Lasers in Manufacturing Conference 2025

Direct welding of metals and glass substrates using GHz-burst femtosecond laser pulses

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Abstract

The GHz-burst mode, a relatively new regime in femtosecond laser processing, offers a novel solution for joining dissimilar materials. Its unique way of energy deposition within materials makes it an excellent candidate for the transparent welding of metal and glass. This study investigates the feasibility of this approach, addressing the challenges posed by the differing physical and chemical properties of the materials. Experimental results confirm the potential of the GHz-burst mode by forming defect-free interfaces between fused silica and steel assemblies, attributed to precise energy deposition and minimal thermal impact. This innovative approach to dissimilar material assembly combines the best characteristics of each material, offering promising potential for advanced applications in the fields of electronics, optics, and photonics.

Keywords: GHz-burst mode; femtosecond laser welding; dissimilar materials; glass

1. Introduction

Glue-free assembly of dissimilar materials, such as glass and metals, is a demanded process but very challenging due to the mismatch of the material properties such as thermal the heat diffusion and different surface roughness (Yang et al., 2024; Matsuyoshi et al., 2018). Laser-based bonding with ultrashort is an interesting approach, especially using the innovative GHz-burst regime consisting of femtosecond pluses at a high repetition rate. This allows for depositing the laser energy in a different way in the sample as the energy is spread over many pulses of low energy. The GHz-burst mode showed an enhanced absorption at the focal point in the glass due to very localized non-linear absorption, which leads to cracks due to excessive heating as has been shown in Lafargue et al., 2025. In consequence, this operation mode in not suited for glass-to-glass welding. In contrary, metals profit from beneficial cumulative heating in the GHz-burst regime featuring a smooth and stable melt pool.

Our objective in this contribution is to explore the potential of the GHz-burst regime for dissimilar welding. The idea is to profit from local heating of the metal and progressive heat conduction from the metal to the glass, thus reducing an abrupt expansion of the glass. In this way, stress can be limited and cracks can be avoided. We obtained first promising results on fused silica and stainless steel welding.

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2. Method

We used a Tangor 100 (Amplitude) operating at 1030 nm in GHz-burst mode with 50 pulses per burst (ppb), where the pulse duration of each individual pulse within the burst is about 500 fs and the repetition rate is 1.28 GHz. The burst repetition rate is adjustable from 1 Hz to 200 kHz, 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, and a beam expander enlarges the beam diameter before entering a galvo scanner (Lasea, LS-Scan XY20) as depicted in Fig. 1. An f-theta lens of 30 mm with a numerical aperture of 0.2 is used for beam focusing. The station is equipped with an off-axis camera (Basler CMOS) for determine the vertical focus position. These components are all mounted on a Z-motorized stage (Alio Industries, AI-LM-10000) for adjusting the focusing position with respect to the assembly interface.

