Micro-laser assisted single point diamond turning of glass materials

Micro-LAM, Inc.
## Test details
- Part: Ø30 mm planar fused silica
- RPM: 1000
- DoC: 1 µm
- Laser power used: 9 W

### Conventional DT
- SWLI interferogram: $Sa = 1.075 \, \mu m$, $Sq = 1.275 \, \mu m$
- SEM image: Wear land
- Tool wear image: Wear land

### μ-LAM process
- SWLI interferogram: $Sa = 0.01 \, \mu m$, $Sq = 0.02 \, \mu m$
- SEM image: Wear land
- Tool wear image: Wear land

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**DT’ed sample using μ-LAM**

- Center
- Edge
- Middle
Chip formation

Diamond tool

Spindle: 1000 RPM
Feed: 1 µm/rev
0.5 mm tool radius

Ductile material removal of fused silica
Machined materials to date

Refractive index vs. Abbe Number chart showing:
- S-NPH3
- N-SF11
- Zerodur
- S-PHM52
- S-FPL51
- N-PK51
- BK7
- FS
Planar fused silica

Test details
- Part: Ø30 mm Edmunds
- RPM: 1000
- Feed: 1 µm/rev
- DoC: 1 µm
- Measured pass: 2
- Laser power: 9 W
- Coolant: GCS_A

Metrology details
- Inst: Zygo ZeGage HR+
- Obj: 50× Mirau
- Filter: 4th order Chebyshev
- FOV: 0.17 mm × 0.17 mm

<table>
<thead>
<tr>
<th>param</th>
<th>Mean (nm)</th>
<th>STD (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sa</td>
<td>17.33</td>
<td>5.81</td>
</tr>
<tr>
<td>Sa</td>
<td>25.47</td>
<td>7.95</td>
</tr>
</tbody>
</table>

Near the center
Middle
Near the edge

-0.5 µm

0.5 µm
Planar Zerodur

**Test details**
- **Part:** 25 mm ZYGO
- **RPM:** 4000
- **Feed:** 1 µm/rev
- **DoC:** 1 µm
- **Measured pass:** 2
- **Laser power:** 9 W
- **Coolant:** GCS_A

**Metrology details**
- **Inst:** Zygo ZeGage HR+
- **Obj:** 50× Mirau
- **Filter:** 4th order Chebyshev
- **FOV:** 0.17 mm x 0.17 mm

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<tr>
<th>param</th>
<th>Mean (nm)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Sa</td>
<td>32.29</td>
<td>8.49</td>
</tr>
<tr>
<td>Sq</td>
<td>47.44</td>
<td>13.16</td>
</tr>
</tbody>
</table>

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![Height value (nm)](chart1.png)

**Near the center**

![Height value (nm)](chart2.png)

**Middle**

![Height value (nm)](chart3.png)

**Near the edge**

![Height value (nm)](chart4.png)
Planar S-NPH3

**Test details**
- **Part:** Ø34 mm Qioptic
- **RPM:** 4000
- **Feed:** 1 µm/rev
- **DoC:** 1 µm
- **Measured pass:** 2
- **Laser power:** 5 W
- **Coolant:** GCS_A

**Metrology details**
- **Inst:** Zygo ZeGage HR+
- **Obj:** 50× Mirau
- **Filter:** 4th order Chebyshev
- **FOV:** 0.17 mm × 0.17 mm

<table>
<thead>
<tr>
<th>param</th>
<th>Mean (nm)</th>
<th>STD (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sa</td>
<td>119.53</td>
<td>3.08</td>
</tr>
<tr>
<td>Sq</td>
<td>153.66</td>
<td>2.44</td>
</tr>
</tbody>
</table>

-0.5 µm  0.5 µm
SPDT of fused silica lens

Test details
- Part: ∅20 mm CX fused silica
- RPM: 1000
- Feed: 1 µm/rev
- DoC: 2 µm
- Laser power: 9 W

Average Sa ≈ 30 nm
Average Sq ≈ 60 nm

Fizeau measurement

DT’ed sample

20× SWLI interferogram

Linear trace across black dotted line

Height (nm)

