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

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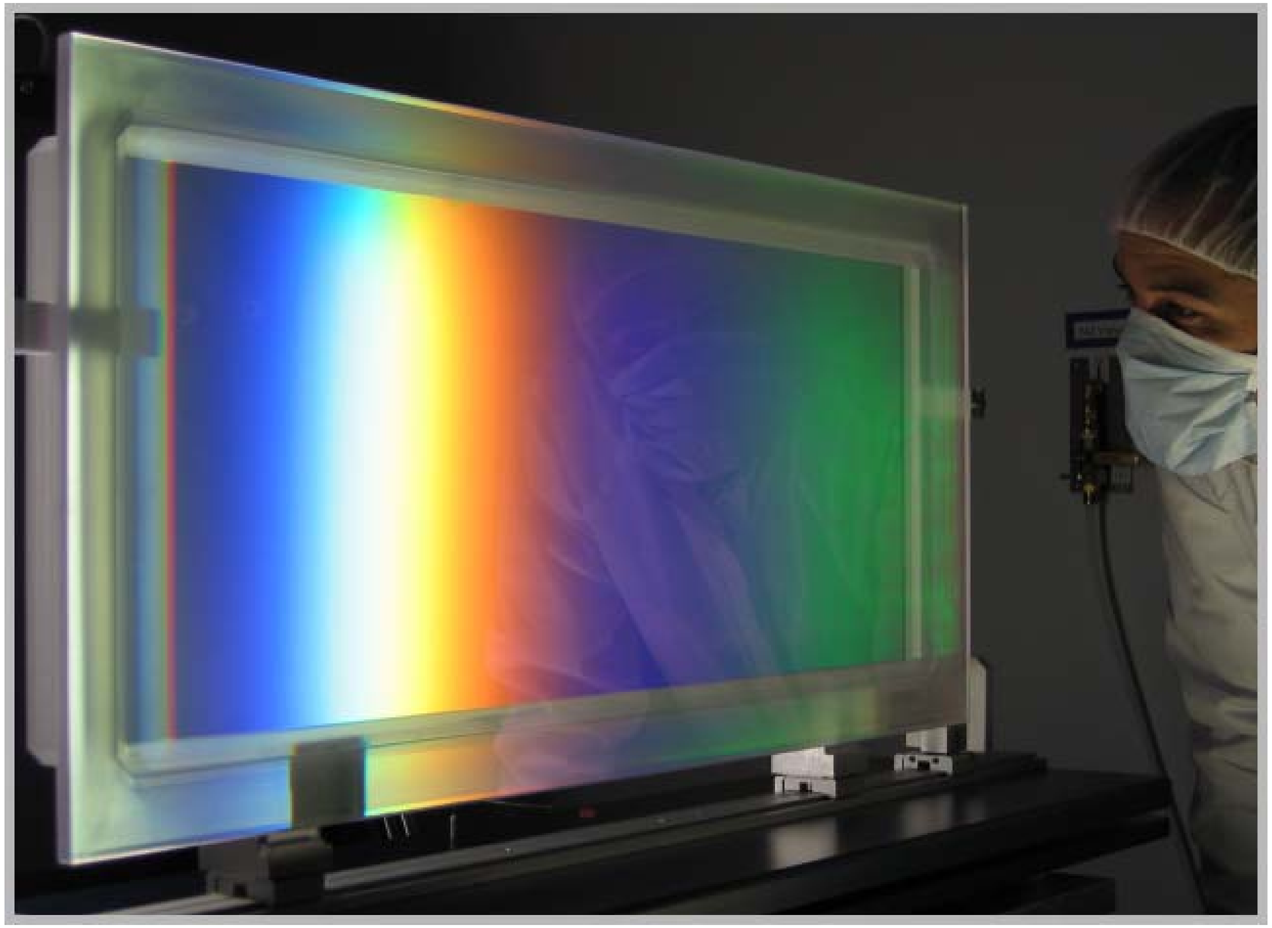
ICUIL 2008
Tongli, China
27-31 October 2008



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

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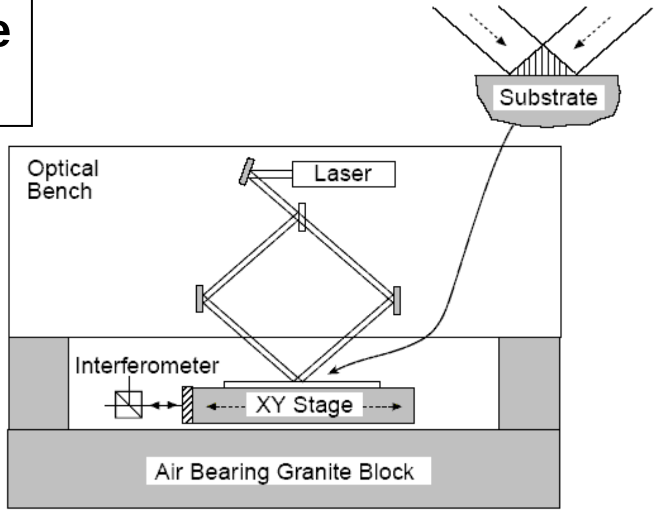
Large Area Pulse Compression Gratings Fabricated Onto Fused Using Scanning Beam Interference Lithography

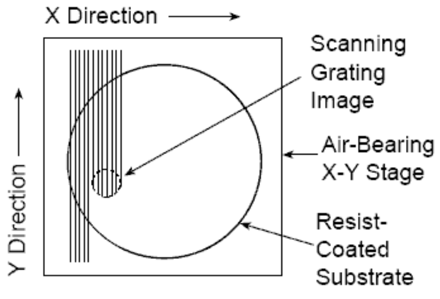
- Introduction to SBIL
- Use of Silica Substrates For Gratings
- Some results from current production
- Grating types
- New Stuff

