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Monitoring and Closed Loop Feedback Control of Ultrafast Glass Welding

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Introduction

High precision manufacturing of nano- and micro-sized objects has become increasingly prominent due to the current drive to fit more into increasingly smaller devices. However, while traditional macro-manufacturing systems rely on automatic feedback to detect errors and act immediately, this is a more difficult task when scaled down to the single micron or less.

Project

The overall aim of this project is the creation of a high speed ultra precision laser processing system with monitoring and feedback control to improve the processing precision and reduce error in the produced components.

The work shown here demonstrates the capabilities of the system by improving ultrafast glass-glass welding. Given the stochastic nature of the process, the system will provide guidance by: 1) terminating processing once a specific weld nugget length is reached, 2) control the focal location, and 3) validating the final weld.

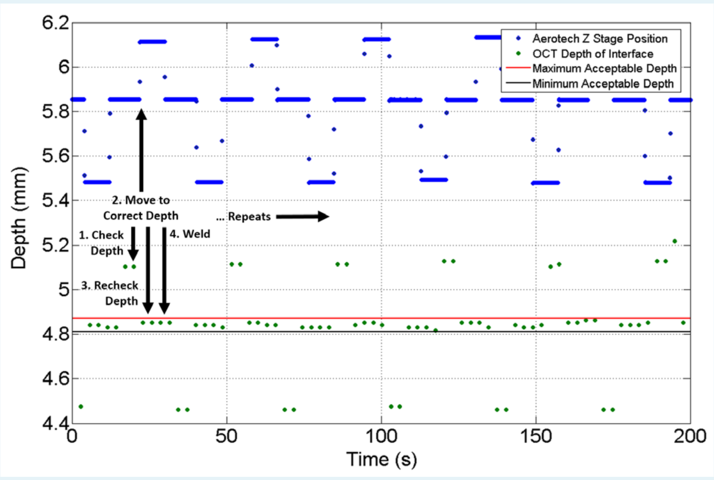
Laser Processing

A control system with multiple imaging systems has been developed for the laser processing platform. The system optimizes the laser system for maximum precision by reducing both precision and manufacturing time by integrating measurement and instrumentation into a single machine.

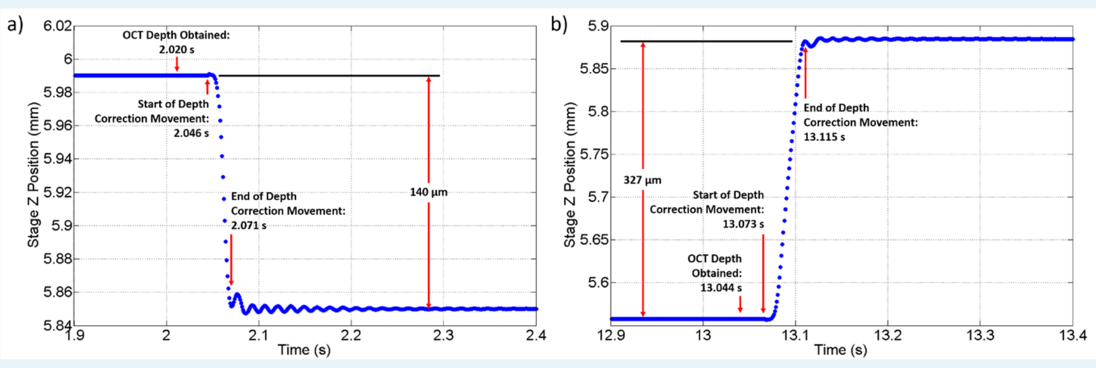
Two imaging techniques are used: 1) optical coherency tomography (OCT) for high speed point inspection, and 2) digital holographic microscopy (DHM), for in-process 3-D monitoring (part inspection). Only OCT is demonstrated here.

In-Process Control

Here, the OCT system is used to monitor the depth of the interface between two glass samples to ensure that a weld is created at the correct depth.



