SAND2011-7121C

Status of the Sandia Large Optics Coating Operation

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Overview

- Description of Sandia's Large Optics Coater and Coating Operation
- Operational Statistics of the Large Optics Coater
- Laser Induced Damage Thresholds (LIDTs) of Sandia Coatings
- Optical Coatings – Lessons Learned at Sandia
- MLD Grating Coatings at Sandia

Sandia's Large Optics Coater – in Retrospect Since 2005

90″ X 90″ X 72″ coating chamber and planetary system installed at Sandia in the Class 100 Optical Support Facility in June 2005

Primary mission to provide AR coated debris shields and vacuum windows for backlighting laser shots (1 debris shield per shot with a shot almost daily)

Also to provide high LIDT coatings for the large optics of Sandia's Z-Backlighter TW and PW lasers

Aspirations to advance state-of-the-art production and design of high LIDT coatings for large optics and to cooperate within this coating community

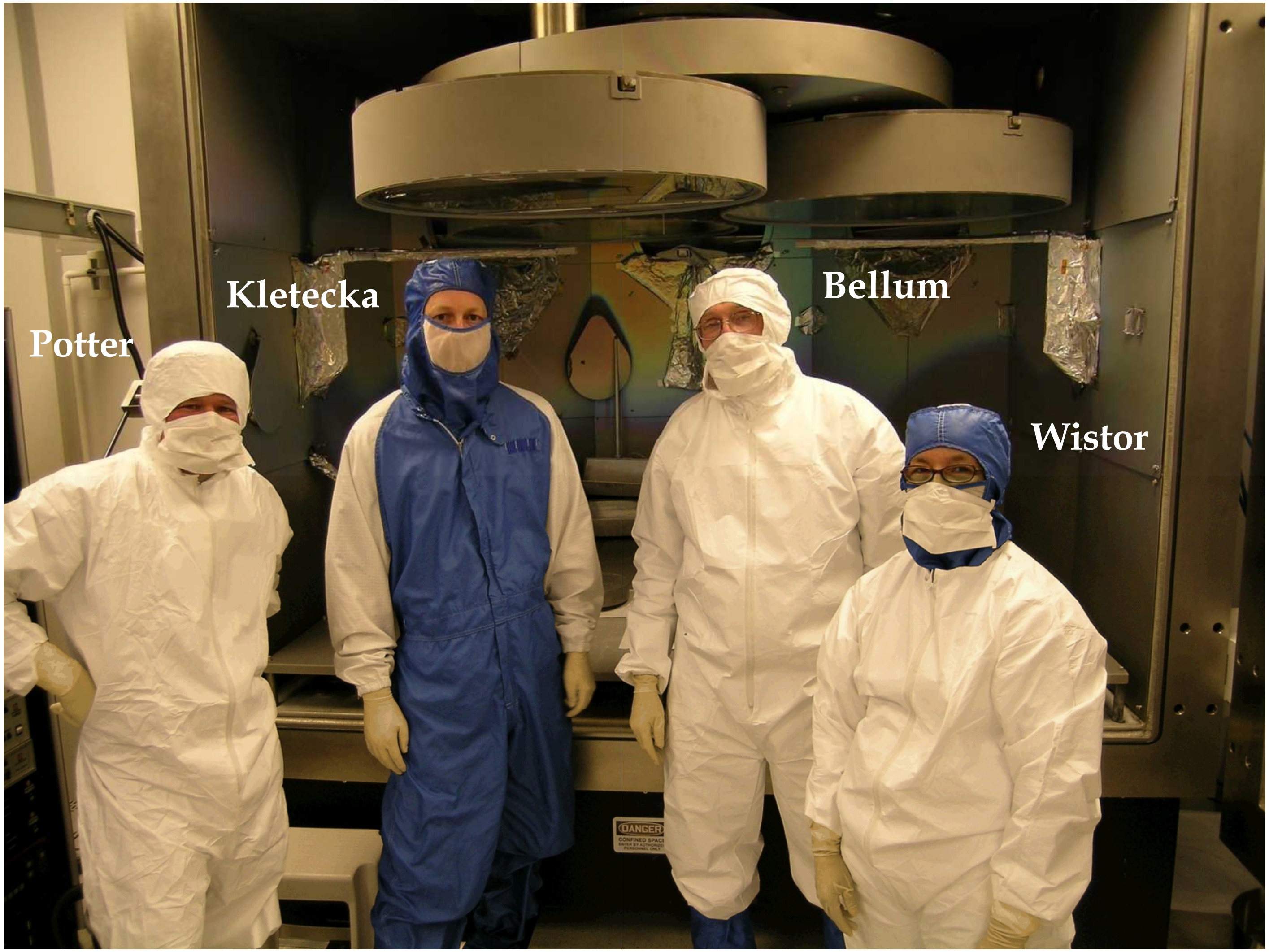
E-beam deposited hafnia/silica coatings for high LIDT

3 planet option accommodates up to 94 cm optic per planet

Process control by means of computer HMI and software linking 3 e-beam sources of thin film materials to deposition control based on crystal sensors to monitor evaporated material

Initial report at the 2005 ILOW – before the coater was operational at Sandia and thus necessarily based on promises and projections. So, what has transpired?

Coating Operation Personnel



Major Upgrades to the Coater Since 2005

RF ion source in 2006 making ion-assisted deposition (IAD) available

Un-interruptable power supply (UPS) battery back-up of the coating system in 2009 – 2010 to provide graceful product coating run interruption in case of power outages and save product runs and expensive product optics

Counter-rotation 2-planet option in 2010 – holds up to 1.2 m optic per planet with optic swinging past the center of the coating chamber

