Ultrafast Laser Microwelding using Filamentation

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Outline

- Brief introduction to application of filamentation
- Ultra-fast laser micro-welding of transparent and heterogeneous materials using filamentation.

Comparison of nano- and femto-second pulses,
Airtight leak test of hermetic ceiling
Filamentation
- balancing between self-focusing and defocusing by plasma -

Δn_z ≠ Δn_{x,y}
Δn = 10^{-4} \sim 10^{-2}
Applications of filamentation

- Waveguide writing
  Waveguides \(^*1\),\(^*7\), WG Couplers \(^*2\)

- Writing optical elements
  Mirrors \(^*3\), Lenses \(^*4\), Photonic Devices \(^*5\)

- Drilling a hole array \(^*7\)

- Welding materials

- Ultra-fast laser micro-welding of glass with filaments

Scanning the filament

Low repetition source
Fast scanning

~ Gap

High repetition source

~ Accumulation of heat

Low repetition
Slow scanning

~ No gap
Optical setup

- Wavelength: 800 nm
- Pulse duration: 130 fs
- Repetition: 1 kHz
- Incidence energy: ~ 1.0 µJ/pulse

Numerical aperture: 0.30
- Irradiation area: 100 µm x 100 µm
- Translation speed: 5.0 µm/s
Micrographs of welded silica glass samples

Schematic

Top view

Side view
Joining strength (Same material)

- 15 MPa ~ 153 kgf/cm²
- Usual adhesive ~ 50 kgf/cm²

(kgf: kilogram force)
Optical transmittance

- Fused silica glass: 87 ~ 89%
  - Theoretical limit: 93%
- Borosilicate glass: 81 ~ 87%
  - Theoretical limit: 92%

Scanning Speed [mm/s]
Pulse Energy [µJ/pulse]
Heterogeneous welding: dissimilar kinds of glass

Map of joining strength

Geometry

- Laser Pulses
- Borosilicate glass: $39^\times10^{-7}/^\circ C$
- Fused silica glass: $5.9^\times10^{-7}/^\circ C$

*Thermal expansion coefficient

Wataru Watanabe, Satoshi Onda, Takayuki Tamaki, Kazuyoshi Itoh, and Junji Nishii,
Joining strength and transmittance

Joining strength

Optical transmittance
Effects of Annealing (silica glass & silica glass)

Annealing makes welded part invisible.
(Implication of disappearance of defects.)
## Enhancement of joining strength & optical transmittance

<table>
<thead>
<tr>
<th>Joining strength</th>
<th>Borosilicate glass</th>
<th>Fused silica glass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before annealing</strong></td>
<td>15 MPa</td>
<td>15 Mpa</td>
</tr>
<tr>
<td><strong>After annealing</strong></td>
<td>33 MPa</td>
<td>33 MPa</td>
</tr>
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</table>

### Optical transmittance

<table>
<thead>
<tr>
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<th>Borosilicate glass</th>
<th>Fused silica glass</th>
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<tbody>
<tr>
<td><strong>Before annealing</strong></td>
<td>88 %</td>
<td>87 %</td>
</tr>
<tr>
<td><strong>After annealing</strong></td>
<td>92 %</td>
<td>91 %</td>
</tr>
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(Theoretical limit: 93 %) (Theoretical limit: 92 %)
Enhancement of optical transmittance by annealing

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<th>Borosilicate glass</th>
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(Theoretical limit: 93 %) (Theoretical limit: 92 %)
- Ultra-fast Laser Micro-welding of

Glass and Copper


# Heterogeneous welding: dissimilar kinds of materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Fused silica glass</th>
<th>Borosilicate glass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Polymer</strong></td>
<td>PMMA 700 [$\times 10^{-7}/^\circ \text{C}$]</td>
<td><strong>Unsuccessful</strong></td>
</tr>
<tr>
<td><strong>Semiconductor</strong></td>
<td>Silicon 28 [$\times 10^{-7}/^\circ \text{C}$]</td>
<td><strong>Successful</strong></td>
</tr>
<tr>
<td><strong>Metal</strong></td>
<td>Cupper 183 [$\times 10^{-7}/^\circ \text{C}$]</td>
<td><strong>Successful</strong></td>
</tr>
<tr>
<td><strong>Alloy</strong></td>
<td>Stainless steel 175 [$\times 10^{-7}/^\circ \text{C}$]</td>
<td><strong>Successful</strong></td>
</tr>
</tbody>
</table>

