ZBacklighter U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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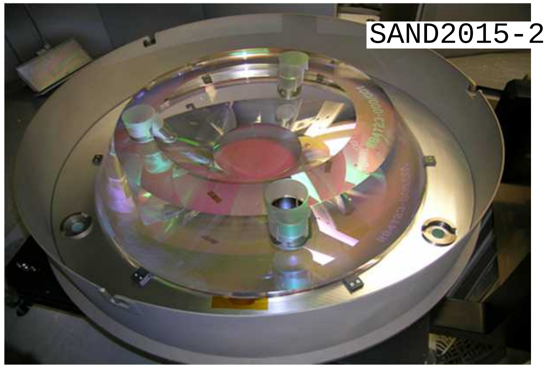


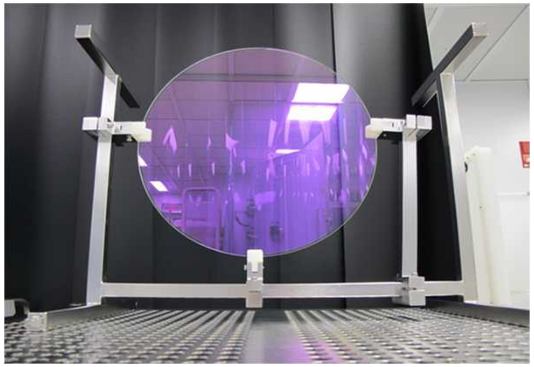
SAND2015-2353C

Overview of large optics coating capabilities and operations at Sandia National Laboratories

John Bellum, Ella Field, and Damon Kletecka

Sandia National Laboratories, USA

International Laser Operations Workshop, CEA-CESTA, France, April 8, 2015



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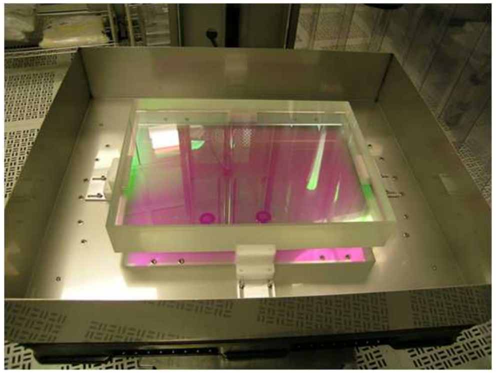
Topics

1. **Coater operational overview** (Bellum)
2. **Development of high index layers for broad bandwidth high reflection (HR) applications** (Field)
3. **Broad bandwidth HR coating for femtosecond (fs)-class PW laser pulses** (Bellum)
4. **Ion milling removal of an un-usable coating to maintain the Z-Backlighter shot schedule despite a failed coating run** (Field)
5. **Summary** (Field)



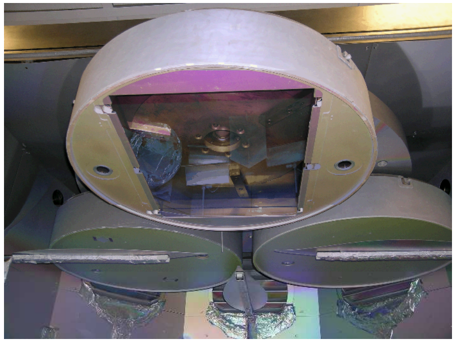
Large Optics Coating Operation

Update

- Coating team and capabilities reinforced by addition of Ella Field in 2012
- Oversight of day-to-day operations conducted by Ella since October 2014
- New coating development efforts pursued since 2012
  - Coatings for increased HR bandwidth
  - Dual wavelength (1w/2w) beam splitter coatings
  - Ion milling to remove failed coatings
- Collaborations established since 2012
  - STFC Rutherford Appleton Laboratory – development of broad bandwidth HR (BBHR) coatings for fs-class PW laser pulses
  - CEA-CESTA – laser-induced damage threshold (LIDT) test comparisons

Review

- Mission: To provide high LIDT optical coatings for large optics in support of Z-Backlighter TW & PW laser operations
- Key features
  - 2.3 m X 2.3 m X 1.8 m coating chamber in a Class 100 clean room
  - E-beam deposited coatings (mostly hafnia/silica layer pairs) with or without ion-assisted deposition (IAD)
  - 3-planet option accommodates up to 94 cm optic per planet
  - 2-planet, counter-rotation option holds up to 1.2 m optic per planet
  - 3 e-beam sources for thin film materials
  - Process control based on crystal sensor monitoring of thin film layers
  - Highest coating demand: 50 – 100 anti-reflection (AR) coated debris shields & vacuum windows needed by backlighting operations per year