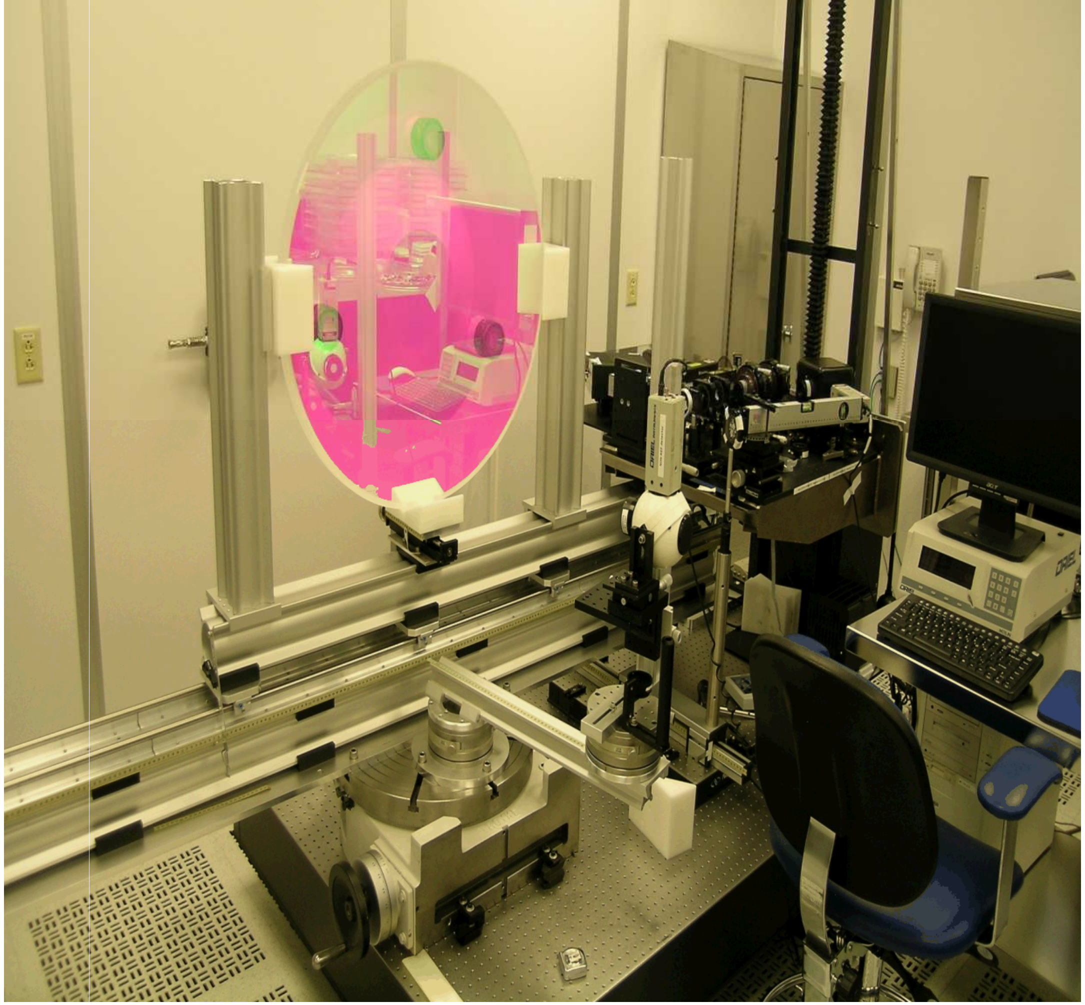
12-crystal sensor dispenser in 2010 – facilitates longer coating runs and mounts on a coating mask arm below the coating plane to allow continuous exposure to coating materials even when an optic swings past the center of the coating chamber, thus enabling the counter-rotation option

Development of the Large Optics Reflectometer

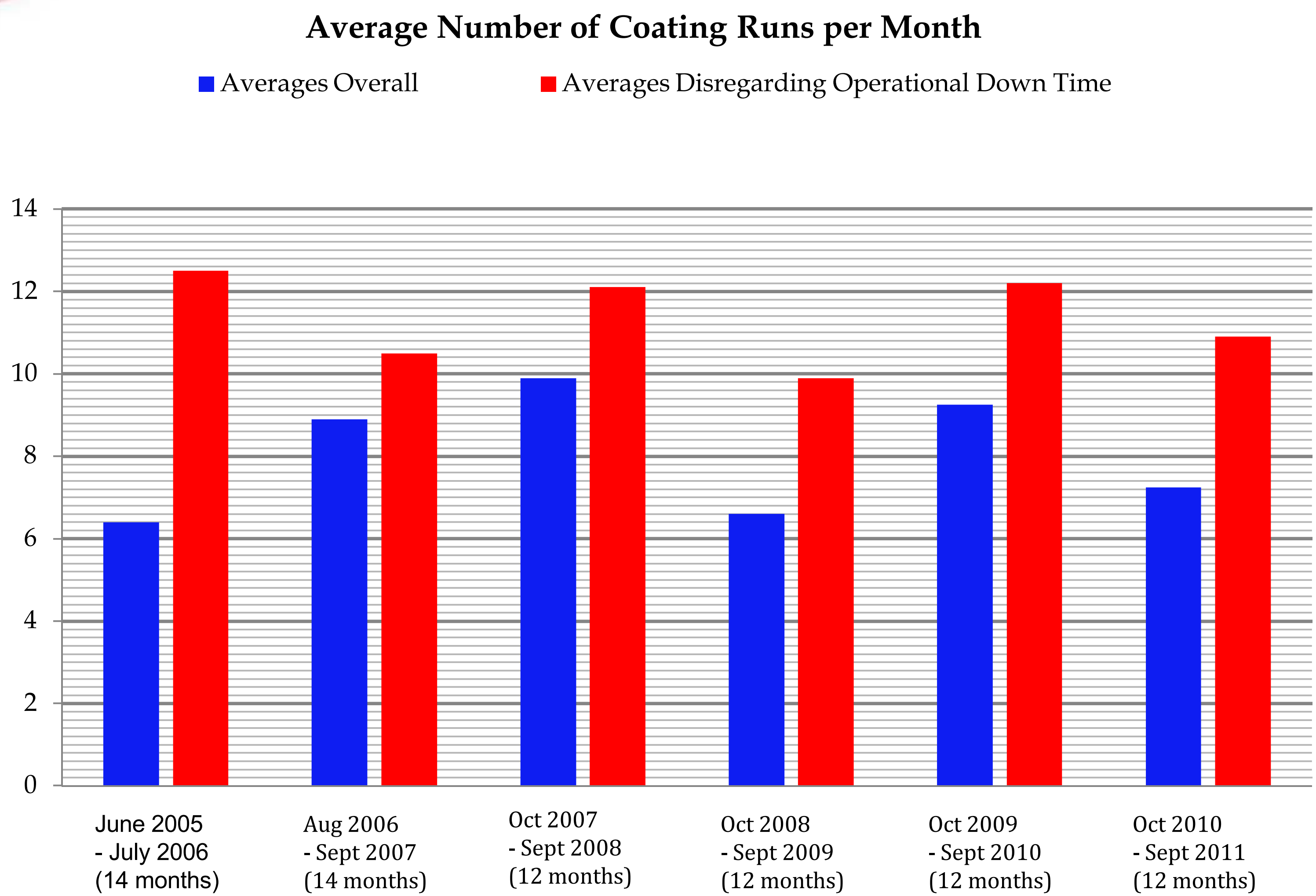
- Measurements at 1w or 2w with lasers on a vertical translation stage
- Accommodates meter class optics weighing hundreds of pounds on a turret-mounted horizontal translation stage
  - for arbitrary points & angles of incidence on flat or curved surfaces
- Detectors optimal for signal and reference stability with use of integrating spheres & proper adjustment of gain, time constant, bandwidth and chopper settings
- Thorough data recording with improved Excel spreadsheet
- System configured for
  - coordinates of surface points of incidence to +/- 1 mm
  - angles of incidence to +/- 15 arcminute

Optic in V-Block Frame: PW FOA Steering Mirror (75cm ϕ) with 50 layer coating for HR at 1w & 2w, 24 – 47 deg AOI, S & P pol

