Large Area Pulse Compression Gratings Fabricated Onto Fused Using Scanning Beam Interference Lithography

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↑ A 91cm x 42cm MLD grating for laser pulse compression
Outline

- Introduction to SBIL
- Use of Silica Substrates For Gratings
- Some results from current production
- Grating types
- New Stuff
In VP-SPIL A Small Beam Of Fringes Scans Across a Large Substrate

VP-SBIL – Variable-Period Scanning Beam Interference Holography

Averaging occurs in scan direction and through overlapping scans
Variable-Period Scanning Beam Interference Lithography (VP-SBIL) Advantages

- Very high level of dose control. Line duty cycle is very consistent and predictable

- Fast change between period spacing (30 minutes)

- Averaging methods reduce pitch and duty cycle variation

- Grating period repeatability is better than 10 ppB from part-to-part.

- There are nearly zero-defects form the exposure process – however, defects do occur in other processes such as resist coating, etching…

- Errors due to turbulence are low - local area is controlled to ± 0.01° K.

- Vibration errors are actively controlled while writing the grating.

There are no fundamental limitations to substrate size
The VP-SBIL Optics platform is Mounted Over a Precision Air Bearing X-Y Stage

- The entire apparatus is quite compact
- The stage position is monitored by stage interferometers (not shown) and column reference mirrors
- A scanning photometer for testing DE can be integrated into this same platform
A 91cm X 42cm Osaka Grating Is Prepared For Imprinting

Current maximum size is about 93 cm x 60 cm
Exposure test at 1740 lines/mm on BF/MLD/120ARC/500PR
3/5/08  1.3 mm apertures; 178t-08-nr2; Doses 150 to 50 mJ/cm²
Pointing Deviation Problems causes Thermal Period Error Is Minimized By Using Fused Silica

Due to 4 times dispersion from the gratings and 4 meters of focusing distance, 35 μm of pointing may occur.

Using Fused Silica For Grating Substrates Will Increase The Stability of Stretchers and Compressors

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal expansion coefficient</th>
<th>Temperature Control</th>
<th>Allowed ΔT in surface</th>
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<tbody>
<tr>
<td>BK-7</td>
<td>$7 \times 10^{-6}$</td>
<td>0.06 °C</td>
<td>0.006°C</td>
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<tr>
<td>Pyrex</td>
<td>$2.8 \times 10^{-6}$</td>
<td>0.14 °C</td>
<td>0.014°C</td>
</tr>
<tr>
<td>Fused silica</td>
<td>$0.4 \times 10^{-6}$</td>
<td>1 °C</td>
<td>0.1°C</td>
</tr>
<tr>
<td>Low expansion Glass</td>
<td>$0.08 \times 10^{-6}$</td>
<td>5 °C</td>
<td>0.5°C</td>
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</tbody>
</table>

* $1740.001 / 1740.000 = 0.5$ ppm

0.5 ppm error result in 2.2 μrad difference in diffraction angle

Spot dev. = 35 μm (equiv. to 0.2λ)

for 0.5 ppm groove change

Spot dev. = 3.5 μm

for 0.05 ppm groove change
Stress in Fused Silica Coatings Must Be Controlled To Eliminate Crazing and Wavefront Distortion

- Excessive Tensile stress distorts wave front and introduces the possibility of crazing
- Excessive Compressive (or Tensile) stress distorts wave front in grating optics

Film thickness is about 6 microns

SEM of a fractured optic.

Normal Crazing
A 12 Cm RF Ion Source In A 1 Meter Chamber Was Used To Develop The IAD Coating For Low Stress

- The RF Ion Source is a reliable source that can operate over a wide range of conditions. For this experiment:
  1. Beam Voltage: 250 to 500 Volts
  2. Beam Current: 150 to 450 Milliamps
  3. Gas: Ar, O₂, or both

- An RF neutralizer provides the electrons for source ignition and beam charge neutralization

- The ion source automatically goes to an idle state after the end of a layer, then ramps up slowly as the e-beam is achieving the target deposition rate

- Different ion bombardment programs are used for the different materials

- E-beam coating is scalable and has been proven to have high damage thresholds

The 12 cm RF ion source operating in a 1 meter chamber with Oxygen
The Low-Stress IAD Process Was Scaled Up In The Okamoto Optics Chamber in Japan

- A 66 cm x 6 cm RF Ion Source Was Used to Make The IAD Production Coatings.