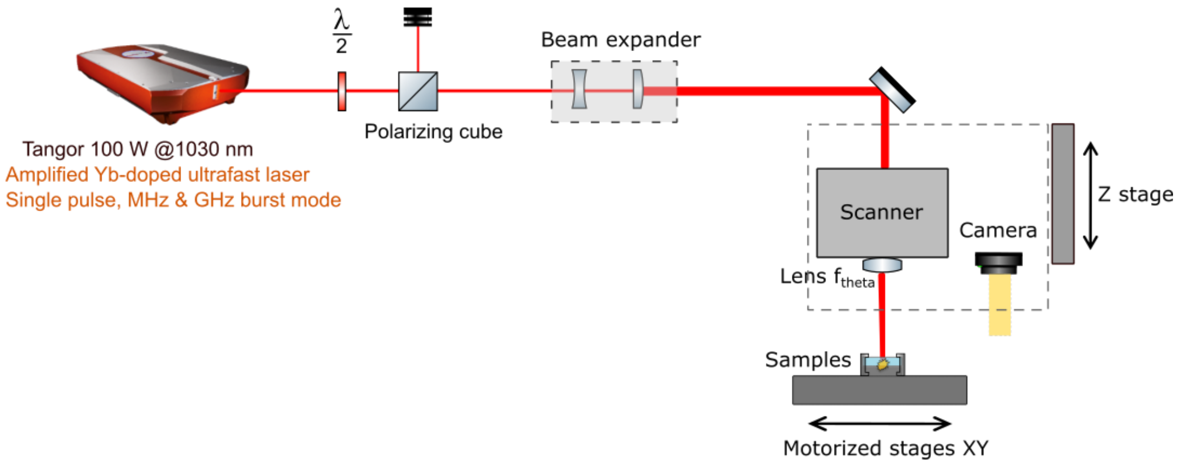

Fig. 1. Schematic drawing of the experimental set-up for glass-metal welding

The experiments were conducted using fused silica glass samples (Corning 7980) with a 25.4 mm diameter, 3 mm thickness, and λ/4 flatness, on the one hand, and on polished stainless steel with a surface roughness of Sa = 9 nm. The samples were positioned under the beam with motorized XY stages (Alio Industries, AI-LM-20000-XY) with a travel range of 200 mm. The samples are 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. In order to find appropriate welding parameters, we carried out line scribing of 3 mm length parallel to the surface at different z focus positions in steps of 50 µm starting at 200 µm above the interface of the two samples. Figure 2 shows a schematic drawing of the experimental protocol.

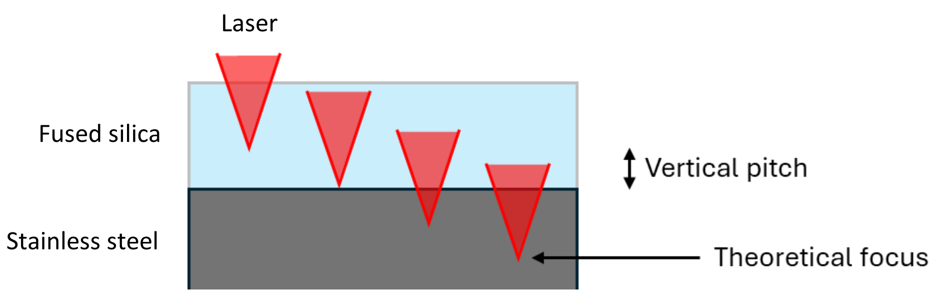

Fig. 2. Schematic illustration of the experimental protocol for parameter optimization

The experiments are realized using the DMCpro control software by moving the mirror of the galvo scanner at a speed of 10 mm/s. The laser parameters were set to GHz-burst operation with 50 ppb at 100 kHz burst repetition rate and 54 µJ burst energy. These parameters had been chosen according to our previous work, where the necessary energy for fused silica melting in GHz-burst mode had been investigated (Lafargue et al., 2025).

3. Results

Figure 3 shows microscope images of the interface of each material, fused silica and stainless steel, respectively, with the lines written at different depths. The zero position corresponds to the interface of both materials. When the laser absorption takes place in the glass part, the modification or melting of the glass occurs above the interface (+200/150 µm) and a large modification at the steel surface is visible. When the laser focus is set at the interface, cracks appear in the glass. When the theoretical focus position is set below the interface, the modification occurs again in fused silica, as the metal reflects the laser beam. However, these modifications are not continuous, and less modifications are visible in stainless steel for theoretical positions of below 150 µm with respect to the interface.