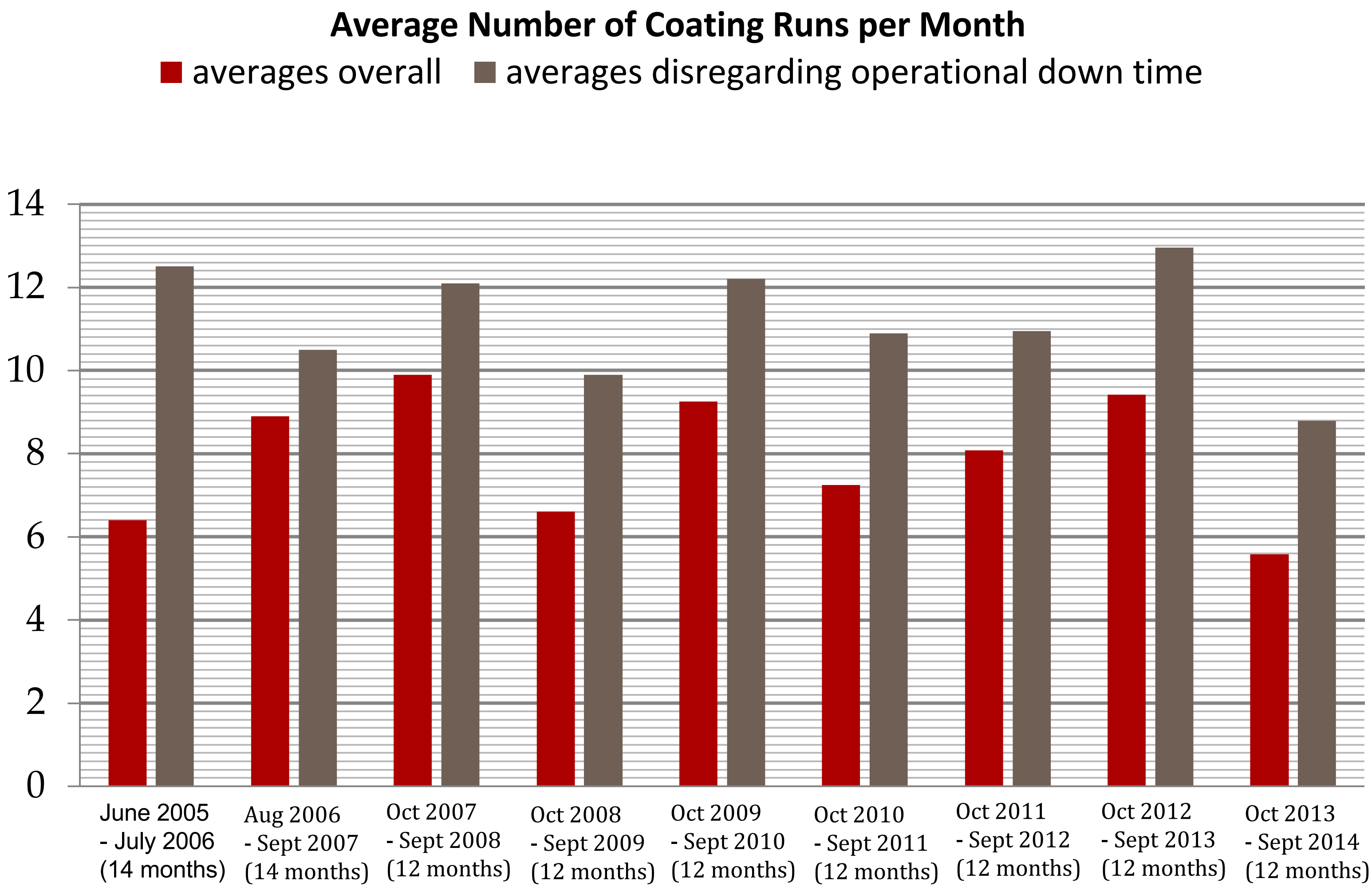


Sandia's Z-Backlighter Laser Facility – Kilojoule class pulsed laser systems coupled to the most powerful and energetic x-ray source in the world, the Z-Accelerator

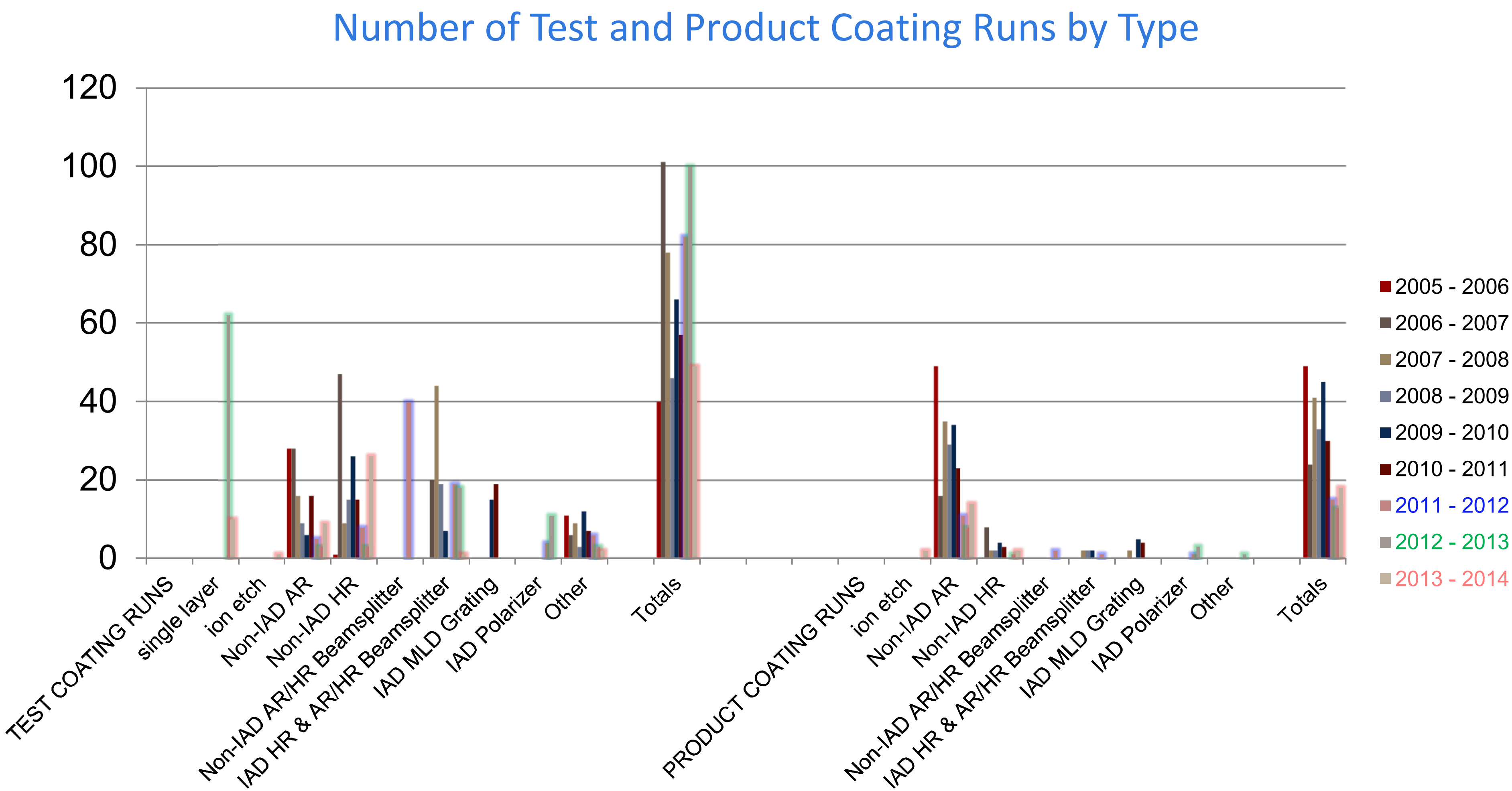
Optical Support Facility and Large Optics Coater
(Class 100 Clean Area)