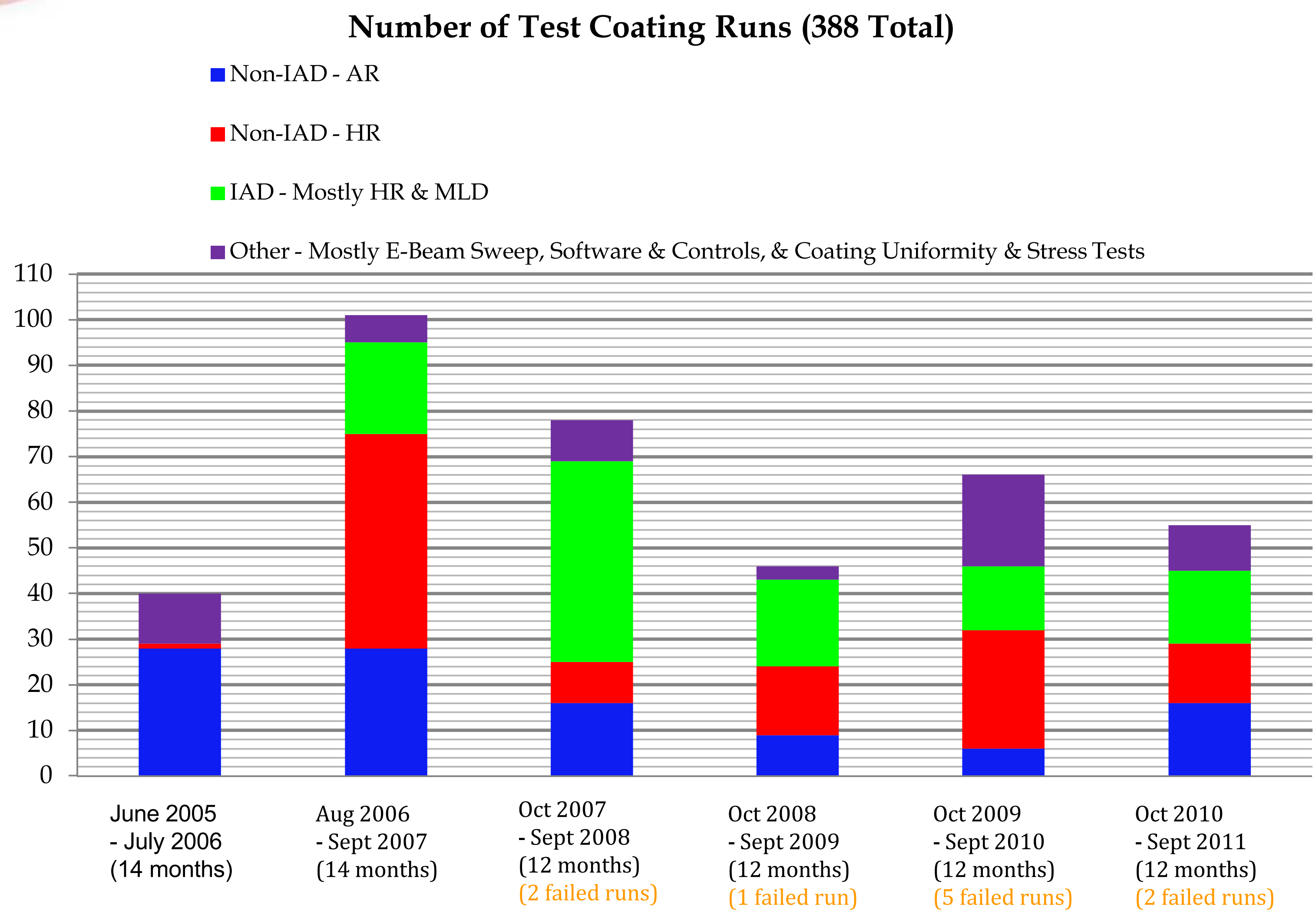
Proc. of SPIE 7504, Paper 75040C (2009)



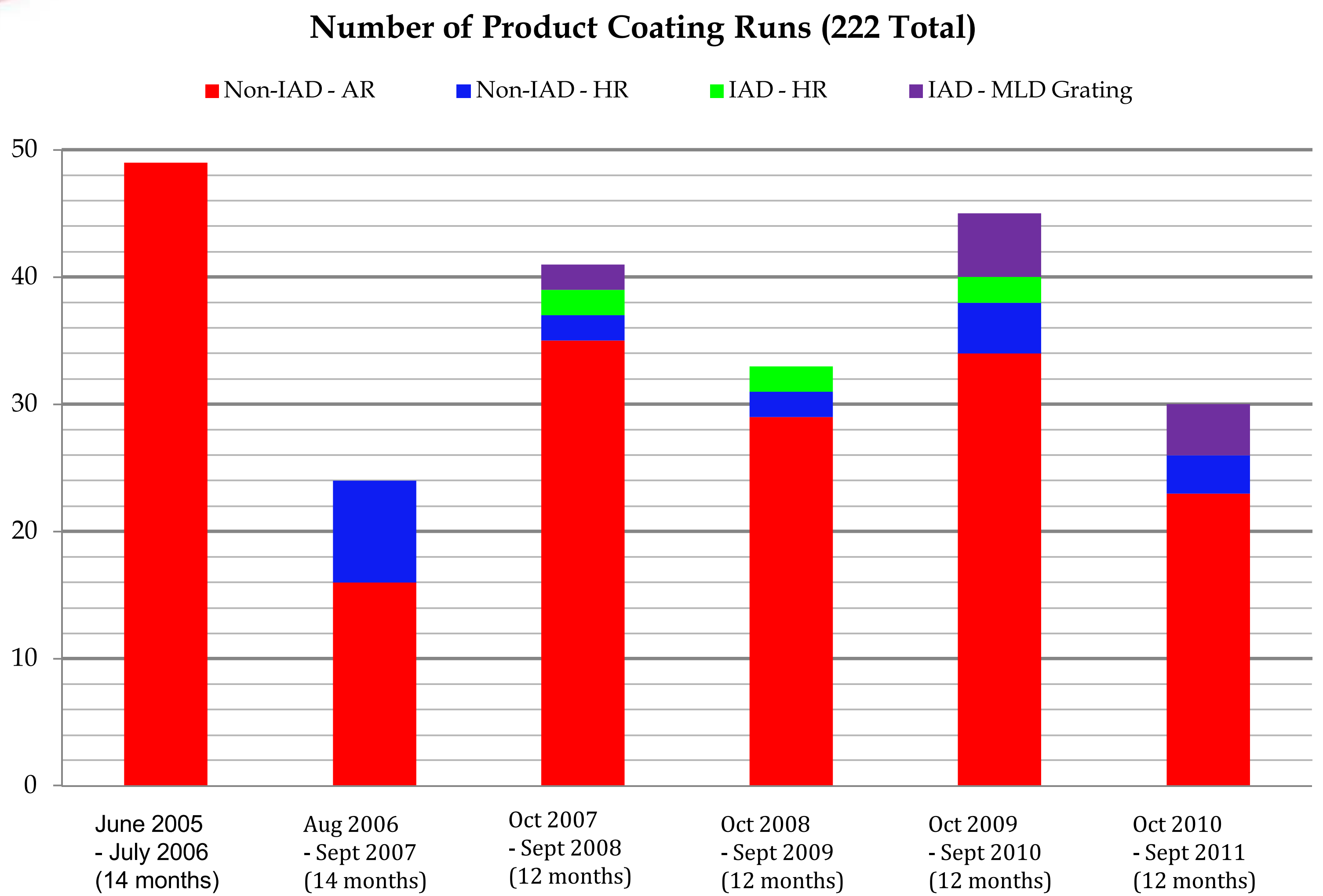
Coating Operation Performance Data: Average Number of Coating Runs per Month