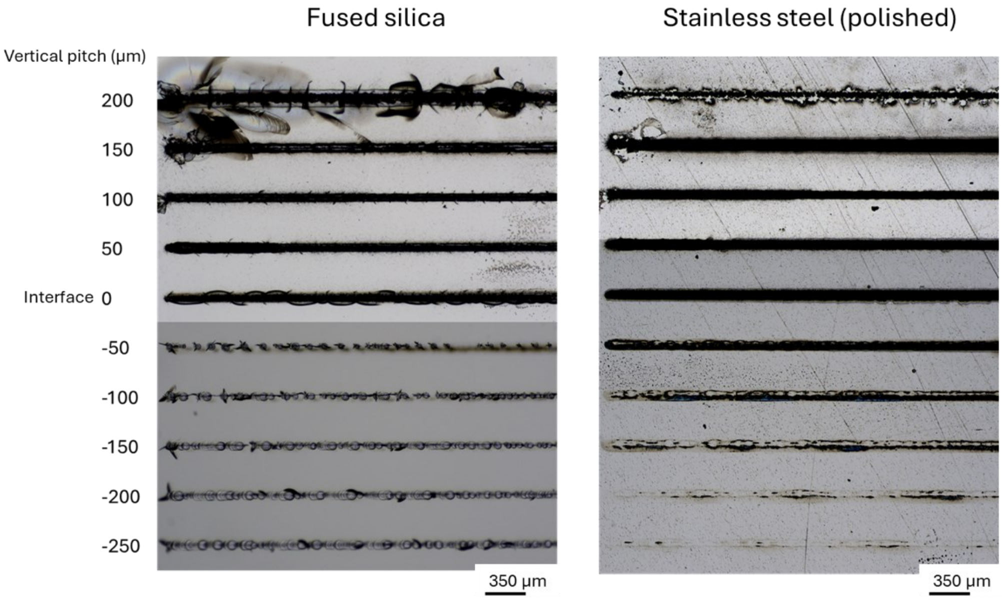

Fig. 3. Microscope images of the surfaces of the fused silica and stainless-steel samples, respectively, after line scribing in GHz-burst mode.

In the following, the focus position was set to z = - 100 µm (below interface), and the laser was focalized using a 10x microscope objective (NA=0.26). Scanning speeds from 0.05 mm/s to 5 mm/s were investigated by moving the samples by the XY translation stages. The burst energy was varied from 18 to 36 µJ/burst at a burst repetition rate of 50 kHz with GHz-bursts of 50 ppb. Figure 4 depicts a photograph of two fused silica - stainless steel samples with the corresponding inscribed lines.

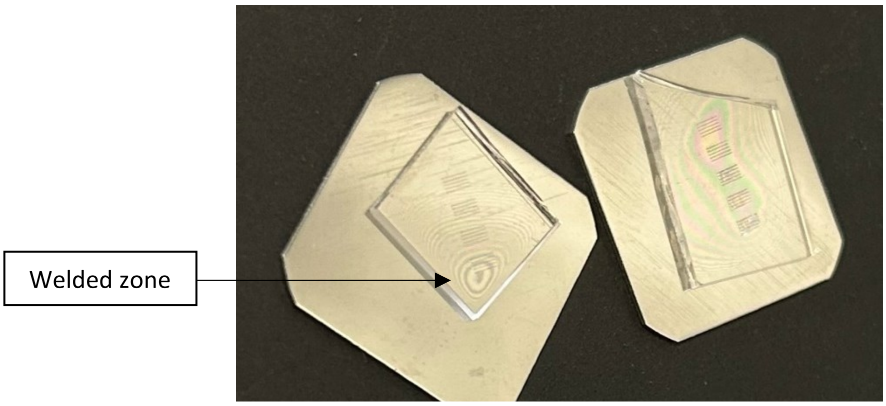

Fig. 4. Photograph of bonded fused silica and stainless steel. The welded zone is indicated by the black arrow.

There is no visible melting of fused silica observable. However, the stainless steel absorbs more energy and heats up leading to a welded zone indicated on Fig. 4. A possible explanation of the bonding mechanism can be found in Zhang et al., 2015. Ablation might occur in the stainless-steel part leading to micro-ejections or splashing of molten material which is projected onto the fused silica surface leading to mechanical interlocking or adhesion. Note that precise focus control is mandatory, and the surface quality of the metal sample is an important factor in order to obtain successful welding of the two dissimilar materials.

Conclusion

We demonstrated the possibility of dissimilar welding of fused silica on stainless steel using the ultrafast laser GHz-burst mode where bursts of 50 ppb at a burst repetition rate of 50 kHz and an energy of 36 µJ have been applied. The welding speed was 5 mm/s at a theoretical focus position of 150 µm below the interface of the samples. In future work, the process will be optimized and other material combinations will be investigated. The GHz-burst mode proves to be an interesting approach for glue-free laser-based bonding of dissimilar materials.

References

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