Z-Beamlet	Z-Petawatt
λ = 527 nm	λ = 1054 nm
τ = 0.3 – 6 ns	τ = 500 fs
I = 10^{16} W/cm^2	I = 10^{20} W/cm^2
E = 4 kJ	E = 500 J

Coating Operation Performance Data



Coating Operation Performance Data



Development of High Index Layers for Broad Bandwidth High Reflection Applications

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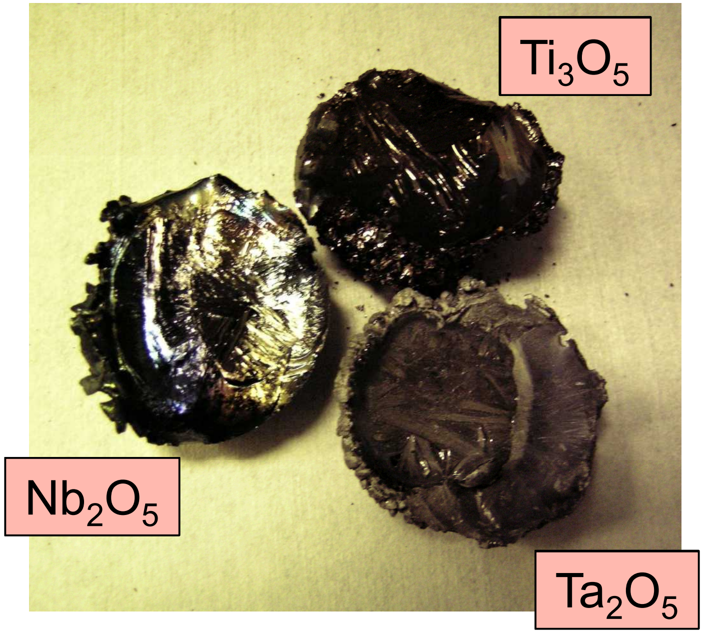
- Materials explored:

Material	Index of Refraction at 500 nm
TiO_2 (from Ti metal)	2.42
TiO_2 (from Ti_3O_5)	2.41
Nb_2O_5	2.37
Ta_2O_5	2.19

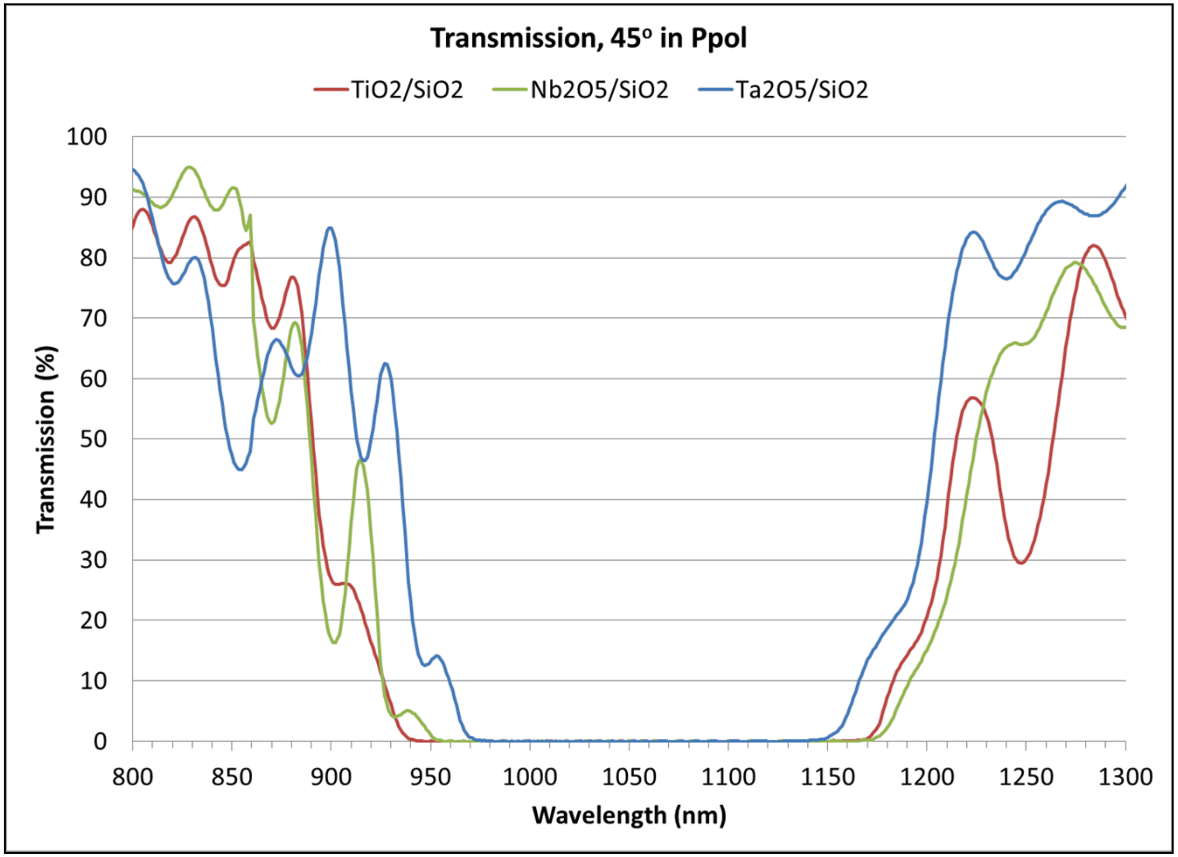


- HR Coating designs:
  - 42-layer quarter wave stacks for 1ω, 45^o Ppol
  - High index materials paired with SiO_2
  - Explored using both HfO_2 and TiO_2 layers within the same coating