Distance from center (mm)
SPDT of BK7 lens

**Test details**
- Part: Ø20 mm CX BK7
- RPM: 1000
- Feed: 1 µm/rev
- DoC: 1 µm
- Laser power: 9 W

**Fizeau measurement**
- Average Sa ≈ 50 nm
- Average Sq ≈ 100 nm

**DT’ed sample**

20× SWLI interferogram

Linear trace across black dotted line
SPDT of SF11 lens

**Test details**
- Part: Ø25 mm CC SF11
- RPM: 1000
- Feed: 1 µm/rev
- DoC: 1 µm
- Laser power: 9 W

Average Sa ≈ 120 nm
Average Sq ≈ 240 nm

20× SWLI interferogram

Fizeau measurement

Linear trace across black dotted line
Form data

Test details
- Part: Ø34 mm CX S-NPH3
- RPM: 4000
- Feed: 0.25 µm/rev
- DoC: 2 µm
- Laser power: 5 W

Before correction

After correction

Average Sa ≈ 86 nm
Average Sq ≈ 140 nm

0.5 µm
Linear profiles across dashed line

PV ≈ 667 nm
RMS ≈ 103 nm

PV ≈ 434 nm
RMS ≈ 59 nm

20× SWLI interferogram
Subsurface damage study

**Test details**
- **Part:** Ø25 mm Fused silica CX
- **Spindle speed**
  - Roughing: 4000 rpm
  - Finishing: 1000 rpm
- **Feed**
  - Roughing: 8 mm/min
  - Finishing: 1 mm/min
- **DoC**
  - Roughing: 20 µm
  - Finishing: 1 µm
- **Number of passes:** 2

**Total time**
- Grinding: 115 min
- 84% less
- 95% less
- Roughed DT: 45 minutes
- Finished DT

**Fizeau interferogram**

**Height vs. Distance from center (mm)**

- Height: -200 to 200 nm
- Distance from center: -10 to 10 mm
Roughness data – white light interferograms

- **Machined sample**
  - Center
  - Middle
  - Edge

<table>
<thead>
<tr>
<th>Near the center</th>
<th>Middle</th>
<th>Near the edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 µm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Sampling details**
  - Number of zones: 3
  - Measurement/zone: 5

- **Roughness measurement**
  - Instrument: Zygo ZeGage HR
  - Objective: 50× Mirau
  - 4th order polynomial removed

- **Average roughness (nm)**
  - **Sa**:
    - Center: ~80 nm
    - Middle: ~60 nm
    - Edge: ~70 nm
  - **Sq**:
    - Center: ~50 nm
    - Middle: ~40 nm
    - Edge: ~60 nm

- **Color scale**
  - -0.4 µm to 0.4 µm
Form data – Luphos acquired height map

Measurement info
- Instrument: Luphoscan 260
- Piston, tilt, power, removed

Measurement statistics
- PV ≈ 821 nm
- RMS ≈ 210 nm
## Tool wear data

<table>
<thead>
<tr>
<th>Before cutting</th>
<th>After 20× obj.</th>
<th>After 50× obj.</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Before cutting" /></td>
<td><img src="image2" alt="After 20× obj." /></td>
<td><img src="image3" alt="After 50× obj." /></td>
</tr>
</tbody>
</table>

- **Worn zone**

After 4.4 km of cutting
## Summary of results to date

<table>
<thead>
<tr>
<th>material</th>
<th>Roughing</th>
<th>Finishing</th>
<th>Part</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sq (nm)</td>
<td>feed (µm/rev)</td>
<td>RPM</td>
</tr>
<tr>
<td>FS</td>
<td>60</td>
<td>3</td>
<td>6000</td>
</tr>
<tr>
<td>BK7</td>
<td>60</td>
<td>3</td>
<td>4000</td>
</tr>
<tr>
<td>Zerodur</td>
<td>TBD</td>
<td>TBD</td>
<td>4000</td>
</tr>
<tr>
<td>S-NPH3</td>
<td>160</td>
<td>2</td>
<td>4000</td>
</tr>
<tr>
<td>SF11</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>
Summary and future work

Summary

- Ductile material removal from glass materials using μ-LAM process demonstrated
- Tool wear greatly reduced
- Form control achieved within 600 nm

Future work

- Optimization of process for other glass materials
- Production of aspherical surfaces
- Quantification of reduction of process time to conventional processes
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Should you have any questions please contact below

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