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Crack-free large-diameter glass welding with femtosecond laser and repetitive single pulses

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Abstract

Transparent laser welding using femtosecond pulses offers a promising solution for precise joining of glass materials. In this study, we demonstrate the successful assembly of large-diameter (20 mm), crack-free fused silica using femtosecond laser welding, without the requirement of chemical pre-treatment or adhesives. A microscope objective, with a numerical aperture of 0.26, was used to focus the laser at the interface, generating a highly localized and intense spot for precise melting of the material. Using a femtosecond laser with a pulse energy of 60 µJ, a repetition rate of 200 kHz, and a scanning speed of 10 mm/s, the spiral pattern minimizes overprocessing and reduces stop-start points, ensuring uniform energy deposition. This approach produced defect-free welds, contributing to improved mechanical resistance, as demonstrated by tensile testing. These results demonstrate the potential for transparent laser welding to be adopted for industrial applications in optics, photonics, and high-precision manufacturing.

Keywords: Femtosecond laser; transparent welding; crack-free; glass

1. Introduction

Glass welding with ultrashort pulse lasers is promising for applications in extreme environment. This technique allows for joining glass without glue and resists to high intensity, temperature or pressure variations. The principle is as follows: a laser beam is focused at the interface of the samples, due to the high intensity at the focal volume, nonlinear absorption occurs. This highly localized energy deposition in glass creates a plasma region and melts the material. If the materials are compatible, they can mix and be joined after re-solidification. Welding of different glasses has already been demonstrated by Miyamoto et al., 2010; and by Richter et al., 2011 but was restricted to small-scale areas featuring relatively low bonding strength.

Our objective is to increase the dimensions of a defect-free welding area, keeping an excellent quality in terms of mechanical strength and low residual stress. To produce a welding seam without defects or cracks, we selected optimal laser parameters according to the results of a systematic study (Lafargue et al., 2025).

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2. Method

2.1. Laser system

We used a Tangor 100 (Amplitude) operating at 1030 nm in repetitive single pulse regime, with a pulse duration of about 500 fs. The repetition rate is adjustable from 1 Hz to 2 MHz, with a maximum output energy of 500 µJ. A half-wave plate and a polarizing beamsplitter cube are put on the trajectory to adjust the energy. A two-lenses beam expander is used to increase the size of the beam before the entry into the microscope objective (Mitutoyo Plan NIR Apo 10X, NA=0.26), resulting in a measured spot diameter of 6 µm at $1/e^2$ in air. The station is equipped with a camera (Basler CMOS), a white light and a couple of dichroic mirrors, to visualize different glass surfaces through the focusing objective as shown in Fig. 1. These components are all mounted on a Z-motorized stage (VP25X, MKS Instruments) for adjusting the focusing position with respect to the assembly interface. The experiments were conducted using fused silica glass samples (Corning 7980) with a 25.4 mm diameter, 3 mm thickness, and λ/4 flatness. The samples were positioned under the beam with motorized XY stages (One-XY60, MKS Instruments) with a travel range of 50 mm.