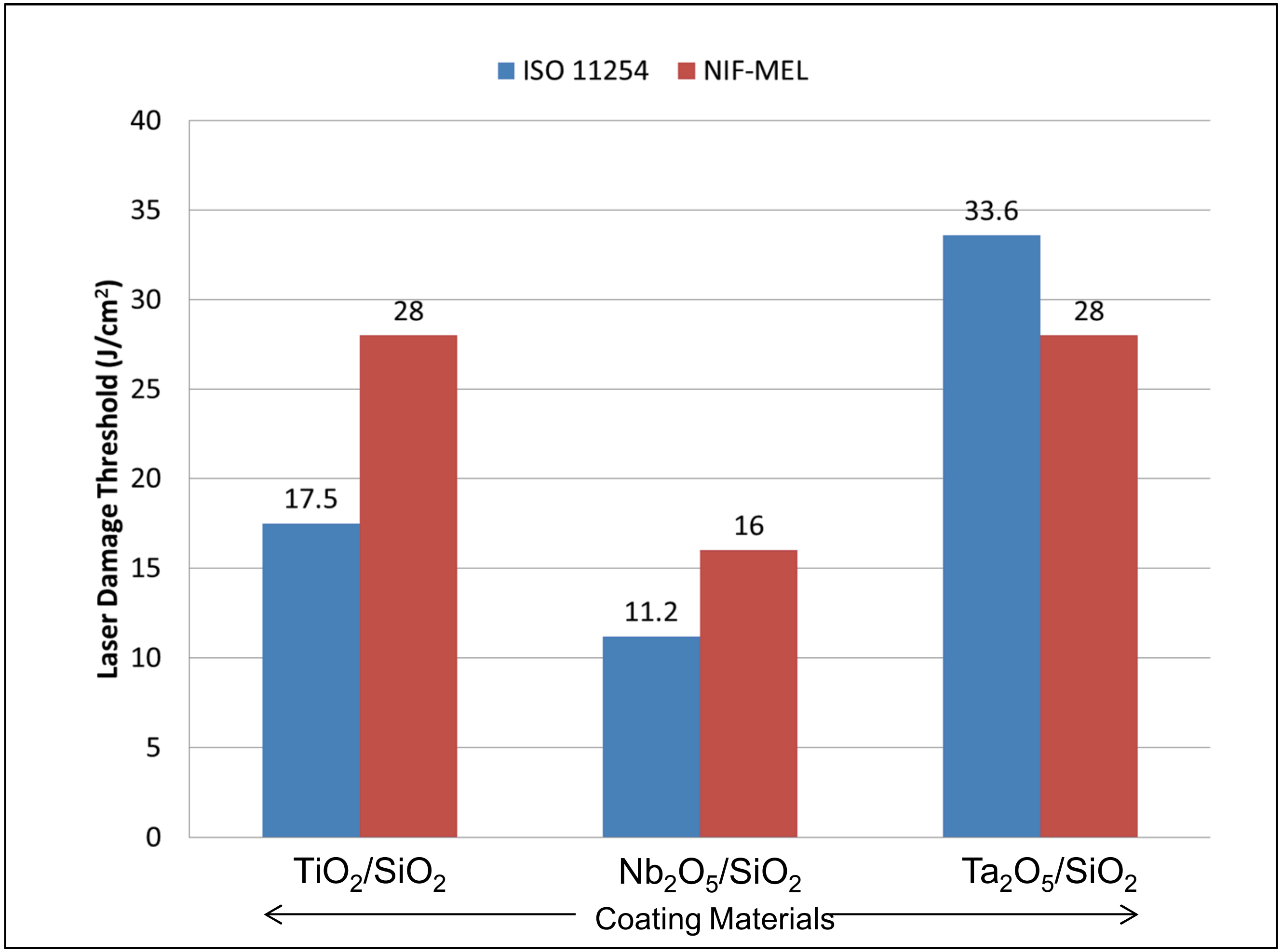
HR Bandwidths for Coatings Containing TiO_2 (from Ti_3O_5), Nb_2O_5, and Ta_2O_5 Layers

- HR bandwidth taken where transmission < 0.5%
- The 42-layer coatings all exhibit higher bandwidth than predicted

Coating Materials	HR Bandwidth, Ppol, 45°	
	Predicted (nm)	Actual (nm)
TiO_2/SiO_2	221.3	231
Nb_2O_5/SiO_2	218.7	221
Ta_2O_5/SiO_2	158.7	177



Laser Damage Thresholds: TiO_2 (from Ti_3O_5), Nb_2O_5, and Ta_2O_5 HR Coatings



Test Protocols at 1064 nm, 45° AOI, Ppol:

- Spica: NIF-MEL Method with 3.5 ns laser pulses
- Quantel: ISO Damage Frequency Method (ISO Standard 11254-1) with 10 ns pulses

Replacing Inner HfO_2 Layers with High Index TiO_2 Layers in 42-Layer Coatings to Increase HR Bandwidth at Expense of LIDT

