapted to customer requirements with the aid of the simulation tool.

Other Applications

The simulation model can be applied to any material where the band gap is large relative to the energy of the photons. Such materials include glass, aqueous solutions and biological tissues. The developed methodology can also be applied to other dielectric materials and even semiconductor materials used in the solar and electronics industries.

Contact

Prof. Wolfgang Schulz
Telephone +49 241 8906-204
wolfgang.schulz@ilt.fraunhofer.de

1 Simulation of laser welding of glass.
© Figure center: I. Miyamoto, Optics Express, 19 (11), 2011.
2 Simulation of optical filaments with variing focal position.
3 Process map of laser ablation of glass.
4 Simulation / cross section of laser ablation of glass.