Coating Operation Performance Data: Number of Test Coating Runs

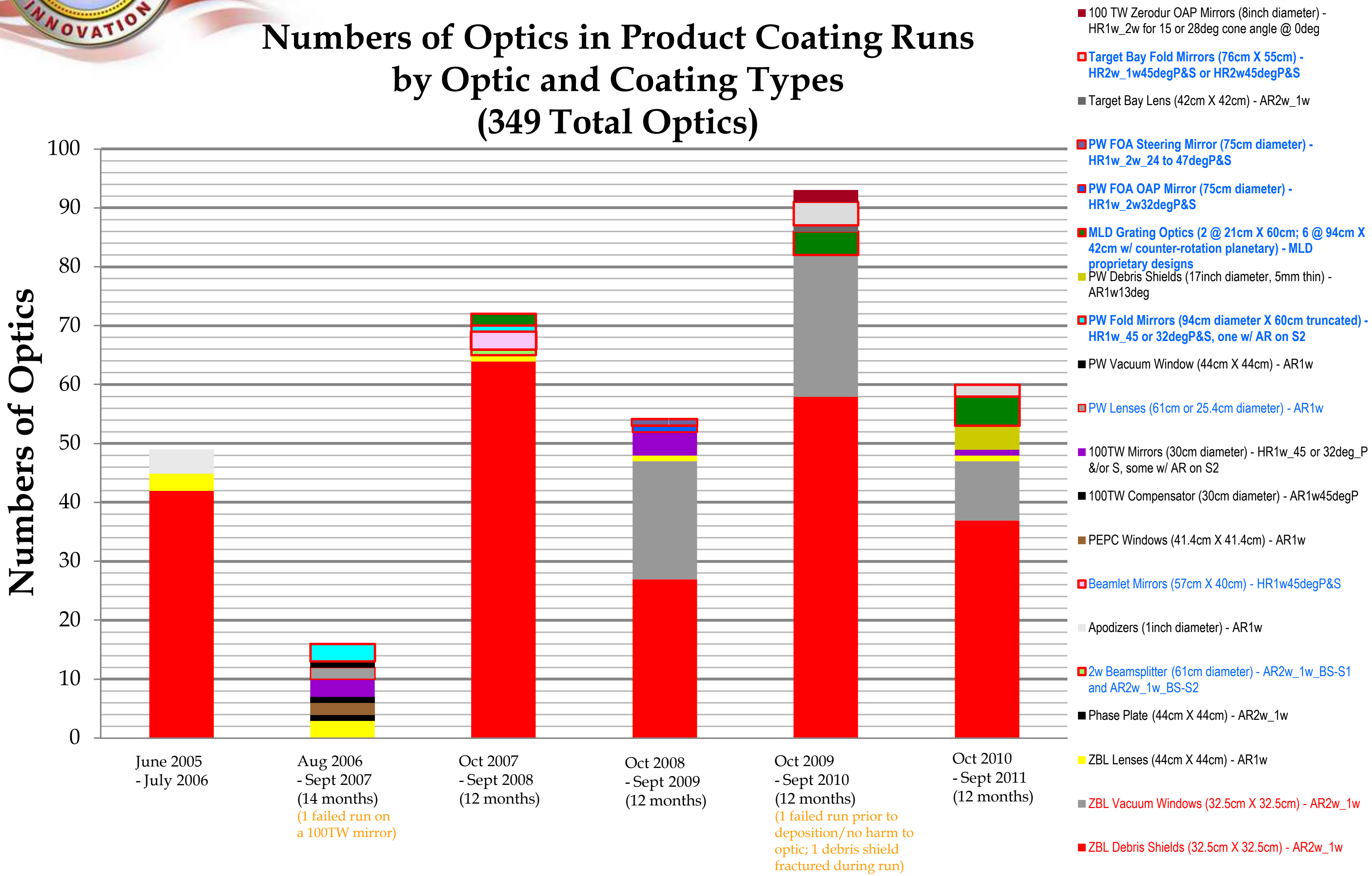


Coating Operation Performance Data: Number of Product Coating Runs



Coating Operation Performance Data: Numbers of Optics in Product Coating Runs by Optic and Coating Types

Numbers of Optics in Product Coating Runs by Optic and Coating Types (349 Total Optics)



Z Backlighter

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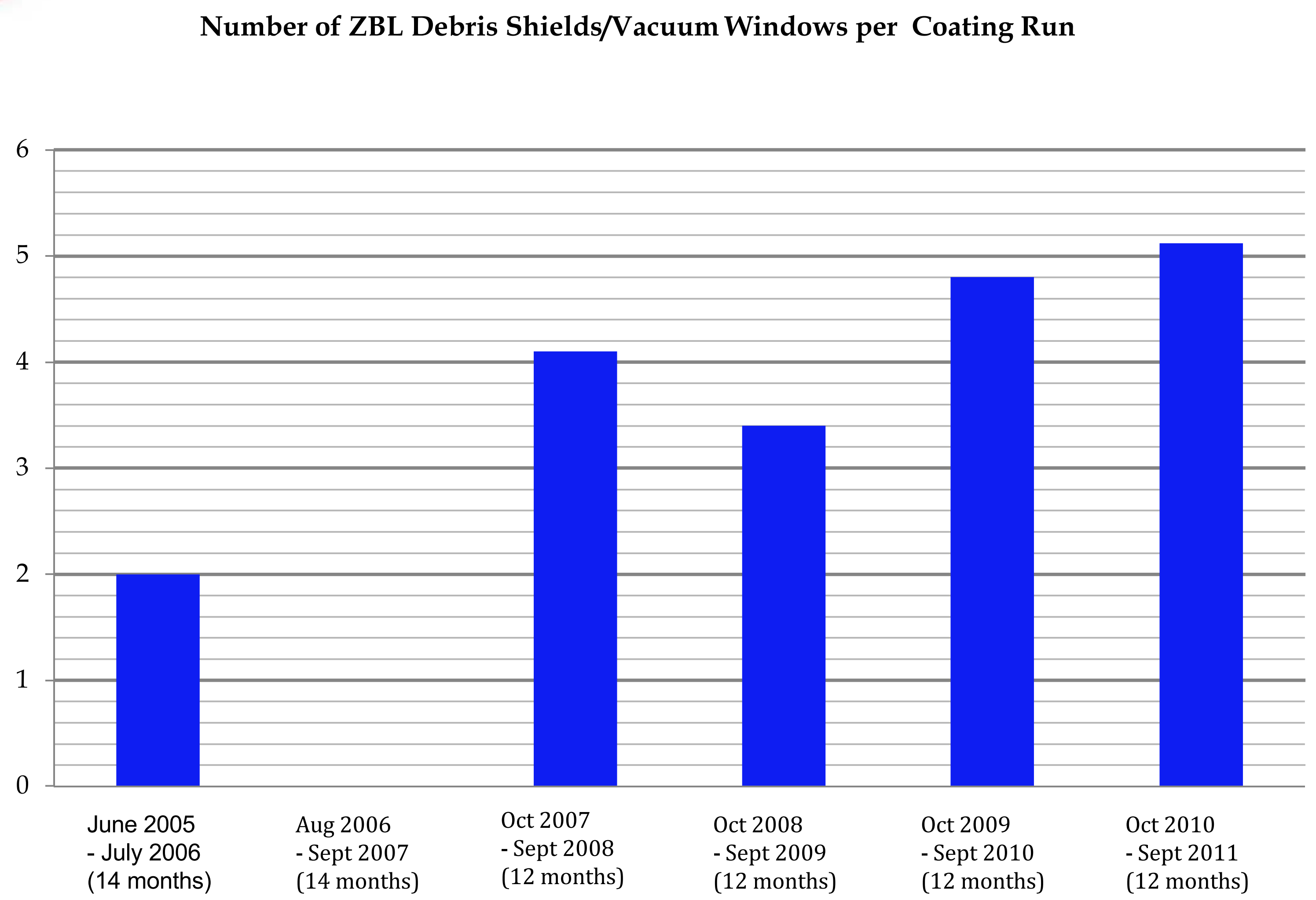
Coating Operation Performance Data: Number of ZBL Debris Shields/Vacuum Windows per Coating Run