In VP-SPIL A Small Beam Of Fringes Scans Across a Large Substrate

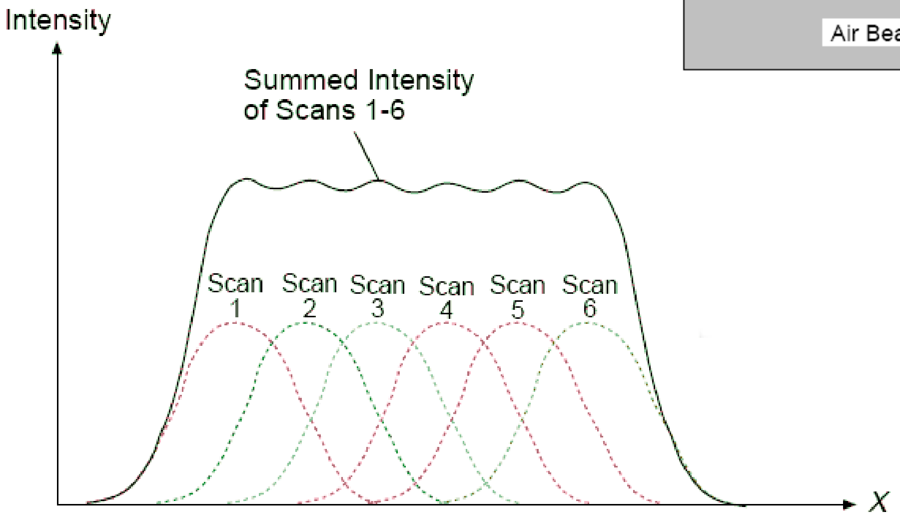
VP-SBIL – Variable-Period Scanning Beam Interference Holography

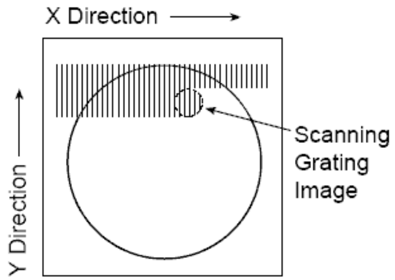
Averaging occurs in scan direction and through overlapping scans





Parallel Scanning





Doppler Scanning

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 ± 0.01º 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

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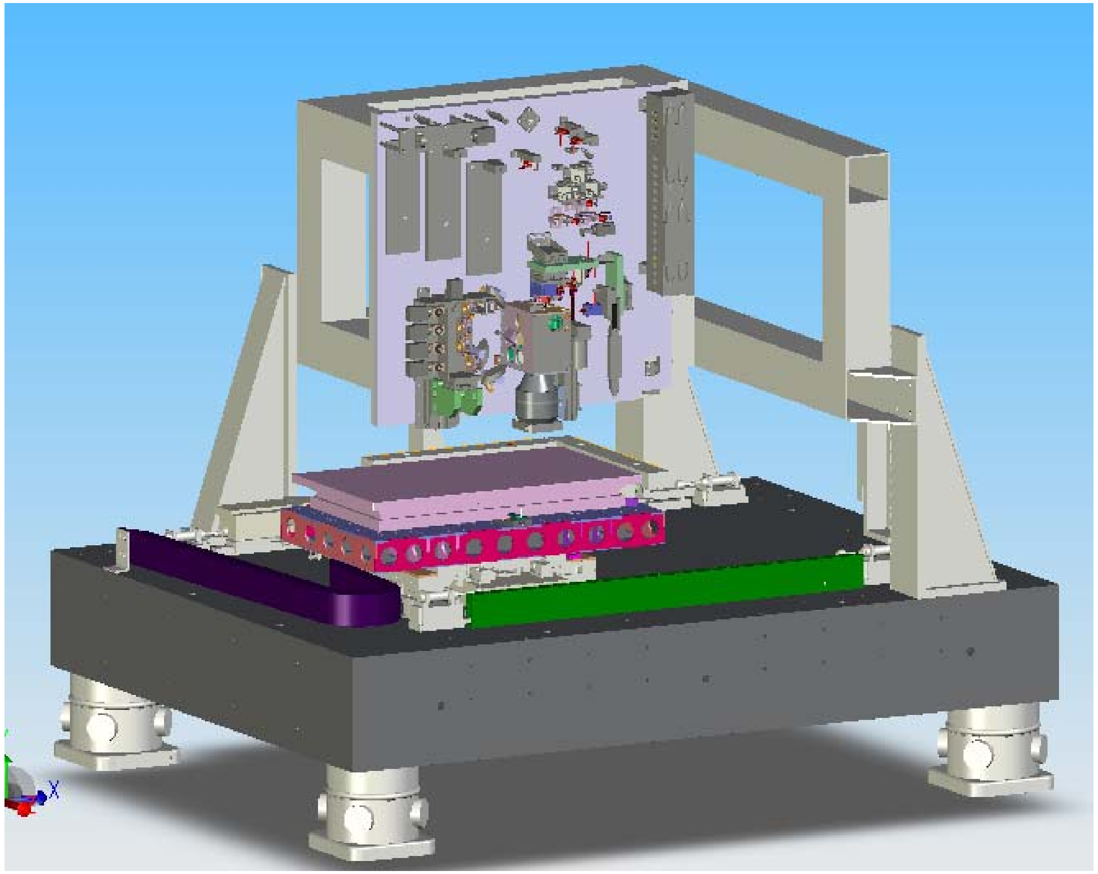
- The entire apparatus is quite compact
- The stage position is monitored by stage interferometers (not shown) and column reference mirrors
- A scanning photometer for testing DE can be integrated into this same platform