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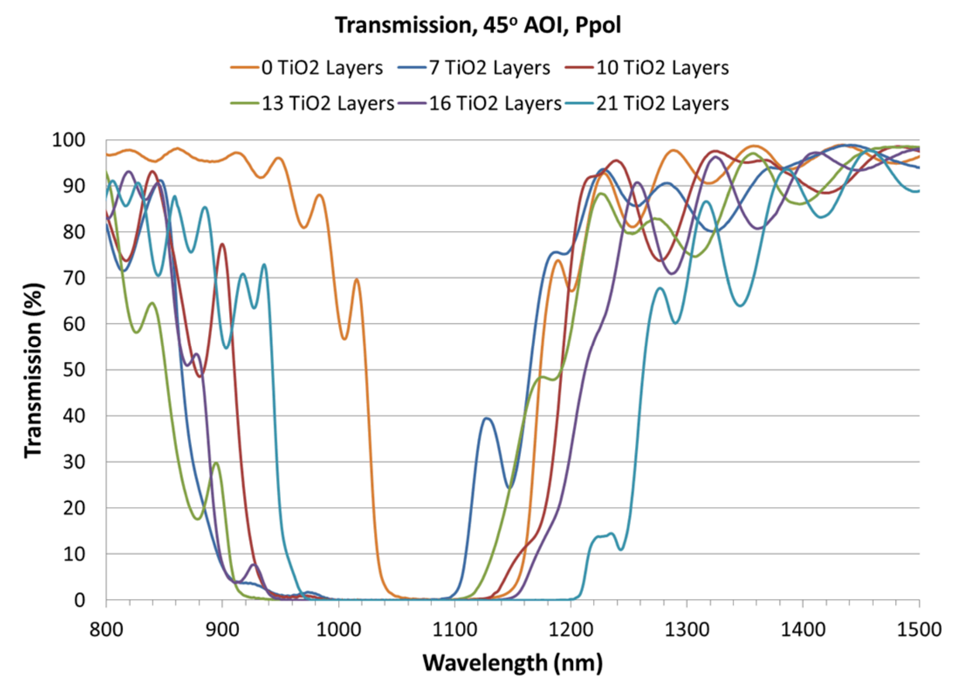
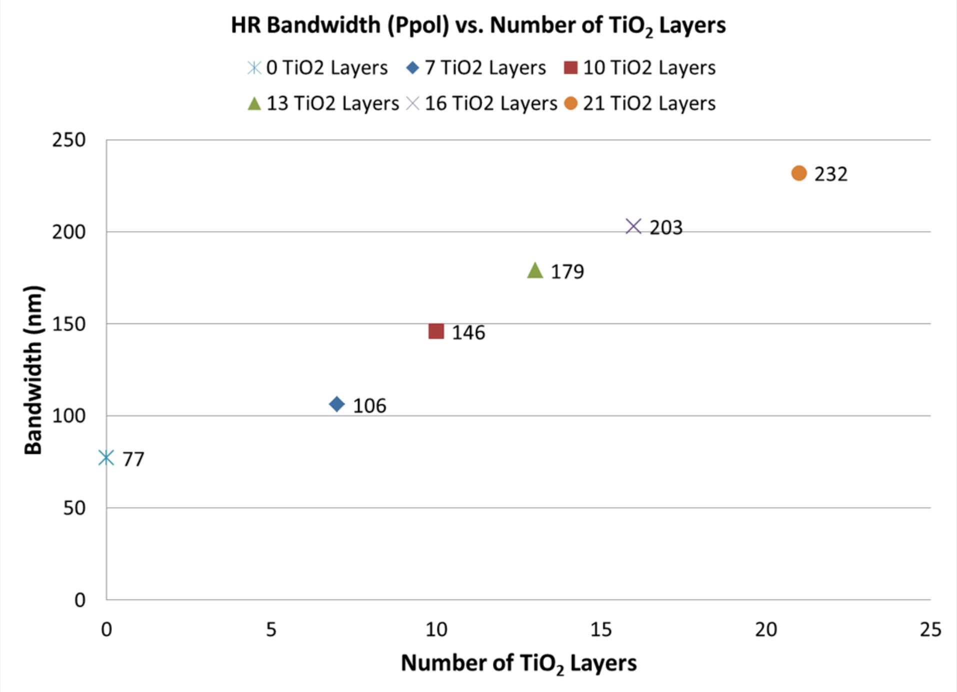
- Studied 42-layer coatings for HR at 45° AOI, Ppol
- Replaced inner HfO_2/SiO_2 layer pairs with 7, 10, 13, 16 and 21 TiO_2/SiO_2 layer pairs
- TiO_2 layers: higher index, lower band gap increases HR bandwidth but decreases LIDT
- HfO_2 layers: lower index, higher band gap increases LIDT but decreases HR band gap
- Achieved high polarization purity in Lambda 950 spectrophotometer measurements by using Glan Thompson polarizer