LIDTs of Sandia Optical Coatings

Measured LIDTs (in J/cm^2) of Sandia Coatings

	AOI	NIF-MEL Tests: 1064 nm (3.5 ns pulses)	NIF-MEL Tests: 532 nm (3.5 ns pulses)	Sandia In-House Tests: 1054 nm (350 fs pulses)	Sandia In-House Tests: 532 nm (7 ns pulses)
AR coatings					
for 1054 nm	0 deg	18, 18, 19, 19, 21, 25, 25, 27, (33)		(1.8)	
for 1054 nm	32 deg	Spol: (37); Ppol: (34)			
for 1054 nm	45 deg	Spol: 47; Ppol: 19			
for 527 & 1054 nm	0 deg	(25), ((19)), [23], [[29]], 19, 22	(9), ((6)), [8], [[13]]	[[~ 2]]	[[38]], [[38]]; 10 shot: [[28]]
for 527 & 1054 nm	22.5 deg	Spol: (38), ((46)); Ppol: (38), ((55))	Spol: (12), ((11)); Ppol: (12), ((13))		
HR coatings (quarter-wave type)					
for 1054 nm	0 deg	IAD: 37, 56, 75; Non-IAD: 82			
for 1054 nm	32 deg	Spol: (79), ((82)); Ppol: (88), ((79)), 70, 91			
for 1054 nm	45 deg	Spol: (82), ((88)), [88]; Ppol: (73), ((75)), [88], 58, 79, 88, 88, 91, 91, 97			
for 527 & 1054 nm	30 deg			Ppol: (1.32), (1.71)	Ppol: 70

For each listed coating, values in similar brackets are for the same coating run

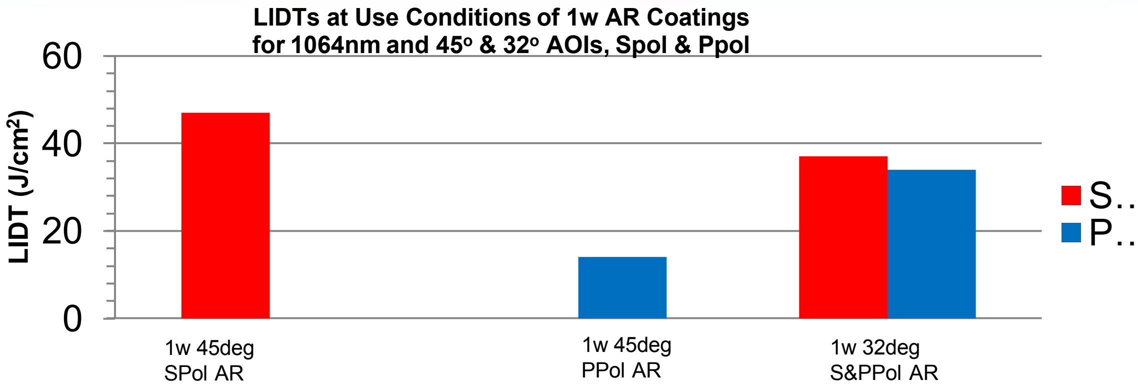
Large Area Conditioning (LAC) Laser Damage Tests of Sandia HR45degP Coatings on Beamlet Mirrors

Work done in cooperation with LLNL and LLE

vendor	Sandia	Sandia	Sandia
type	e-beam	IAD	e-beam
s/n	B-2359A	94-0240	93-0235
run#	24P-08	29P-08	23P-08
coating	45deg, p-pol	45deg, p-pol	45deg, p-pol
LAC	LAC3	LAC3	LAC3
date	11/5/2008	11/12/2008	11/25/2008
starting scan aperture	534 x 373mm	534 x 373mm	534 x 373mm
10 J/cm^2	pass	pass	pass
14 J/cm^2	pass	pass more plasmas observed	pass
18 J/cm^2	fail 1 site near center, reduce scan aperture for next scan to (534x183mm)	pass	pass
20 J/cm^2	pass used reduced scan aperture	pass	fail 3 sites, reduce scan aperture for next scan to (534x340mm)
22 J/cm^2	fail multiple damage sites from scan onset	pass	fail multiple damage sites from scan onset
24 J/cm^2		fail multiple damage sites from scan onset	

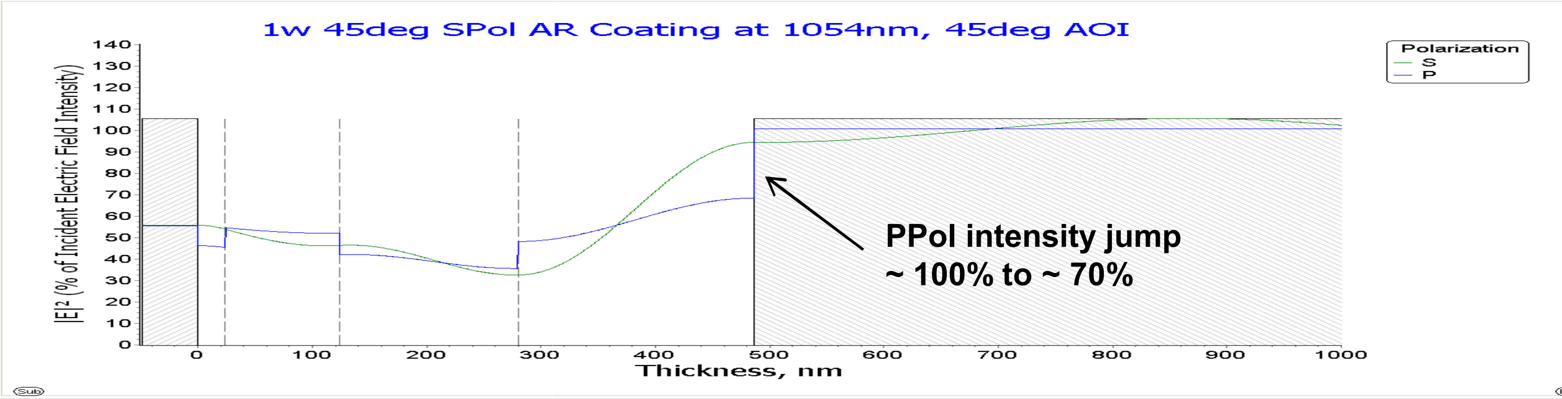
Lessons Learned: Correlation Between LIDTs and E-Field Behaviors of AR Coatings

Low LIDTs correlate with the high E-field Intensities or intensity peaks in the coating layers and also with Ppol intensity jumps at boundaries between coating layers