A 91cm X 42cm Osaka Grating Is Prepared For Imprinting

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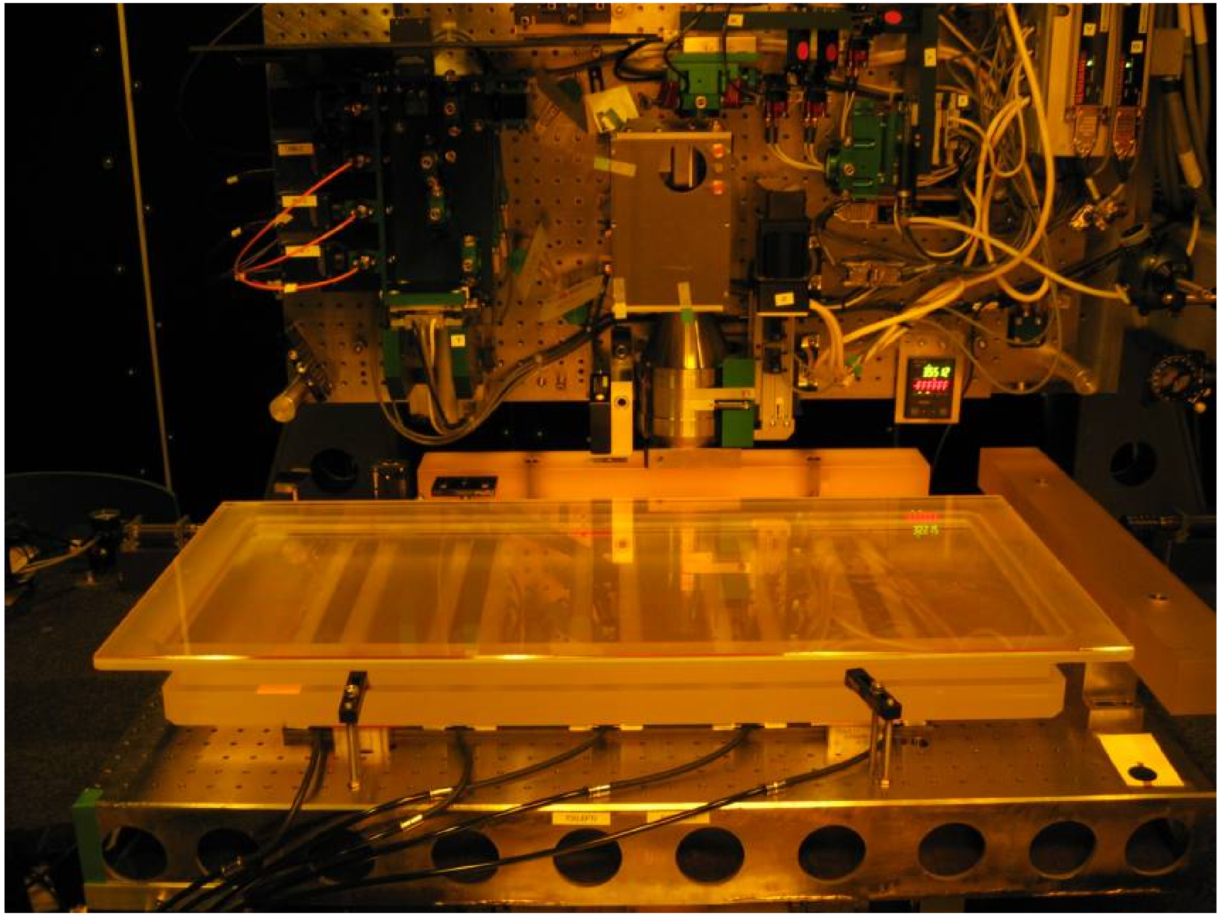
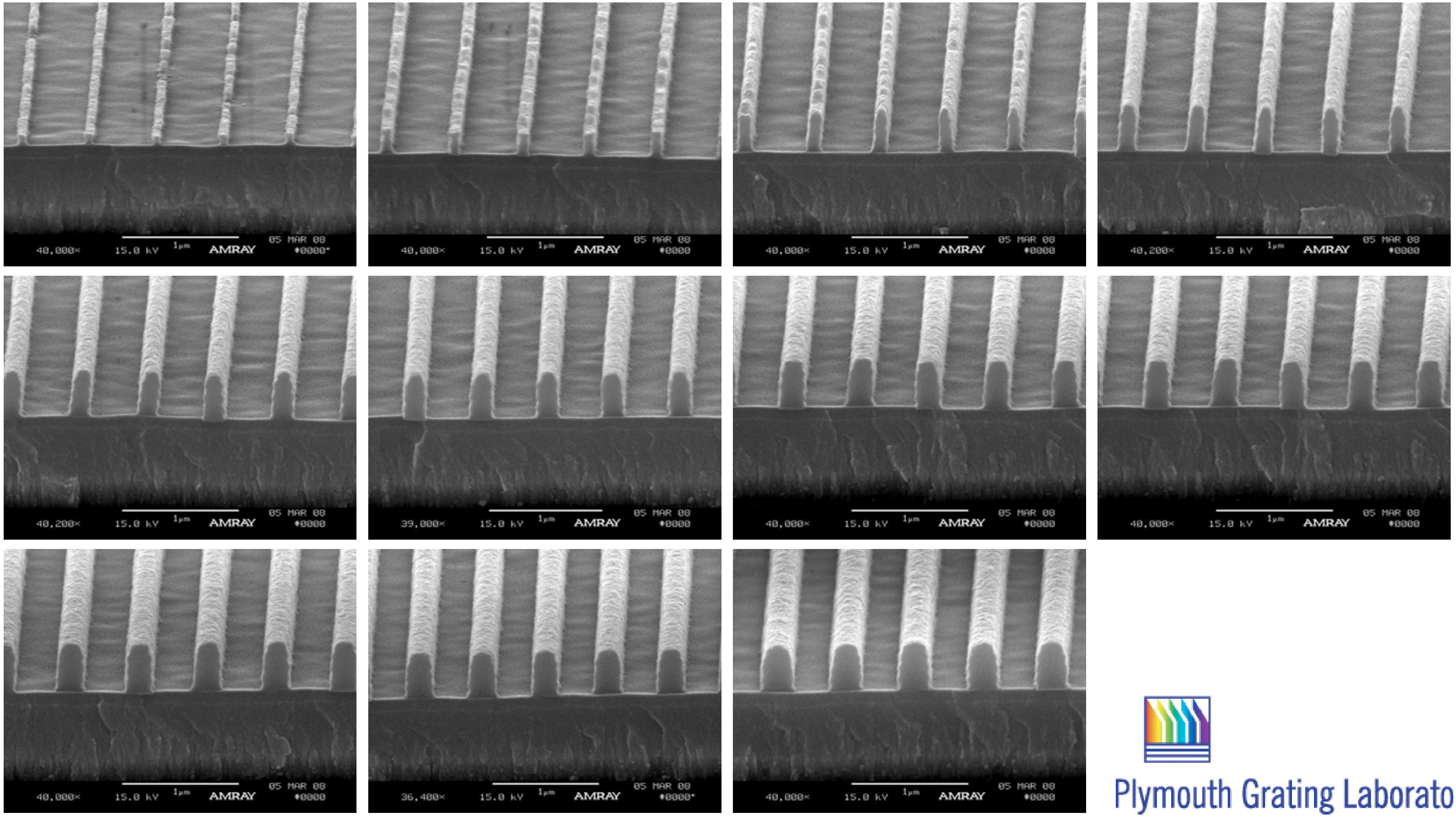


Current maximum size is about 93 cm x 60 cm

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



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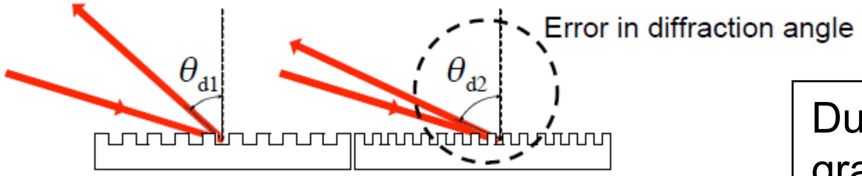
Pointing Deviation Problems causes Thermal Period Error Is Minimized By Using Fused Silica

ILE Osaka

Predicted by M. Rushford (LLNL) at ICUIL 2004.