HR Bandwidth Results

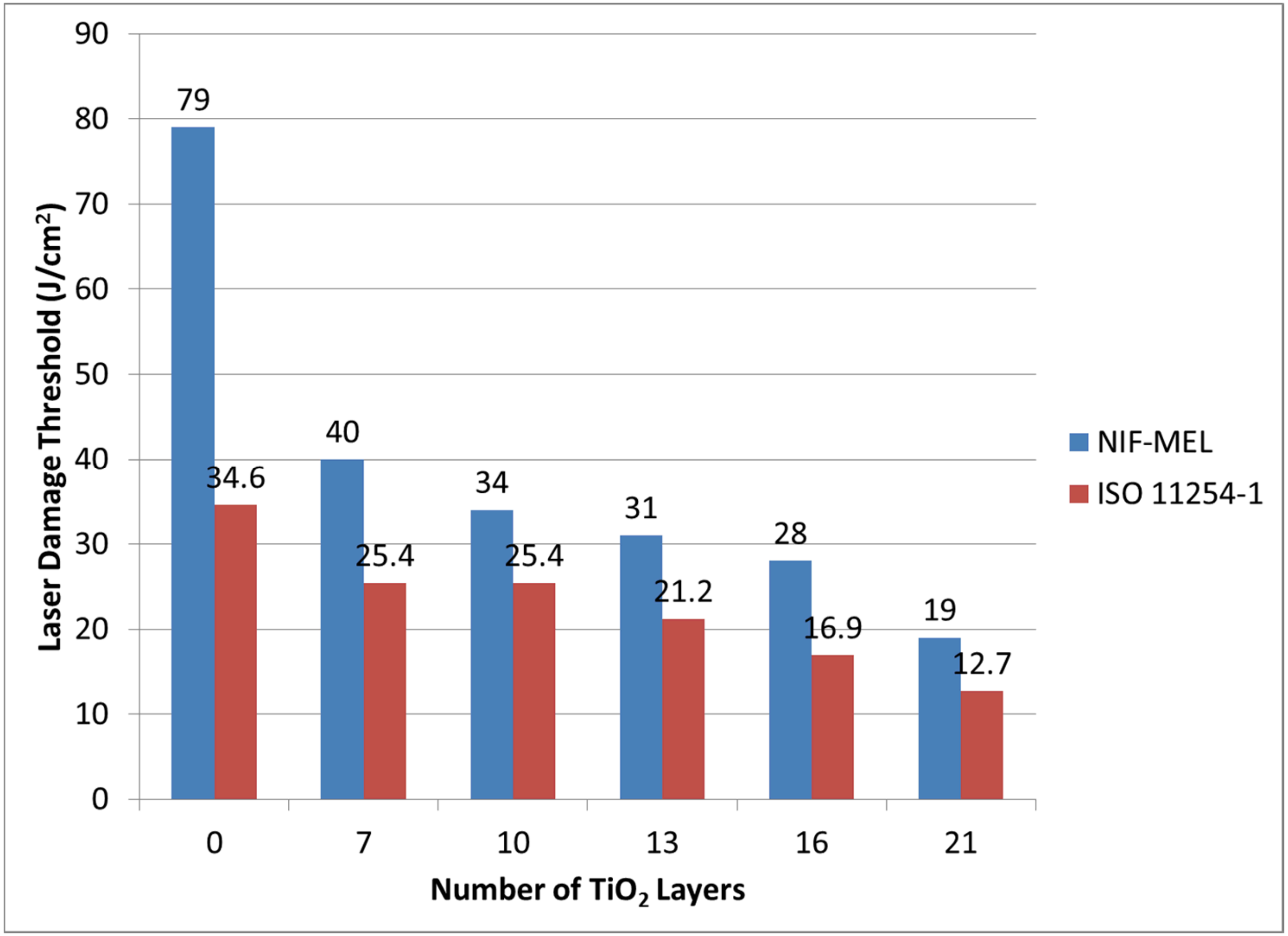




Bandwidth measured across T < 0.5%

Replacing Inner HfO_2 Layers with High Index TiO_2 Layers in 42-Layer Coatings to Increase HR Bandwidth at Expense of LIDT

LIDT Results



Test Protocols at 1064 nm, 45° AOI, Ppol:

- Spica: NIF-MEL Method with 3.5 ns laser pulses
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High reflection coatings for fs-class PW laser pulses

(Work in collaboration with and supported by STFC, Rutherford Appleton Laboratory)

Requirements:

- Broad bandwidth high reflection (BBHR)
- High LIDT
- Reflection that does not temporally distort or stretch the fs pulses
- Reflection at non-normal AOI, usually 45°, in P and S polarization for laser beam steering

BBHR Coating Design Goals:

- Reflectivity → R > 99.5% for 45° AOI, Ppol
- Operational Bandwidth → 800 – 1000 nm
- LIDT → > 800 mJ/cm^2 for fs class pulses
- GDD → < 20 fs^2 over the operational bandwidth

These requirements may also accommodate coating spectral drift and provide AOI flexibility for picosecond and nanosecond class laser pulses

fs pulses and dispersion in coatings for BBHR at non-normal AOI

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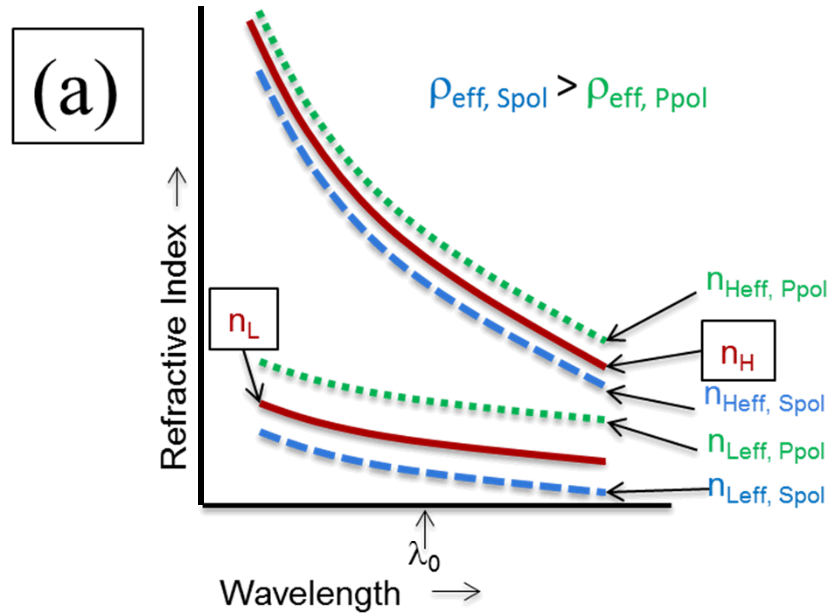
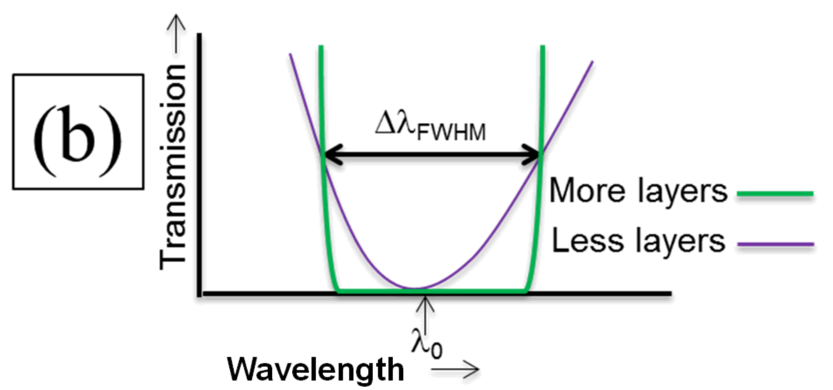
- Wide range of phase correlated frequencies combine to form fs pulses
- Coating layers provide different optical thicknesses for wavelengths across the BBHR band
- Optical propagation velocities and directions in coating layers vary across fs pulse wavelengths
- Example: TiO_2/SiO_2 layers of thicknesses t_H & t_L:

	H-index layers		L-index layers	
	800 nm	1000 nm	800 nm	1000 nm
layer index	2.295884	2.269580	1.457966	1.455900
propagation angle in layer	17.938°	18.153°	29.0122°	29.0573°
path in layer	1.0511 x t_H	1.0524 x t_H	1.1435 x t_L	1.1440 x t_L
optical path in layer	2.4132 x t_H	2.3885 x t_H	1.6672 x t_L	1.66555 x t_L