*Thermal expansion coefficient

Wide range of heterogeneous welding
Ultra-fast Laser Micro-welding of Glass and Copper

Realizing tight contact between glass and copper
Optical microscope images

(a) Side view  (b) Top view  (c) Whole image

Laser source: Regenerative Ti:sapphire laser (Spectra Physics, Spitfire)
Central wavelength: 800 nm
Pulse duration: 130 fs
Repetition rate: 1 kHz
Pulse energy: 4 µJ/pulse
Scan speed: 1 mm/s

Joining strength: ~20 MPa
Joining Strength & Electron Micrograph of Interface

- **0.4 µJ**
- **Average: 21.5 MPa**

No crack nor gap observed but some bumpy irregularity presents.
Comparison with ns-pulse welding

Femtosecond pulse: 800 nm, 130 fs, 1 kHz
Nanosecond pulse: 527 nm, 600 ns, 1 kHz
Translation speed: 1 mm/s

Lower energy welding is possible by using fs pulses.
Sample morphology

Nanosecond pulse welding
(527 nm, 600 ns, 50 µJ, 1 kHz, 1 mm/s)

Femtosecond pulse welding
(800 nm, <100 fs, 1 µJ, 1 kHz, 1 mm/s)

Lower energy welding with fs pulses is advantageous for minimizing heat effects
Difference of heat sources

Femtosecond pulses

- Nonlinear absorption in filament (Heating)
- Linear absorption (Heating)

Nanosecond pulses

- No filament
- No absorption (No heating)

Glass
Metal

Linear absorption (Heating)
Application of Ultra-fast Laser Micro-welding to Metal Package (Glass & Kovar)

(a) Birds-eye view

(b) Top view
Hermetic ceiling of ceramic package

- Ceramic cavity
- Electroless nickel plating
- Ceramic package (92% Alumina)
- Welded part
- Schott D263 glass
## Leakage test

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample</th>
<th>Leakage after welding (Pascal m²/sec)</th>
<th>Leakage after annealing (Pascal m²/sec)</th>
<th>Leakage after thermal shocks (100 cycles) (Pascal m²/sec)</th>
<th>Annealing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>$5.6 \times 10^{-10}$</td>
<td>–</td>
<td>$2.9 \times 10^{-10}$</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>$2.0 \times 10^{-10}$</td>
<td>–</td>
<td>$0.7 \times 10^{-10}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>$2.0 \times 10^{-10}$</td>
<td>–</td>
<td>$0.0 \times 10^{-10}$</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>$2.0 \times 10^{-10}$</td>
<td>$2.0 \times 10^{-10}$</td>
<td>$0.3 \times 10^{-10}$</td>
<td>$200^\circ C$ (-1\ hr)</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>$1.4 \times 10^{-10}$</td>
<td>$1.3 \times 10^{-10}$</td>
<td>$0.3 \times 10^{-10}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>$1.3 \times 10^{-10}$</td>
<td>$1.1 \times 10^{-10}$</td>
<td>Removal of lid</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>$1.5 \times 10^{-10}$</td>
<td>Removal of lid</td>
<td>unmeasurable</td>
<td>$500^\circ C$ (-1\ hr)</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>$1.7 \times 10^{-10}$</td>
<td>$1.5 \times 10^{-10}$</td>
<td>$0.5 \times 10^{-10}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>$1.4 \times 10^{-10}$</td>
<td>$1.2 \times 10^{-10}$</td>
<td>$0.0 \times 10^{-10}$</td>
<td></td>
</tr>
</tbody>
</table>

The results are almost perfect.
Summary

-Ultra-fast laser micro-welding of homogeneous and heterogeneous materials
- silica glass and copper

average joining strength: 21.5 Mpa
( ~220 kgf/cm² )

-filaments alleviates the focusing requirements
and acts as an important source of heat for welding.
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Konica Minolta Opto, Inc.