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

Incidence angle：72.5 deg		
Diffraction angle	1740 l/mm	61.462311 deg
	1740.001 l/mm	61.462437 deg

→ 0.5 ppm error result in 2.2 μrad difference in diffraction angle

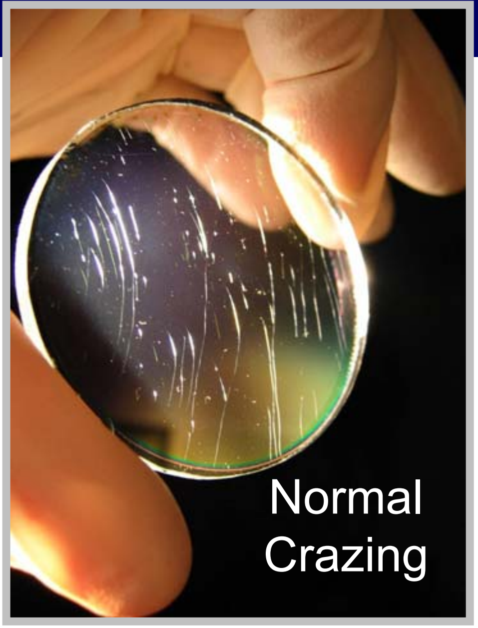
Using Fused Silica For Grating Substrates Will Increase The Stability of Stretchers and Compressors

Material	Thermal expansion coefficient	Temperature Control	Allowed ΔT in surface
BK-7	7×10^{-6}	0.06 ℃	0.006℃
Pyrex	2.8×10^{-6}	0.14 ℃	0.014℃
Fused silica	0.4×10^{-6}	1 ℃	0.1℃
Low expansion Glass	0.08×10^{-6}	5 ℃	0.5℃
		for 0.5 ppm* groove change Spot dev.=35μm	for 0.05 ppm groove change Spot dev.=3.5μm (equiv. to 0.2λ)

* 1740.001 / 1740.000 = 0.5 ppm

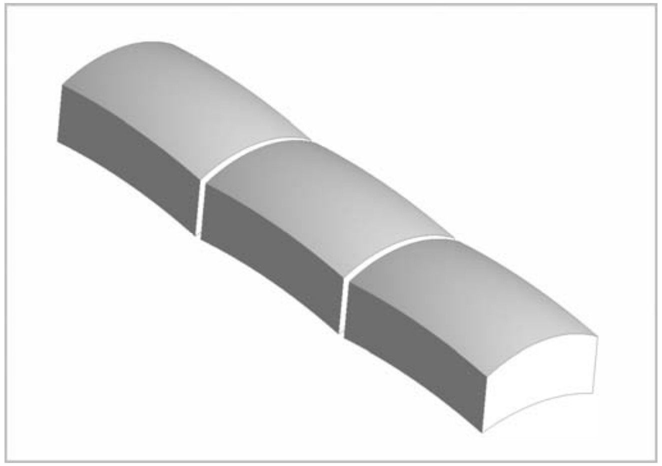
Stress In Fused Silica Coatings Must Be Controlled To Eliminate Crazing and Wavefront Distortion

SEM of a fractured optic.



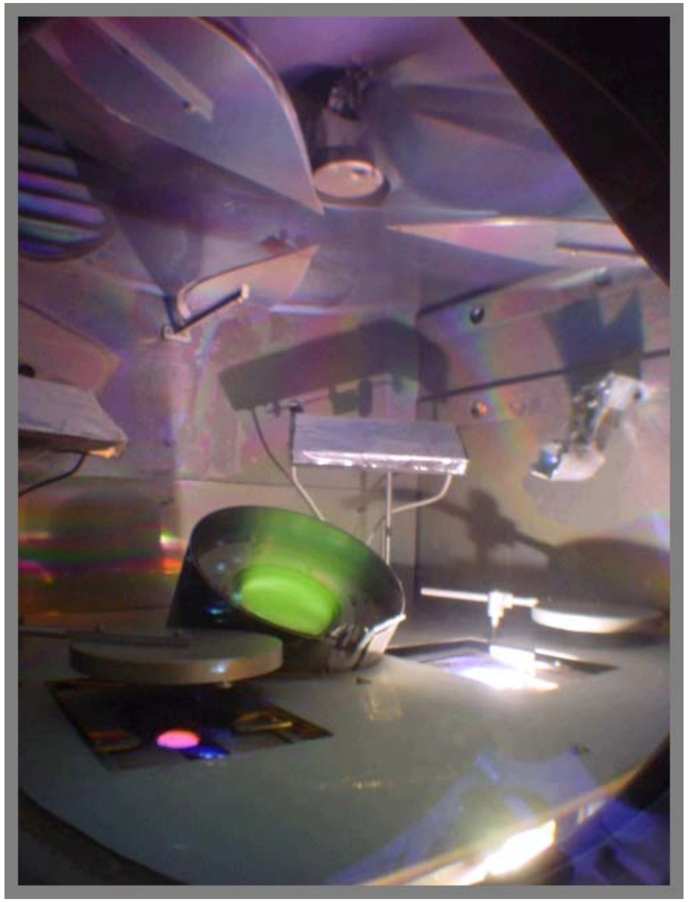
- Excessive Tensile stress distorts wave front and ↑ introduces the possibility of crazing

- Excessive Compressive (or Tensile) stress distorts wave front in grating optics →



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, O_2, 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**