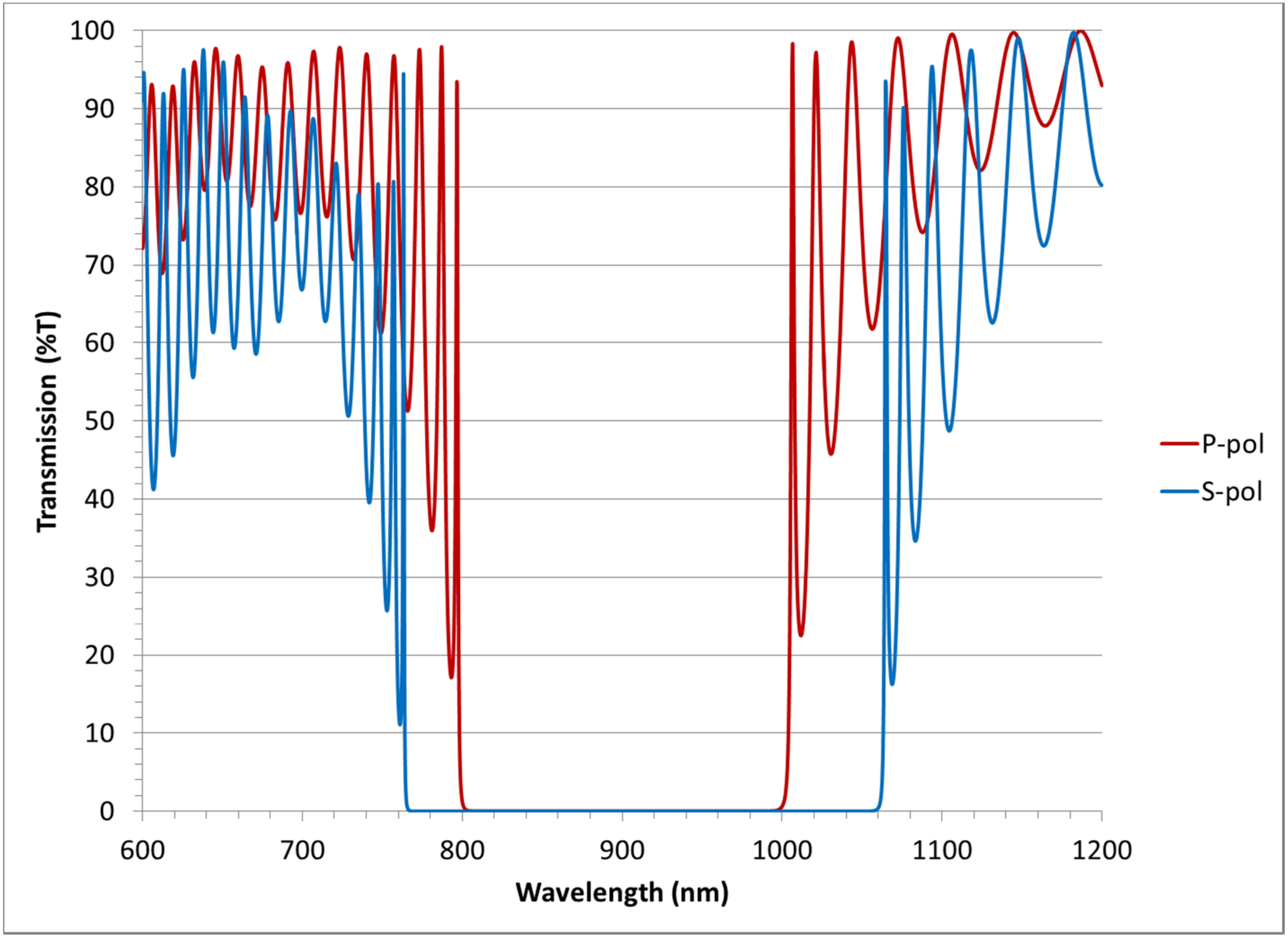


Frequency Components
- Leads to non-constant group delay dispersion (GDD) across BBHR band
- disrupts relative phases between fs-pulse frequency components
- results in temporal broadening of the pulse