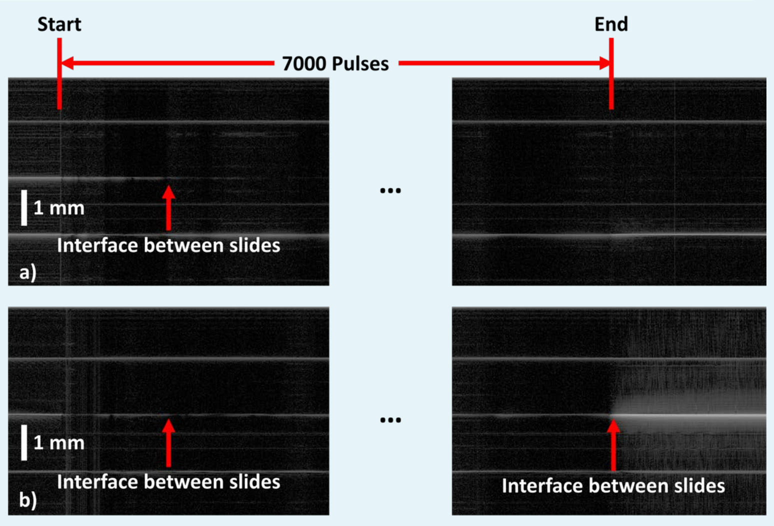
Left: *In-situ* depth control data for glass welding.
Below: Response time of the system to the depth control signal where a) and b) show responses to a drop and rise in depth respectively.

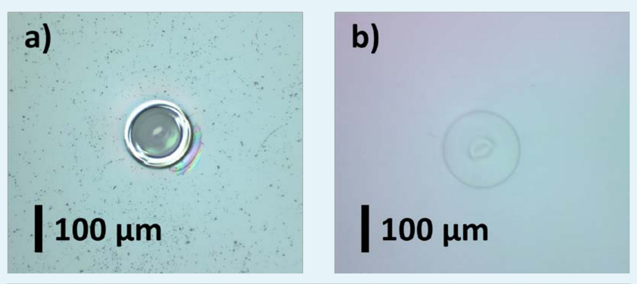


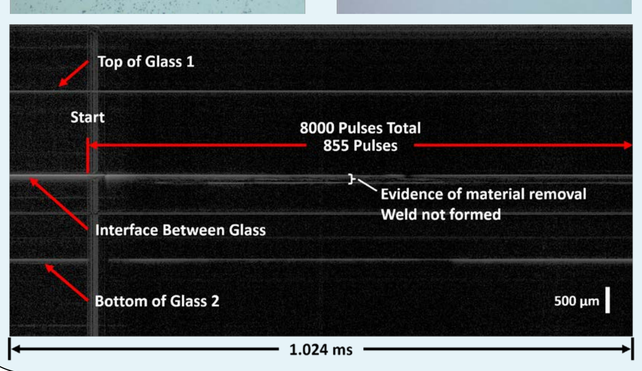
Post-Process Control

The OCT system is also used to monitor the quality of the weld. If the weld succeeds, the melted glass forms good optical contact with its surroundings, resulting in no interface (i.e. no air gap). OCT can also detect material removal due to poor contact between samples (i.e. a failed weld).

Right: OCT *in-situ* images of a) successful weld (i.e. no interface / air gap) and b) non-successful weld.