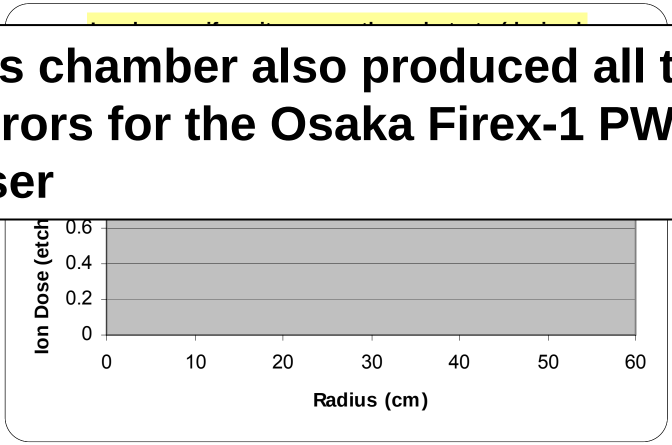


The 12 cm RF ion source operating in a 1 meter chamber with Oxygen

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

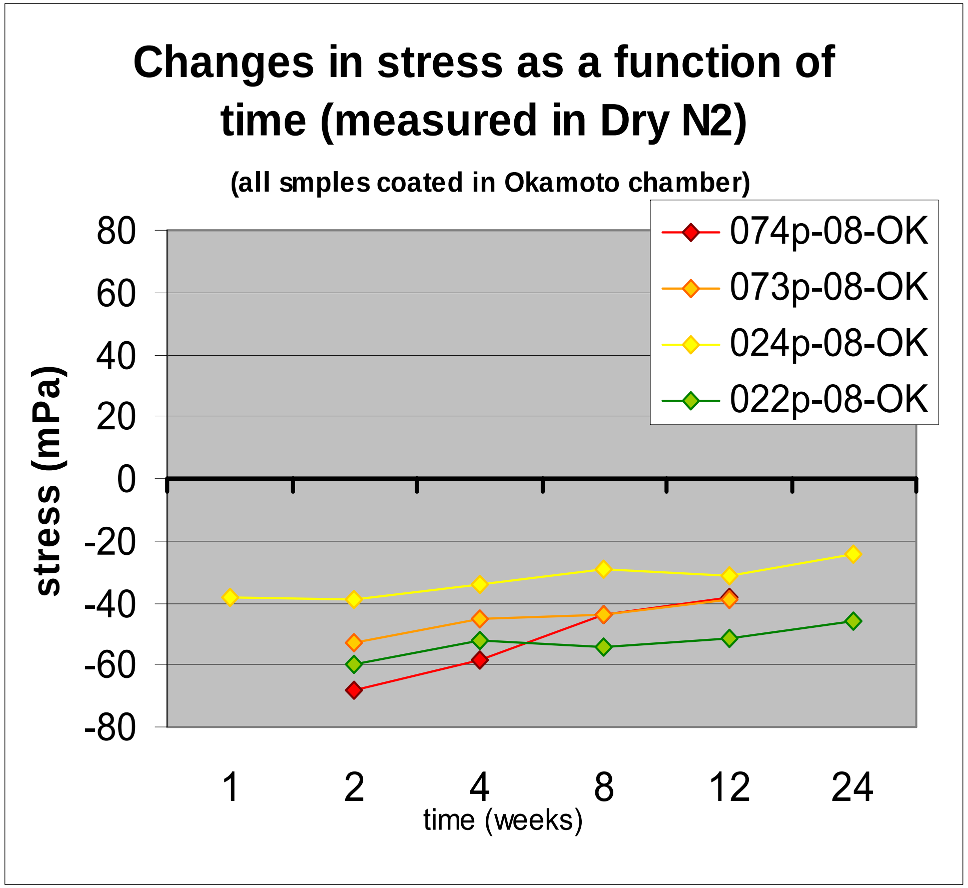


Coating Stress Is Slightly Compressive To Eliminate The Risk Of Tensile Failure

Compressive Stress is Negative
Tensile Stress is Positive

Ion Source Parameters*

Sample	IAD total power Watts Hafnia	 Silica	Current Stress (mPa)	Run Temp 癈
022p-08-OK	175	290	-46	150
024p-08-OK	175	290	-24	100
073p-08-OK	87.5	290	-39	100
074p-08-OK	87.5	290	-39	100



2008 runs show lower stress overall and less variation over time.

* **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

Etching, Resist Coating, And Metrology Tools Also Are All Scaled To 1 Meter Optics

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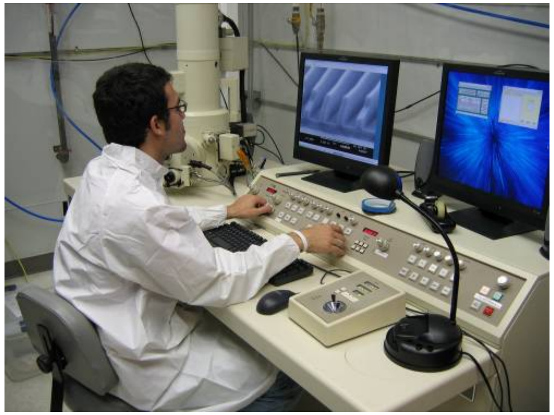

Etched MLD Diffraction Efficiency Is Uniform and High Across The VP-SPIL MLD Gratings

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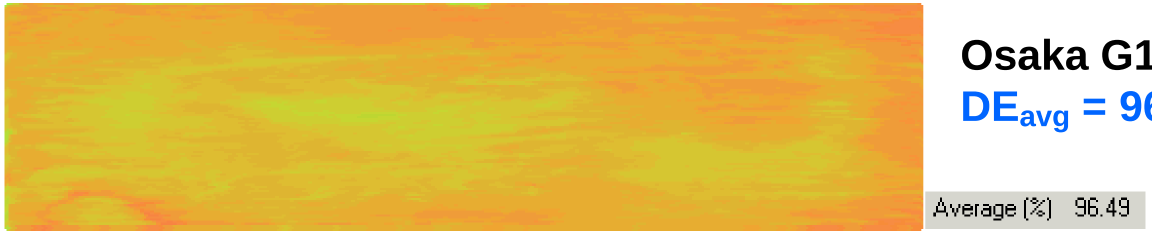
- **Below are examples of 1740 lns/mm from this 2008 Production**

