FEMTOSECOND LASER WRITING IN LASER GLASSES

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In the case of a femtosecond laser pulse, the light is absorbed by electrons, and the optical excitation ends before the lattice is perturbed.

A femtosecond laser pulse is tightly focused inside transparent glasses. At the point of laser focus, the laser intensity becomes high enough to cause nonlinear absorption (i.e., multiphoton, tunneling, and avalanche ionization, continuum generation).

If enough laser energy is deposited into the material, permanent structural changes (i.e., damage – voxels, lines) are produced at the laser focus.
Motivation

- Microstructuring of optically-active glasses*
  - *Miniaturization* of photonic components
  - *Integration* of active photonic devices
- Room temperature persistent spectral hole burning (PSHB)**
  - Application to *high-density frequency domain optical storage*
  - Samarium-doped aluminum silicate
    (inhomogeneous line width, compositional variations, and ease of production)

Objectives

- **Demonstrate** writing of dots and lines in optically active glasses

- **Study** the evolution of the structures in these glasses

- **Characterize** topography and structure generated
Glass Sample Preparation

- Samarium alumino-silicate (SAS) glass*
  - $10\text{Sm}_2\text{O}_3\cdot25\text{Al}_2\text{O}_3\cdot65\text{SiO}_2$

- Laser glass - Nd-doped alkali/alkaline earth aluminophosphate glass

<table>
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<th>Oxide</th>
<th>(mol%)</th>
<th>adj mol%</th>
<th>source</th>
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<tr>
<td>$\text{Al}_2\text{O}_3$</td>
<td>10.00</td>
<td>9.82</td>
<td>$\text{Al}_2\text{O}_3$</td>
</tr>
<tr>
<td>$\text{BaO}$</td>
<td>15.00</td>
<td>14.73</td>
<td>$\text{BaCO}_3$</td>
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<tr>
<td>$\text{K}_2\text{O}$</td>
<td>15.00</td>
<td>14.73</td>
<td>$\text{K}_2\text{CO}_3$</td>
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<tr>
<td>$\text{Nd}_2\text{O}_3$</td>
<td>0.00</td>
<td>1.80</td>
<td>$\text{Nd}_2\text{O}_3$</td>
</tr>
<tr>
<td>$\text{P}_2\text{O}_5$</td>
<td>60.00</td>
<td>58.92</td>
<td>$\text{P}_2\text{O}_5$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Batching, melting, remelting, casting, cooling and annealing

* Dr. Delbert Day (UMR)
Femtosecond Laser Writing

- Coherent RegA Ti-sapphire amplified system
  - Operating at: 250 kHz, 100 fs, 800 nm
- Focusing conditions 0.25 NA
- Estimated spot area 3 µm²
- Power 0.2 - 0.66 W
- Energy 0.9 - 2.6 µJ
- Fluence 0.56-1.68 (J/m²) □ 10⁶
- Room temperature
- Surface/near surface
Written Structures & Characterization

- Lines (3 sets using 0.6, 1.7, and 2.7 µJ, 100 µm apart)
  - 50 µm
  - 400 µm/s, 1875 pulses
  - 200 µm/s, 3750 pulses
  - 100 µm/s, 7500 pulses
  - 50 µm/s, 15000 pulses

- Dots
  - 50 µm
  - 250000, 500000, ....
  - 2500000 pulses (100 µm/s)

- Characterization
  - Non-contact optical profilometry (≥20), AFM, SEM/EDS, micro-Raman
Structures in SAS-Glass

400 µm/s, 1875 pulses

200 µm/s, 3750 pulses

100 µm/s, 7500 pulses

50 µm/s, 15000 pulses
Profilometry

X Profile

Y Profile

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AFM Results

250000 500000 ..... 2500000 pulses (100 µm/s)

50 µm

2500000 5000000 ..... 25000000 pulses (100 µm/s)

Digital Instruments Nanoscope
Scan size: 35.00 µm
Scan rate: 1.277 Hz
Number of samples: 256
Image Data: Height
Data scale: 5.000 nm

Digital Instruments Nanoscope
Scan size: 34.82 µm
Scan rate: 2.977 Hz
Number of samples: 256
Image Data: Height
Data scale: 5.000 nm

Digital Instruments Nanoscope
Scan size: 57.93 µm
Scan rate: 2.977 Hz
Number of samples: 256
Image Data: Height
Data scale: 5.000 nm

U.S. Department of Energy
Pacific Northwest National Laboratory
AFM Results

250000  500000  .....  2500000 pulses (100 µm/s)

50 µm

2500000  5000000  .....  25000000 pulses (100 µm/s)
AFM Results

250000  500000  .....  2500000 pulses (100 µm/s)

50 µm

2500000  5000000  .....  25000000 pulses (100 µm/s)

25000000 pulses (100 µm/s)

Digital Instruments Nanoscope
Scan size  50.00 µm
Scan rate  2.977 Hz
Number of samples  256
Image Digit. Height
Data scale  5.000 nm

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Profilometry - Top Line
(0.88W/1875 pulses)
SEM Results – 0.88W/1875 pulses
SEM Results - 0.88W/3750 pulses
SEM Results - 0.88W/7500 pulses
SEM Results - 0.88W/15000 pulses
Submicron Structures

- **Shock waves?**

- **Surface ripples?**

- Samarium □ increasing electronic conductivity - higher thermal conductivity - rapid cooling
Laser Glass - Profilometry – 0.22 W
Profilometry (continued) – 0.22 W
Profilometry (continued) – 0.22 W
Profilometry (continued) – 0.42 W
Profilometry (continued) – 0.42 W
Profilometry (continued) – 0.88 W
Micro-Raman Data

Blue Laser Glass (Bulk); 514.5 nm

Blue Laser Glass (Inside Track); 514.5 nm
Summary

- Our writing experience in active glasses shows familiar features and sequence of structure evolution- *cone formation, collapsing, and crater-forming* in all the samples.

- Substructure formed within lines written in samarium aluminosilicate glass may be *signatures of shock waves or surface ripples* frozen in the glass as the writing progresses.
Acknowledgement

- Summer interns Richard Shtiveland (OSU) and Brian Riley (UW) - preparation of the laser glass
- PNNL business development - support
- Department of Energy - support