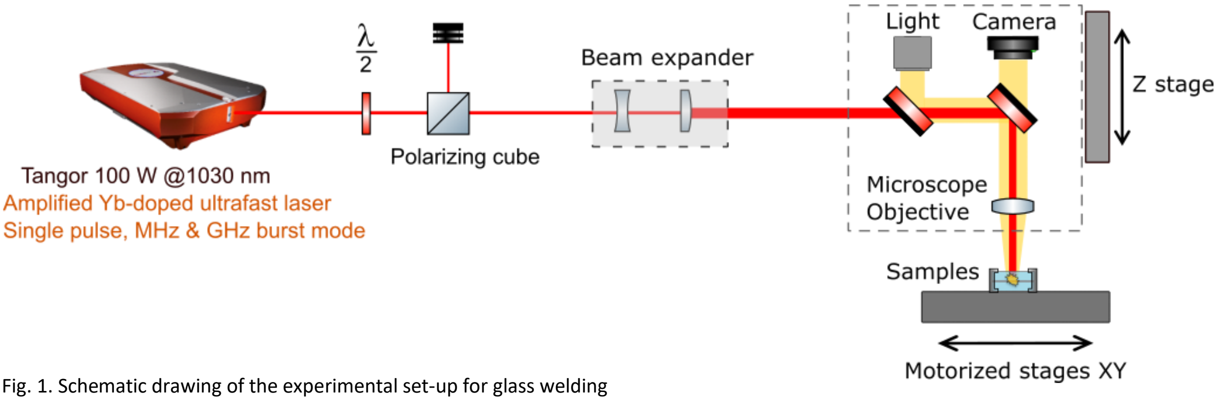

Fig. 1. Schematic drawing of the experimental set-up for glass welding

2.2. Welding protocol

To avoid defects and ensure good contact between the glass plates, the samples are first inspected. If dust is present on the surface, it is removed with dry air. The samples are then put in a home-made clamping tool applying uniform pressure to ensure homogeneous contact throughout the process. The laser focus alignment at the interface is done using the camera. The welding pattern consists in a spiral starting at the center of the sample, where the distance between the turns is 75 µm to have an overlap. It is realized using the DMCpro control software by moving the XY stages, while the laser beam remains stationary.

3. Results

The welding results shown on Fig. 2 have been realized with repetitive single pulses at a repetition rate of 200 kHz and with a moving speed of 10 mm/s of the XY stages for the spiral trajectory. The pulse energy was set to 51.2 µJ. Figure 2(a) shows a photograph of three welded samples with different welding diameters of 5 mm, 10 mm, and 20 mm, respectively. Figure 2(b) shows a side-view microscope image of the welded interface with a laser induced modification. A top-view image of the welding spiral is depicted in Figure 2(c). Note that fused silica always exhibits a bubble on the top of the laser-modified zone as has been published by Lafargue et al., 2025, but the welding seam is stable and very regular.

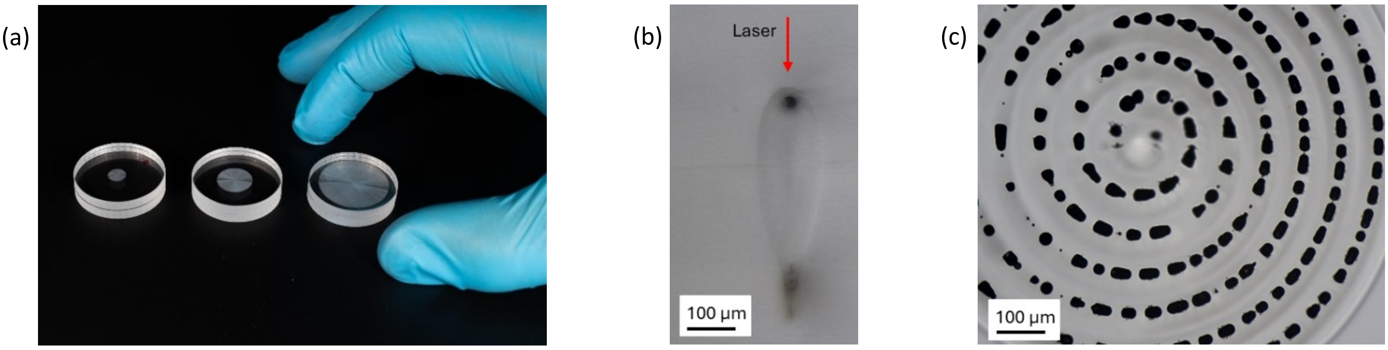

Fig. 2. (a) Fused silica samples (3 mm thick) laser-welded using spiral patterns with different diameters; (b) Side-view microscope image of a laser-induced modification at the interface of two fused silica samples; (c) Top-view microscope image of the welded sample

4. Conclusion

Large-scale welding of fused silica glass, with a diameter of 20 mm, was successfully performed without any visible cracks and without requiring chemical cleaning prior to the process. The welded area is not transparent due to the presence of voids within the laser-induced modifications which are always present for this material. Further studies will focus on evaluating residual stress, performing strength measurements, and investigating alternative welding patterns.

References

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