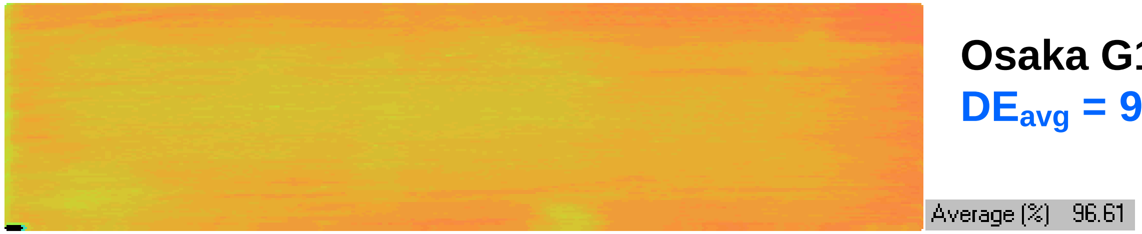
Stretcher 200x400mm

DE$_{avg}$ 95.9%



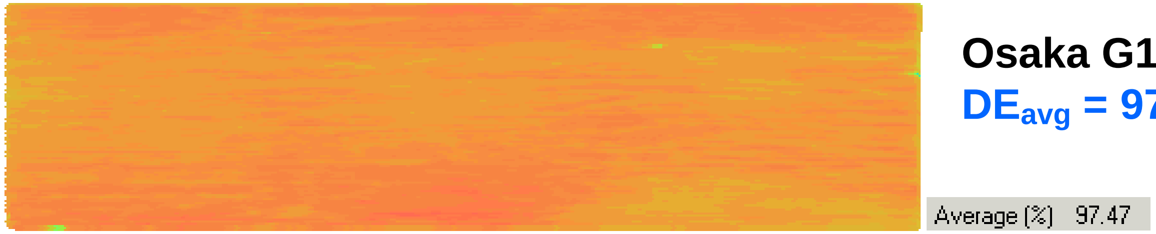
Osaka G16 - 920mm x 410mm

DE$_{avg}$ = 96.5%



Osaka G13 - 920mm x 410mm

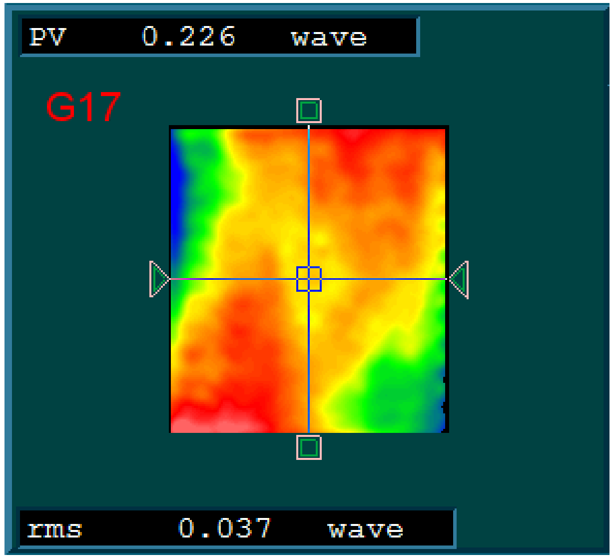
DE$_{avg}$ = 96.6%



Osaka G12 - 920mm x 410mm

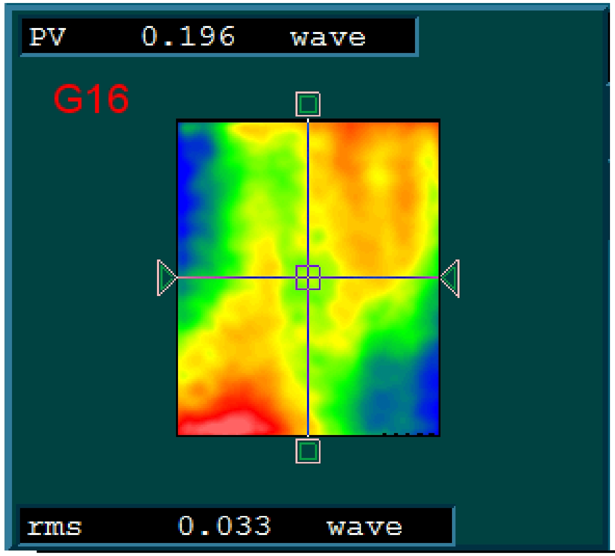
DE$_{avg}$ = 97.5%

All diffracted results shown are single pass at 1054nm and include both grating and substrate errors (exception noted)