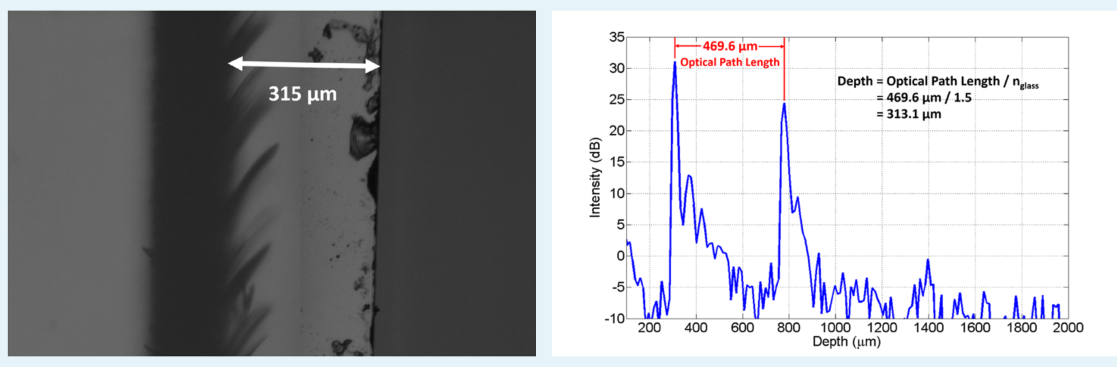




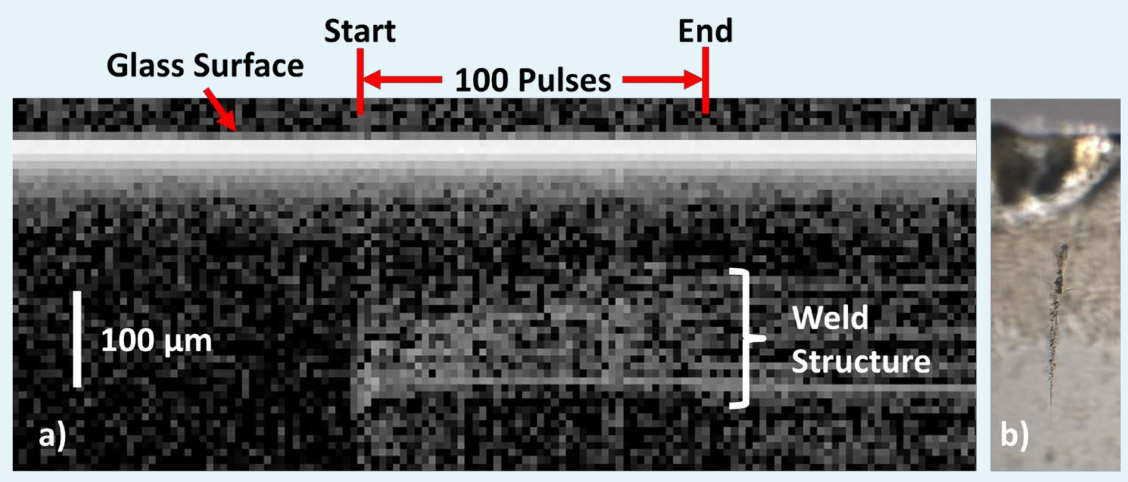


Left Top: Optical microscope images of a) weld crossing the interface between gaps and b) not crossing the interface. These correspond to the OCT images above.
Left Bottom: OCT identification of unsuccessful weld due to poor contact.

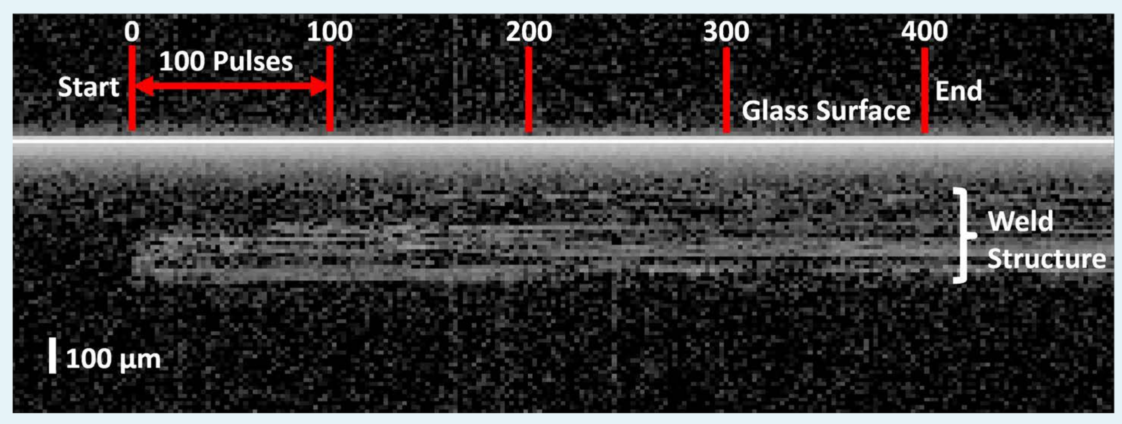
Glass Modification

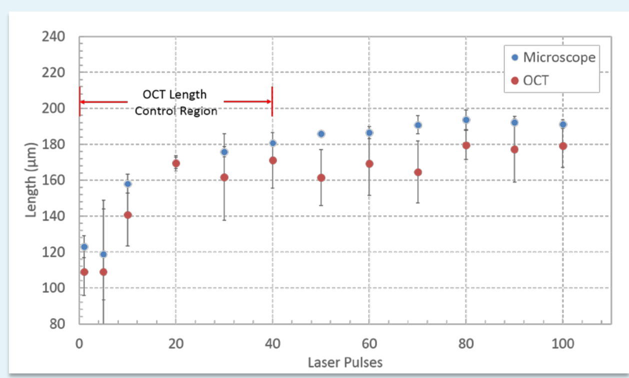


Above Left: Ultrafast induced modification inside of glass.
Above Right: OCT A-line showing the depth of the modification, matching what is observed. OCT is thus able to provide control during within a material.