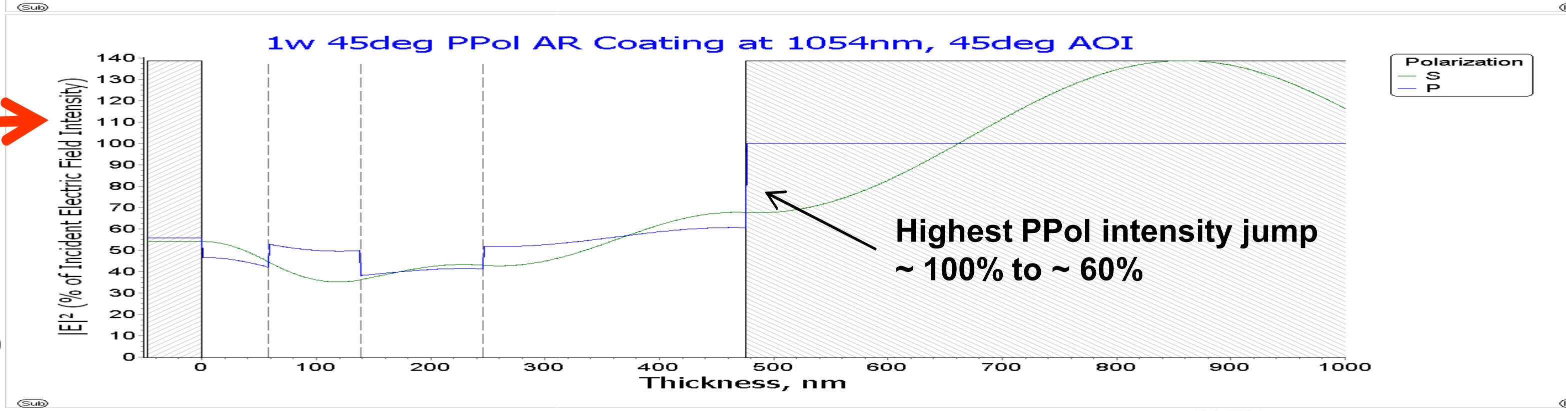


Vertical dashed lines mark coating layer boundaries

PPol LIDTs are lower than SPol LIDTs. This correlates with the PPol intensity jumps at boundaries, the largest being between layer 4 & the incident medium.



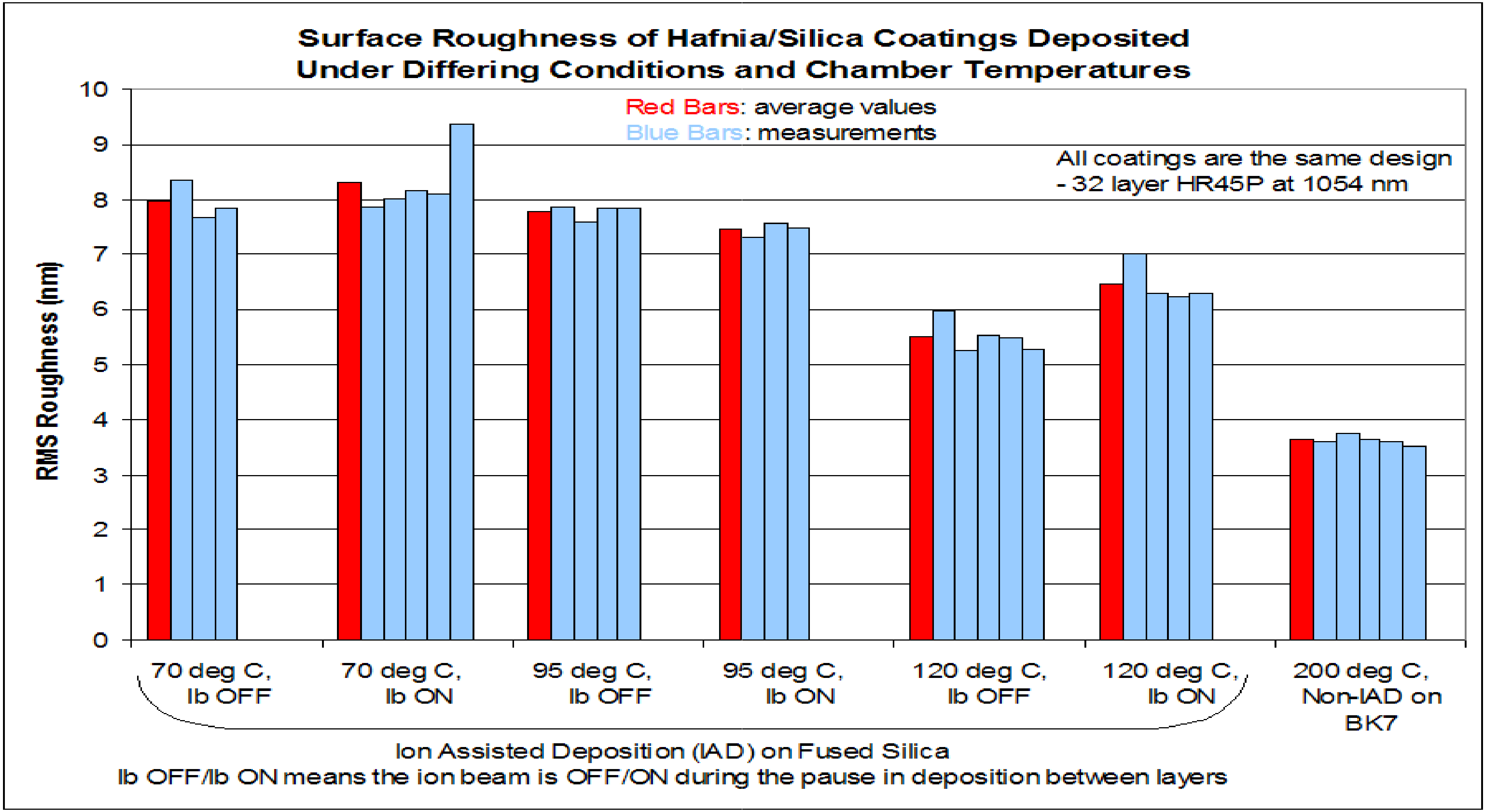
The 1w 45deg PPol AR coating has both a low PPol LIDT and a large PPol intensity jump, a combination that is consistent.



Appl. Opt. 50, C340-C348 (2011)

Lessons Learned: Achieving Smoother IAD HR Coatings

Surface roughness lowest with Ib OFF at 120 °C



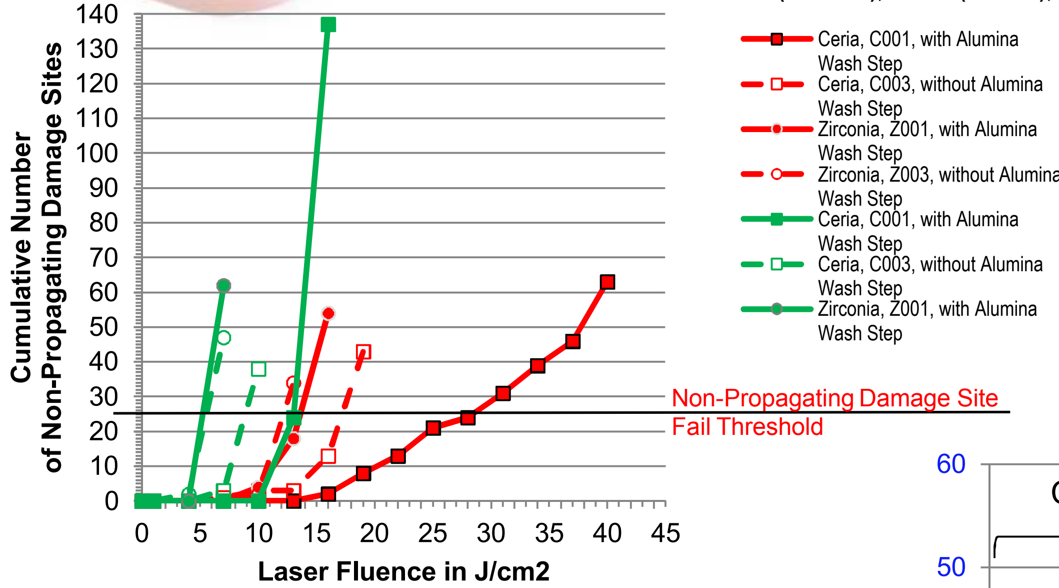
Proc. of SPIE 7504, Paper 75040C (2009)

Lessons Learned: The Role of an Alumina Slurry Wash Step and Ceria Based Optical Polishing in Enhancing AR Coating LIDTs

Work done in cooperation with Sydor Optics, Inc.