PV 0.226 wave

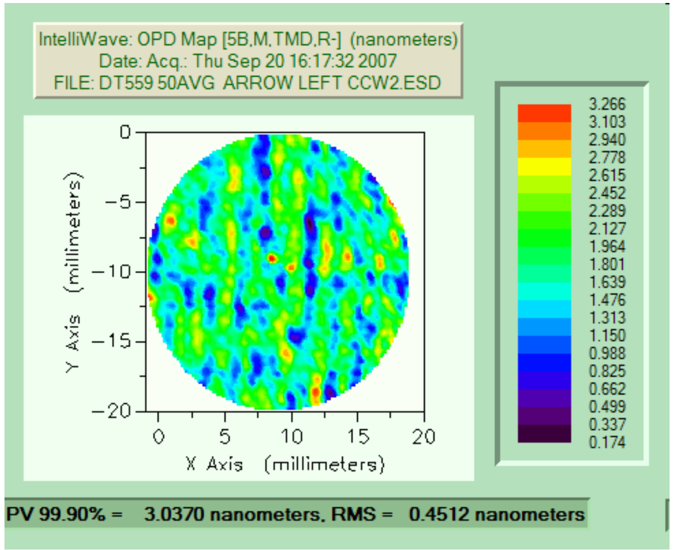
rms 0.037 wave



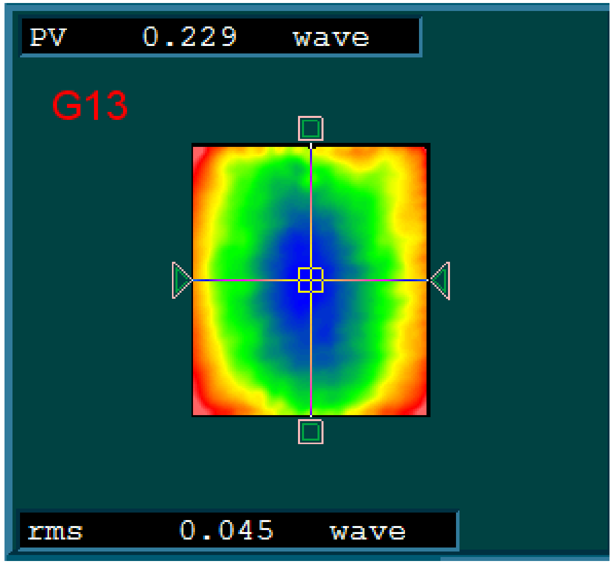
PV 0.196 wave

rms 0.033 wave

Small scale length (20mm)
Holographic errors

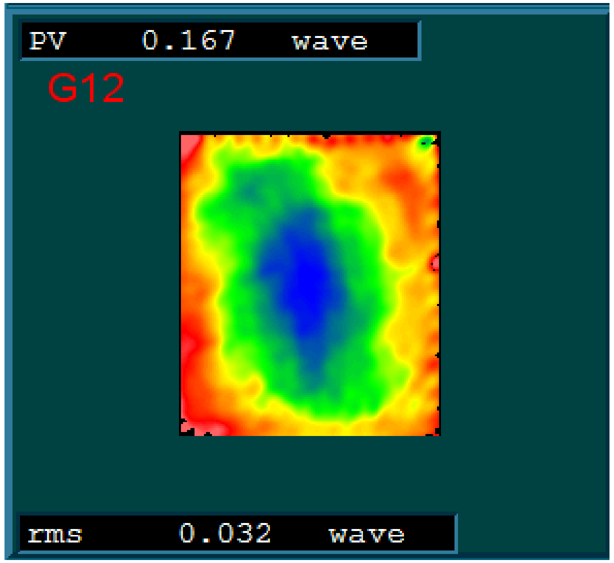

IntelliWave: OPD Map [5B,M,TMD,R-] (nanometers)
Date: Acq.: Thu Sep 20 16:17:32 2007
FILE: DT559 50AVG ARROW LEFT CCW2.ESD

PV 99.90% = 3.0370 nanometers, RMS = 0.4512 nanometers



PV 0.229 wave

rms 0.045 wave



PV 0.167 wave

rms 0.032 wave

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Damage Threshold of the Gratings have been tested by UR/LLE and Osaka

	LLE / Rochester		**Osaka**	**LLE / Rochester**	
Date	**10psec 1-on1**	**10psec N-on1**	**3.2 psec 1-on-1**	**750fsec 1-on-1**	**750fsec 1-on-1**
12/4/2006 A	3	3.01		1.34	1.37
12/13/2006 B	3.01	2.99		1.39	1.39
12/13/2006 C	3.01	2.96		1.39	1.46
6/6/2007 D	3.13	3.03		1.28	1.27
10/7/2008			3.9		
10/8/2008			4.7		

“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

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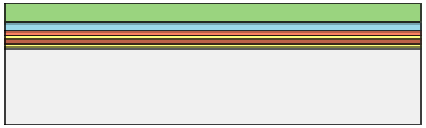
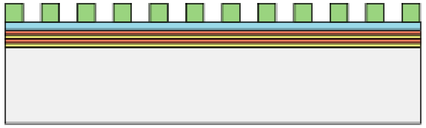
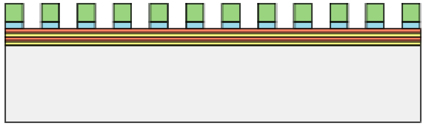


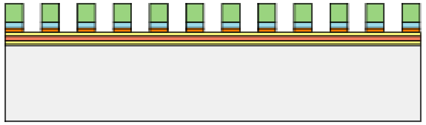
1) Coat substrate with MLD, ARC and photoresist.



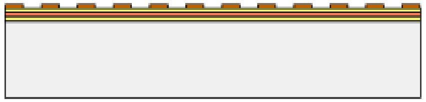
2) Pattern grating by SBIL and develop.



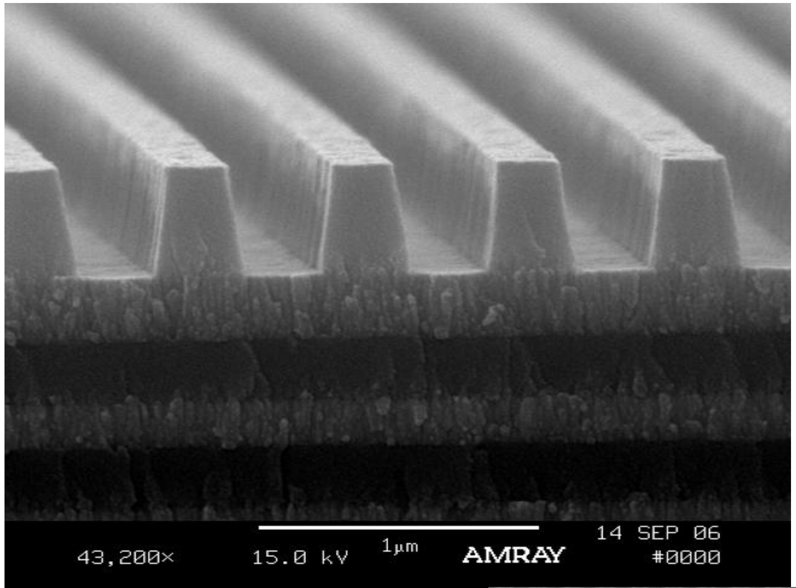
3) Etch ARC by oxygen RIBE.

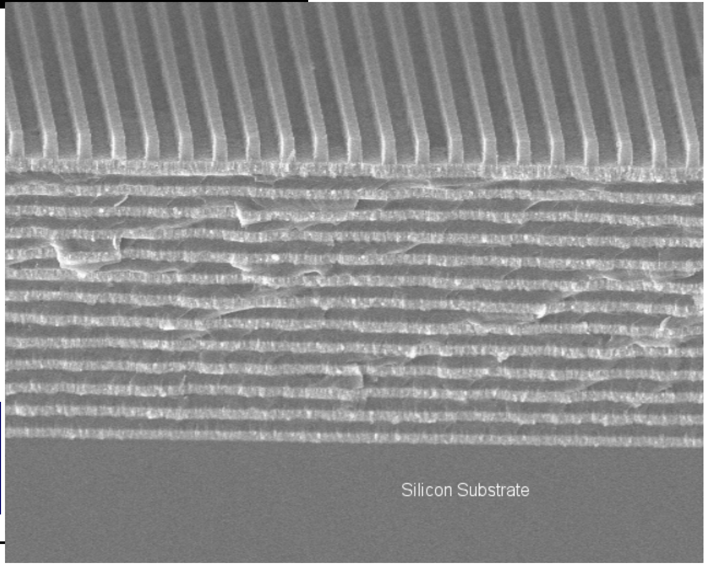


4) Etch MLD top layer by fluorine RIBE.