- Extra effort was required to obtain a uniform ion dose across the large substrate.

- A 91cm x 42cm Osaka Grating substrate (fused silica) is seen mounted in a 2-meter e-beam coating chamber.

This chamber also produced all the mirrors for the Osaka Firex-1 PW Laser.
Compressive Stress is Negative
Tensile Stress is Positive

Coating Stress Is Slightly Compressive To Eliminate The Risk Of Tensile Failure

Changes in stress as a function of time (measured in Dry N2)
(all samples coated in Okamoto chamber)

<table>
<thead>
<tr>
<th>Sample</th>
<th>IAD total power</th>
<th>Current Stress (mPa)</th>
<th>Run Temp</th>
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<tbody>
<tr>
<td></td>
<td>Watts</td>
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<tr>
<td>022p-08-OK</td>
<td>175 290</td>
<td>-46 150</td>
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<tr>
<td>024p-08-OK</td>
<td>175 290</td>
<td>-24 100</td>
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<tr>
<td>073p-08-OK</td>
<td>87.5 290</td>
<td>-39 100</td>
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<tr>
<td>074p-08-OK</td>
<td>87.5 290</td>
<td>-39 100</td>
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IAD total power

<table>
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<tr>
<th>Sample</th>
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<th>Silica Watts</th>
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* Low stress ion-assisted coatings on fused silica substrates for large-aperture pulse compression diffraction gratings
Smith, McCullough, Smith, Mikami, Jitsuno, Boulder Symposium on Laser Damage, 2008

2008 runs show lower stress overall and less variation over time.
Etching, Resist Coating, And Metrology Tools Also Are All Scaled To 1 Meter Optics
Etched MLD Diffraction Efficiency Is Uniform and High Across The VP-SPIL MLD Gratings

- Below are examples of 1740 lns/mm from this 2008 Production

  Stretcher 200x400mm
  \[ \text{DE}_{\text{avg}} = 95.9\% \]

  Osaka G16 - 920mm x 410mm
  \[ \text{DE}_{\text{avg}} = 96.5\% \]

  Osaka G13 - 920mm x 410mm
  \[ \text{DE}_{\text{avg}} = 96.6\% \]

  Osaka G12 - 920mm x 410mm
  \[ \text{DE}_{\text{avg}} = 97.5\% \]
All diffracted results shown are single pass at 1054nm and include both grating and substrate errors (exception noted).
Damage Threshold of the Gratings have been tested by UR/LLE and Osaka

<table>
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<th>Osaka</th>
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“Optimizing a cleaning process for multilayer-dielectric- (MLD) diffraction grating”
B. Ashe, C. Giacofei, G. Myhre, and A. W. Schmid
In Laser-Induced Damage in Optical Materials: 2007
MLD Grating Fabrication Process

1) Coat substrate with MLD, ARC and photoresist.

2) Pattern grating by SBIL and develop.

3) Etch ARC by oxygen RIBE.

4) Etch MLD top layer by fluorine RIBE.

5) Strip resist and ARC.

1740 l/mm MLD grating
There are several different types of metal gratings.

**Binary Gold Gratings**
- Gold over Photoresist
- Conventional Coating

**Improved Coating Method**

**Etched Grating**
- Low-contrast resist sinusoidal grating, (silver overcoat)

**Gold Over Etched Grating**
PGL will use a period division method developed by MIT to make gratings with 100 nm period.

- This process allows a doubling, tripling, or quadrupling of the highest frequency allowed by the Nanoruler (5000 lns/mm).
- The images at left showed the last steps in the quadrupling process. The final result is a grating with a period=50 nm or 20,000 lns/mm!
- A pitch of 100 nm is optimum for the WGP application, so for this work PGL will double the frequency.
- Scale-up of this technology remains to be proven.


Large Area Pulse Compression Gratings Fabricated Onto Fused Using Scanning Beam Interference Lithography

- VP-SBIL has great advantages for P-C Gratings
- Silica is the preferred substrate for stability
- DE and Wavefront results are quite good and consistent
- MLD and Gold gratings can be made
- Plans are underway to expand capability to 1.5 meter substrates