NIF-MEL LIDT Tests:

Red (1064 nm); Green (532 nm); 3.5 ns pulses

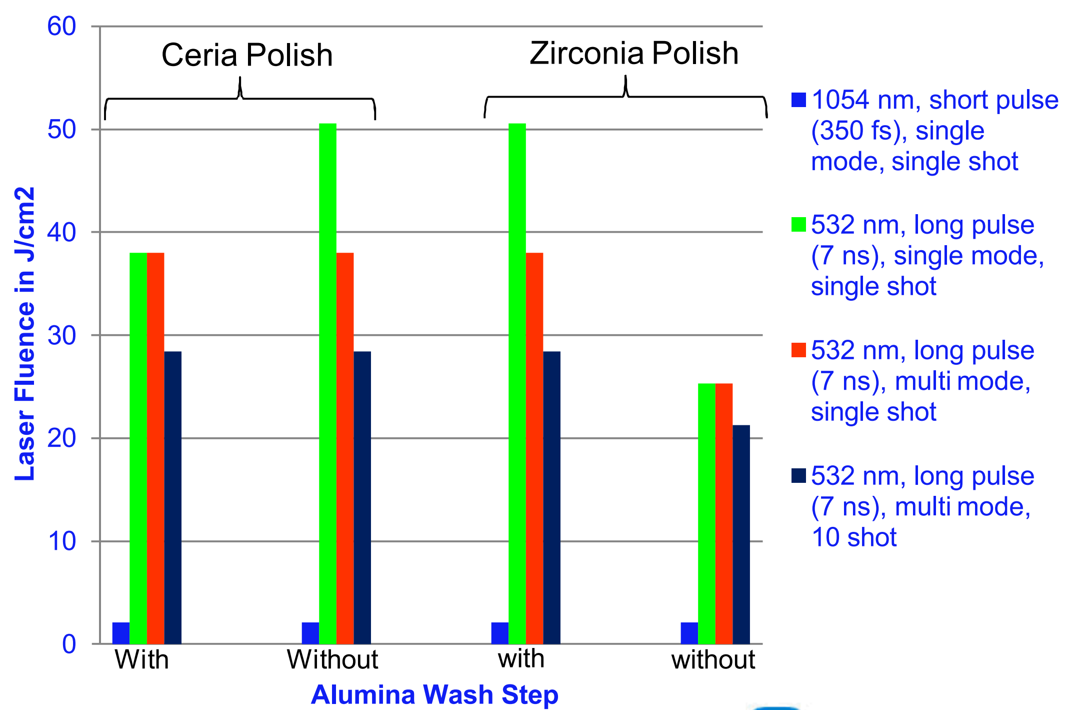


Ceria polish affords better LIDTs than zirconia polish

LIDTs with the alumina wash step are the same as or higher than those without the alumina wash step in all long pulse (3.5 ns & 7 ns) cases except for the test at 532 nm, single mode, single shot.

<u>In the short pulse (350 fs) case, LIDTs are all the same regardless of polish type or washing with or without the alumina wash step</u>

Sandia In-House LIDT Tests



These results confirm that ceria and zirconia polishing compound

- **remains at trace levels in the polished optical surface microstructure**
- **and affects the LIDT of AR coatings on the polished surfaces**

And that an alumina wash step can reduce the amount of residual polishing compound on the surfaces and so improve the LIDT of AR coatings on those surfaces

Proc. of SPIE <u>7842</u>, Paper 784208 (2010)

Lessons Learned: Target Bay Fold Mirrors and HR Coating Bandwidth & Spectral Drift Challenges at 2w

Non-IAD, 46 layer coating designed for 2w & 1w HR at 45 deg AOI and P & S pol

~ 2.5 % spectral drift occurred over 10 months (assumed to be due to aging effects)

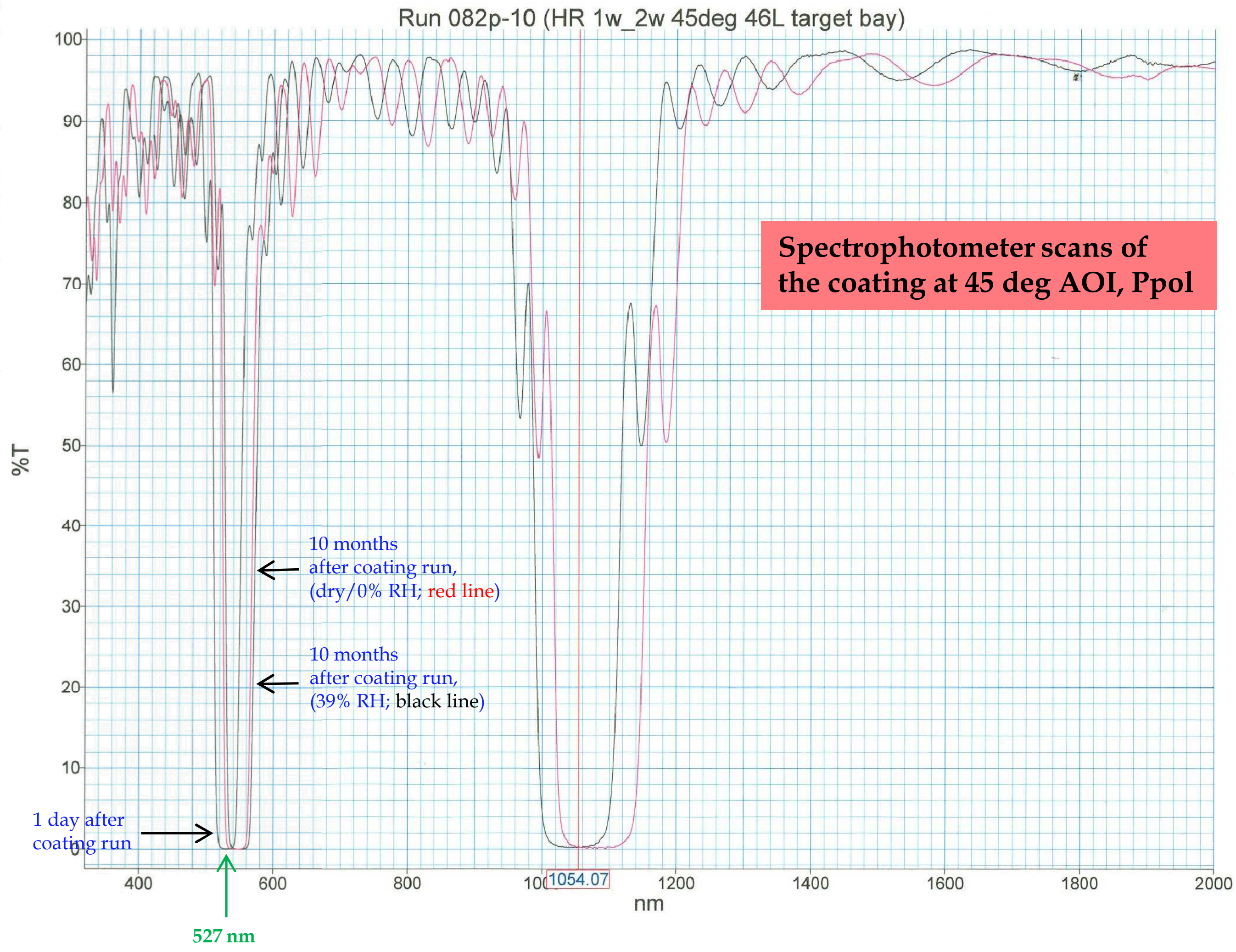
Spectral shifts due to the effects of ambiant humidity are ~ 0.5%