5) Strip resist and ARC.



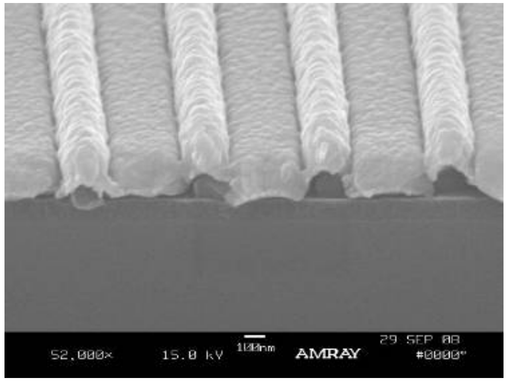


1740 l/mm MLD grating

There Are Several Different Types Of Metal Gratings

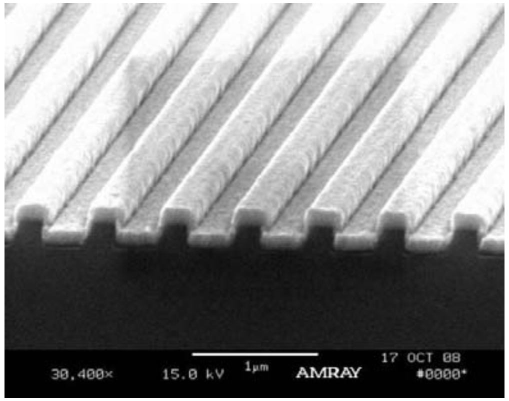
Binary Gold Gratings

Gold over Photoresist
Conventional Coating



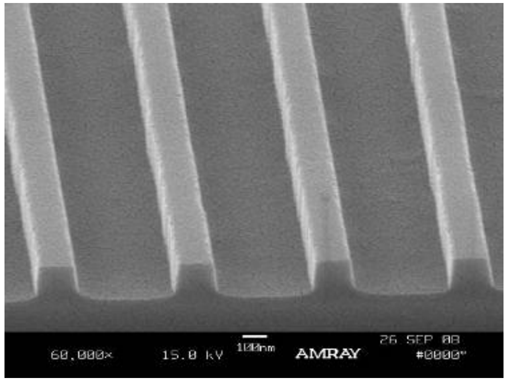
	DE
CW	**87.5**
CCW	**78.7**

Improved Coating Method

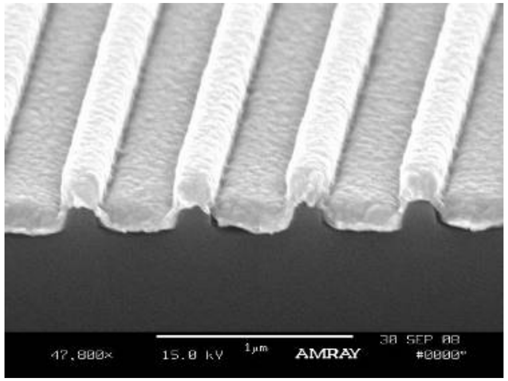


	DE
CW	**94.3**
CCW	**94.1**

Etched Grating

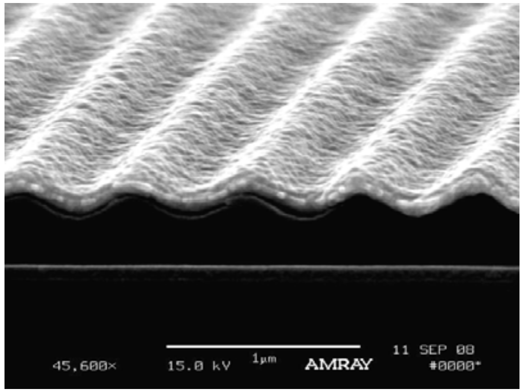


Gold Over Etched Grating

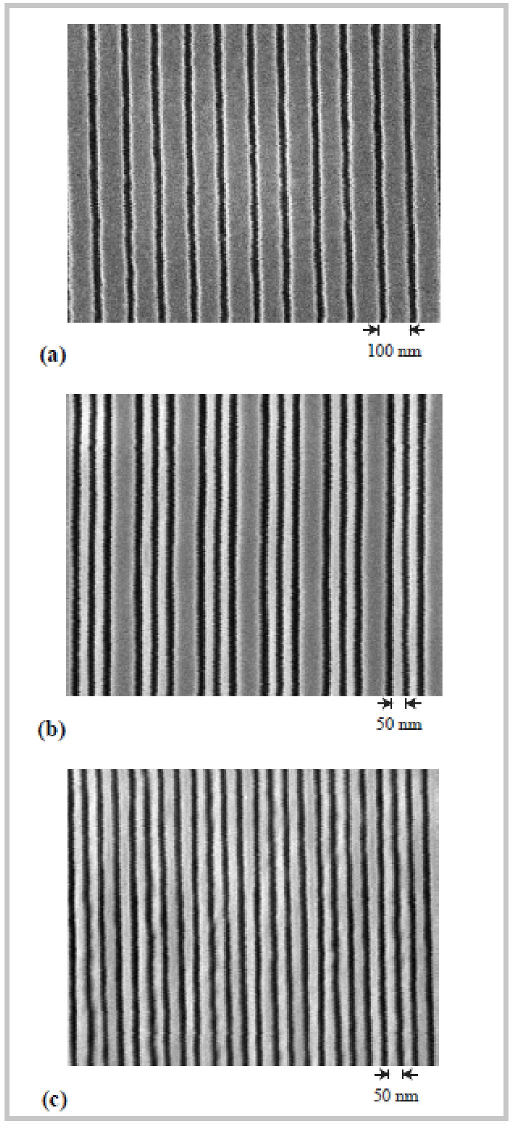


CW	**94.5**
CCW	**94.5**

Low-contrast resist
sinusoidal grating,
(silver overcoat)



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

Images are from "Fabrication of 50 nm-period gratings with multilevel interferencelithography," C.-H. Chang, Y. Zhao, R.K. Heilmann and M.L. Schattenburg, Opt. Lett. 33, pp. 1572-1574 (2008).

Dr. Chih-Hao Chang, Multilevel Interference Lithography – Fabricating Sub-wavelength Periodic Nanostructures, Ph.D. Thesis, Department of Mechanical Engineering, July 2008.

Summary

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

Plymouth Grating Laboratory

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