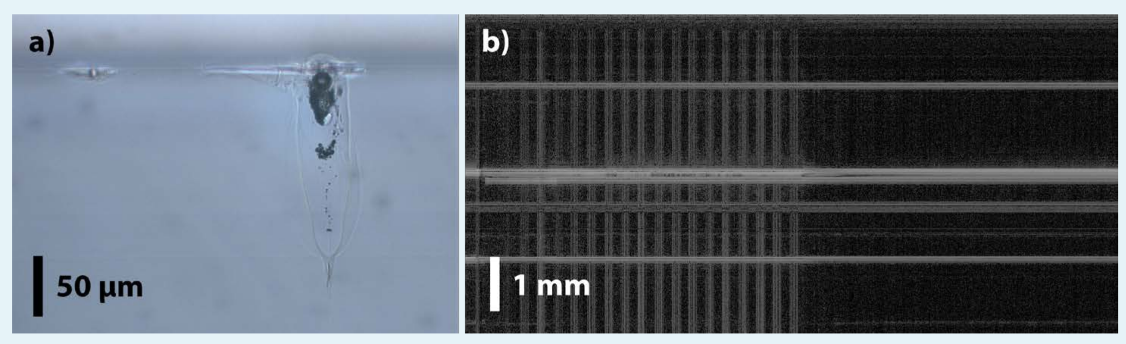


Above: a) OCT monitoring of weld structure formation in bulk SiO_2 and b) corresponding microscope image of structure. The depth scale is the same for both images.
Below: OCT capture of modification in bulk fused silica after 400 processing beam pulses.



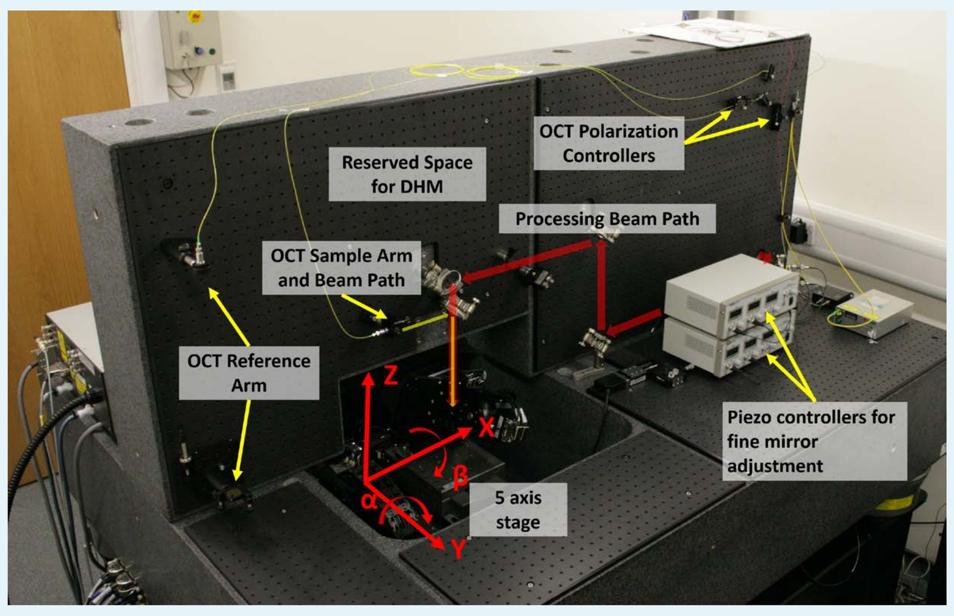


Left: OCT and optical microscopy measurement of structure length in bulk fused silica.
Below: a) Failed weld due to poor contract and b) corresponding OCT M-mode.



Laser Processing Platform

Above: The laser processing platform. The system utilizes 4 different wavelengths (355, 535, 1030, and 1064 nm) and 2 different pulse durations (280 fs and <15 ps) to target specific applications.
Below: The OCT system is operational and able to provide data for laser processing. The system utilizes piezo controllers for mirror mounts to maintain high precision. The 5 axis stage also enables unique processing capabilities (e.g. slanted cavities and undercuts).



Outcomes

- Ruggedized OCT system with in-process feedback control (1-D)
- Integrated system for precision 5 axis machining with *in-situ* control
- Use of OCT to improve glass welding processing

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