Early onset of 2w laser damage has occurred in this coating for Target Bay Fold Mirrors under ambient conditions

One such mirror used for 45 deg AOI, Ppol reflection also exhibited low reflectivities varying from ~ 70 % to ~ 30 %

This varying reflectivity is consistent with the mirror operating along the steep drop in reflectivity beyond the HR bandwidth as influenced by ~ 0.5 % spectral drifts due to variations in ambiant humidity

2w Efield intensities quench rapidly within the coating in the HR bandwidth but exhibit strong peaks consistent with occurrence of laser damage just outside the HR bandwidth consistent with onset of laser damage



These challenges are much less for Spol because HR bandwidths are significantly larger for Spol than for Ppol

MLD Grating Coatings: Sandia's Large Scale (94cm X 42cm) Gratings

Five (5) large scale gratings (1740 l/mm) were produced by Plymouth Grating Laboratory (PGL) on MLD coated substrates by means of the nano-ruler technique

The MLD coatings were produced by Sandia in its large optics coater in the counter-rotation option to accommodate the large dimension (103cm diagonal) grating optics

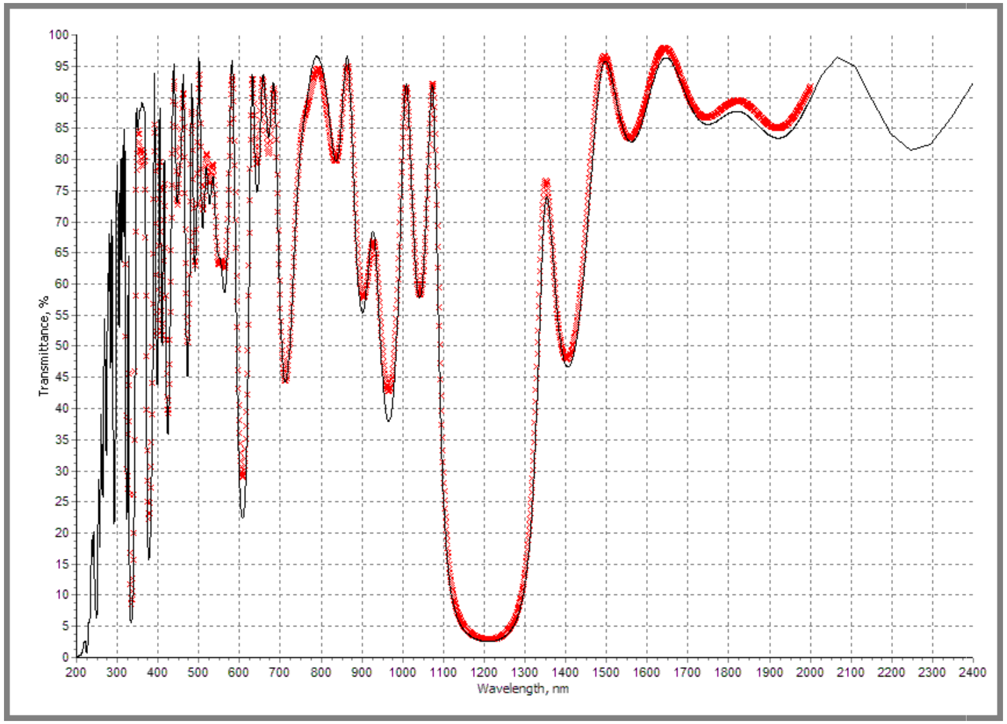
Groundwork was laid earlier with similar but smaller product gratings with SNL providing MLD coatings for 2 of 5 (21cm X 60cm) gratings

SNL collaborated with PGL
-in implementing the counter-rotation option
-in developing the IAD deposition process to achieve
- good coating uniformity
- suitable increase of coating density
- adequate reduction of stress mismatch between coating and substrate

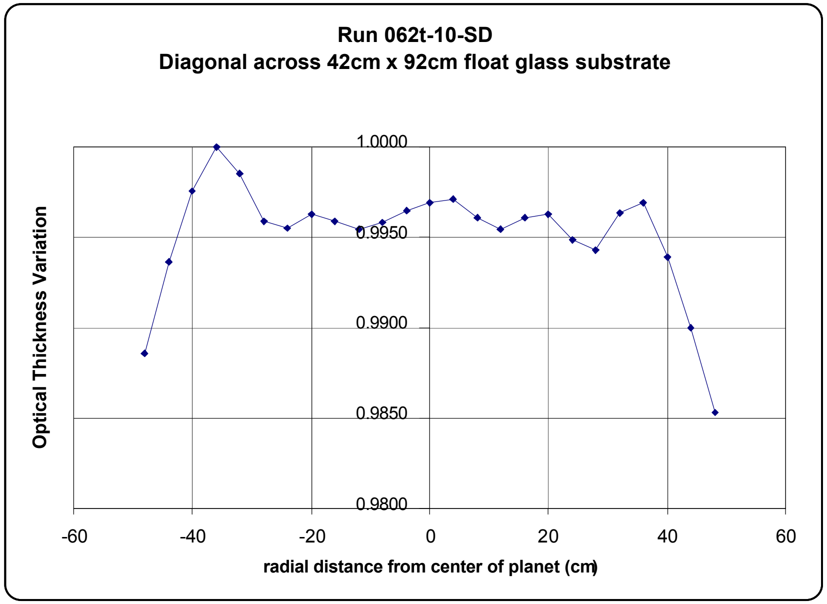
so that the MLD grating coatings do not craze or delaminate during the grating fabrication process or in vacuum environments

Sandia's MLD coatings have not crazed or delaminated during the grating fabrication process (including pirhana etch) or in the vacuum use environment of the product gratings

MLD Grating Coatings at Sandia: Results from Test Run 062t-10 Just Prior to the Product Runs on the Large Scale (94cm X 42cm) Grating Substrates



Transmission measurements (spectrophotometer scan, in red) for the MLD grating coating of test run 062t-10 compared with theory black. Data was uniformly shifted up 1.5% to better view the data fit. (coating is 1.5% thin)



Uniformity measurement of the MLD coating along the diagonal of a 42cm X 92cm thick float glass substrate in test run 062t-10. This coating uniformity is very good for a large thick substrate in the counter-rotating planetary option.

Conclusion

Sandia's Large Optics Coating Operation

- has successfully met production goals for the debris shield and vacuum window AR coatings required for the backlighting mission of the Z-Backlighter lasers
- And has also provided high LIDT coatings for the large optics of Sandia's Z-Backlighter TW and PW laser beam trains

In-house capabilities in state-of-the-art coating designs and production of high LIDT coatings on large (> 1m dimension) optics have steadily advanced year by year

Sandia has engaged in collaboration within the high LIDT large optics coatings community and has shared knowledge and experiences in forums and publications

Major accomplishments are the MLD coatings for Sandia's large scale gratings and the PW FOA Steering and OAP Mirrors

Challenges remain in addressing the issues of coating spectral shifts and HR bandwidths at 2w

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