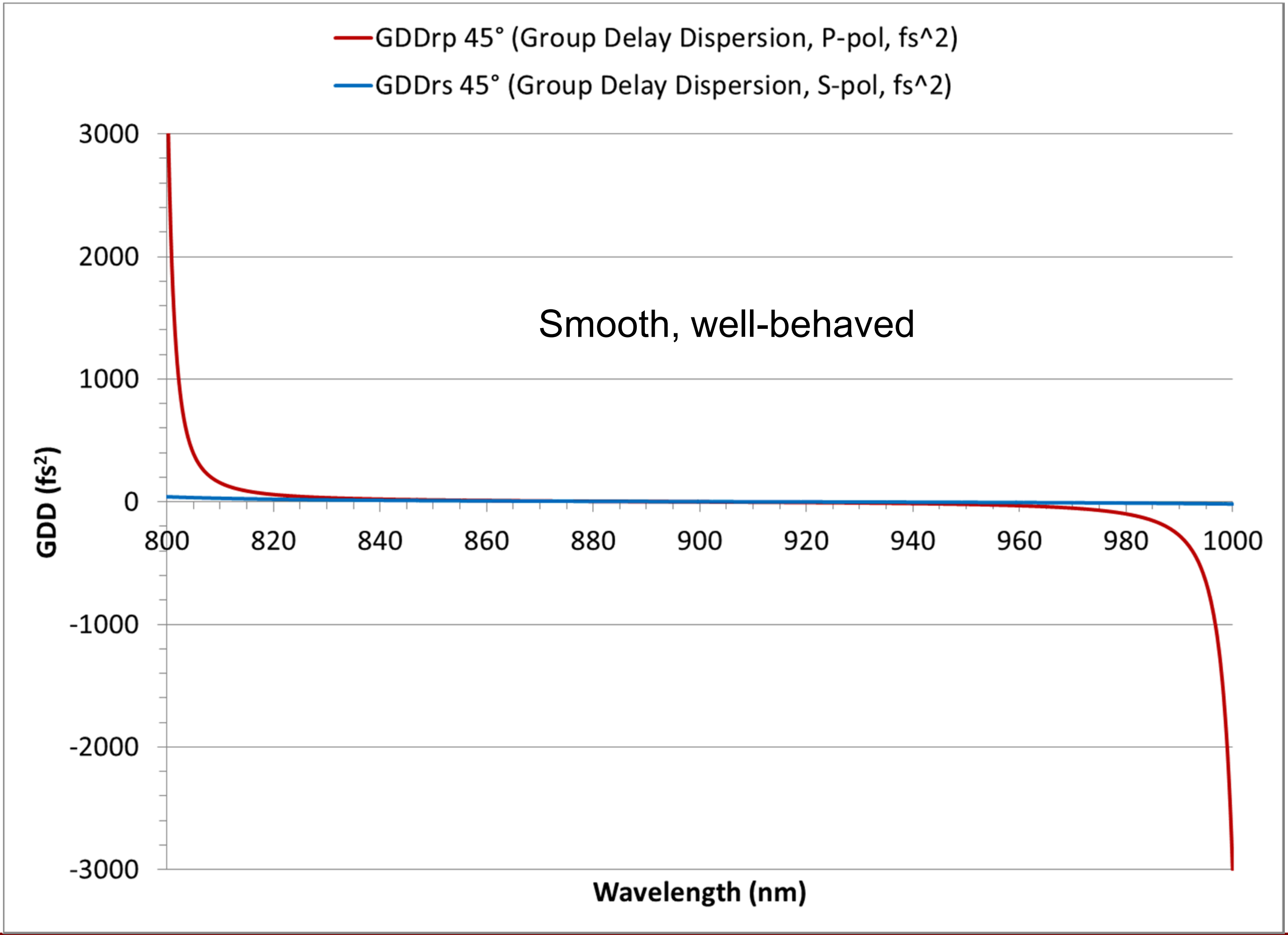


Transmission at 45° AOI, P and S pol, for the BBHR coating design

R_p > 99.5%, 801 – 999 nm (198 nm bandwidth)

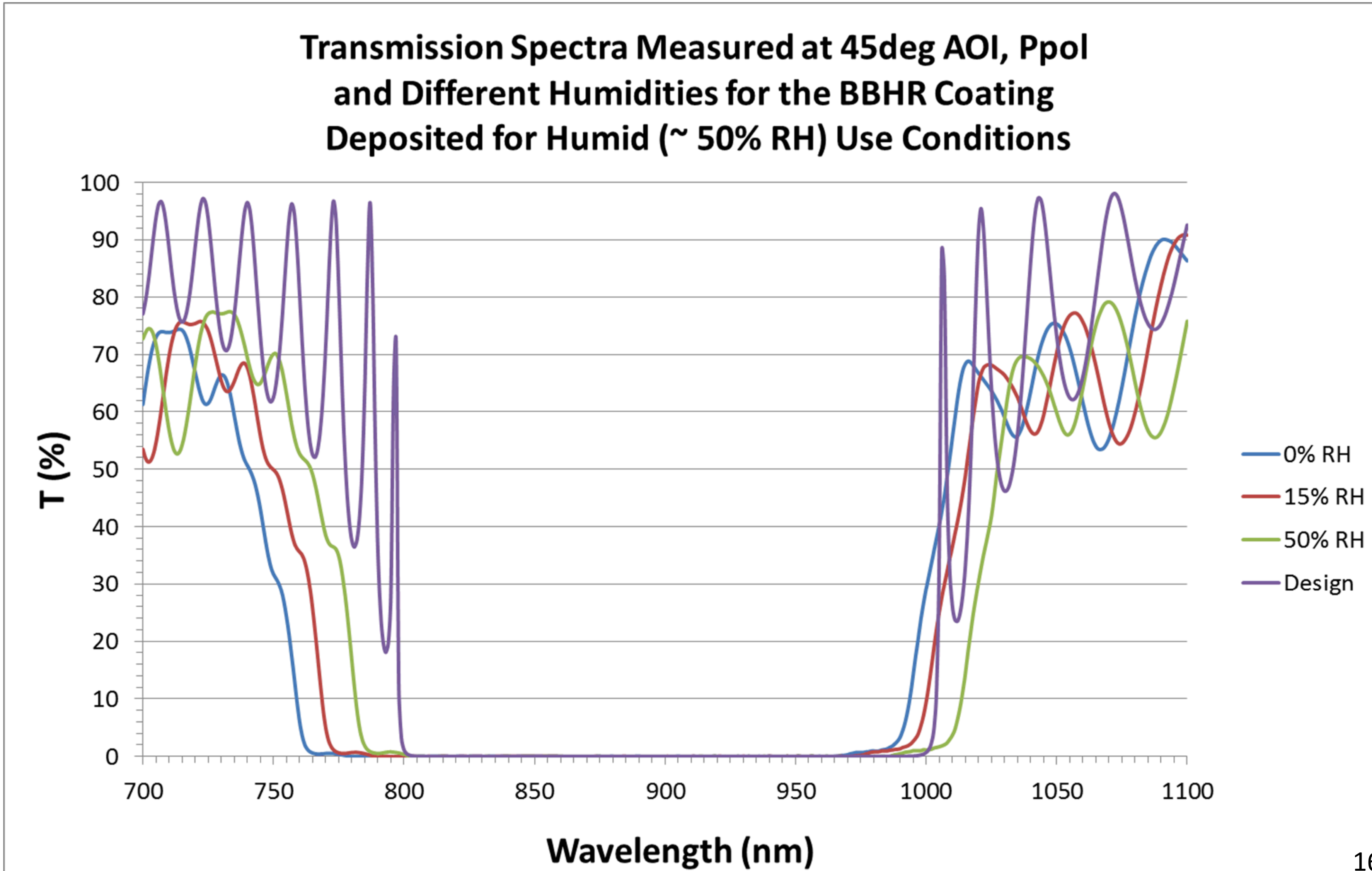


GDD on reflection for 45° AOI, S and P pol, from 800 nm to 1000 nm for the BBHR coating design



Results from the Initial Set of BBHR Coating Test Runs

- BBHR Coating for Use in ~ 50% Ambient Relative Humidity -



Initial Test Coating Run for BBHR Design

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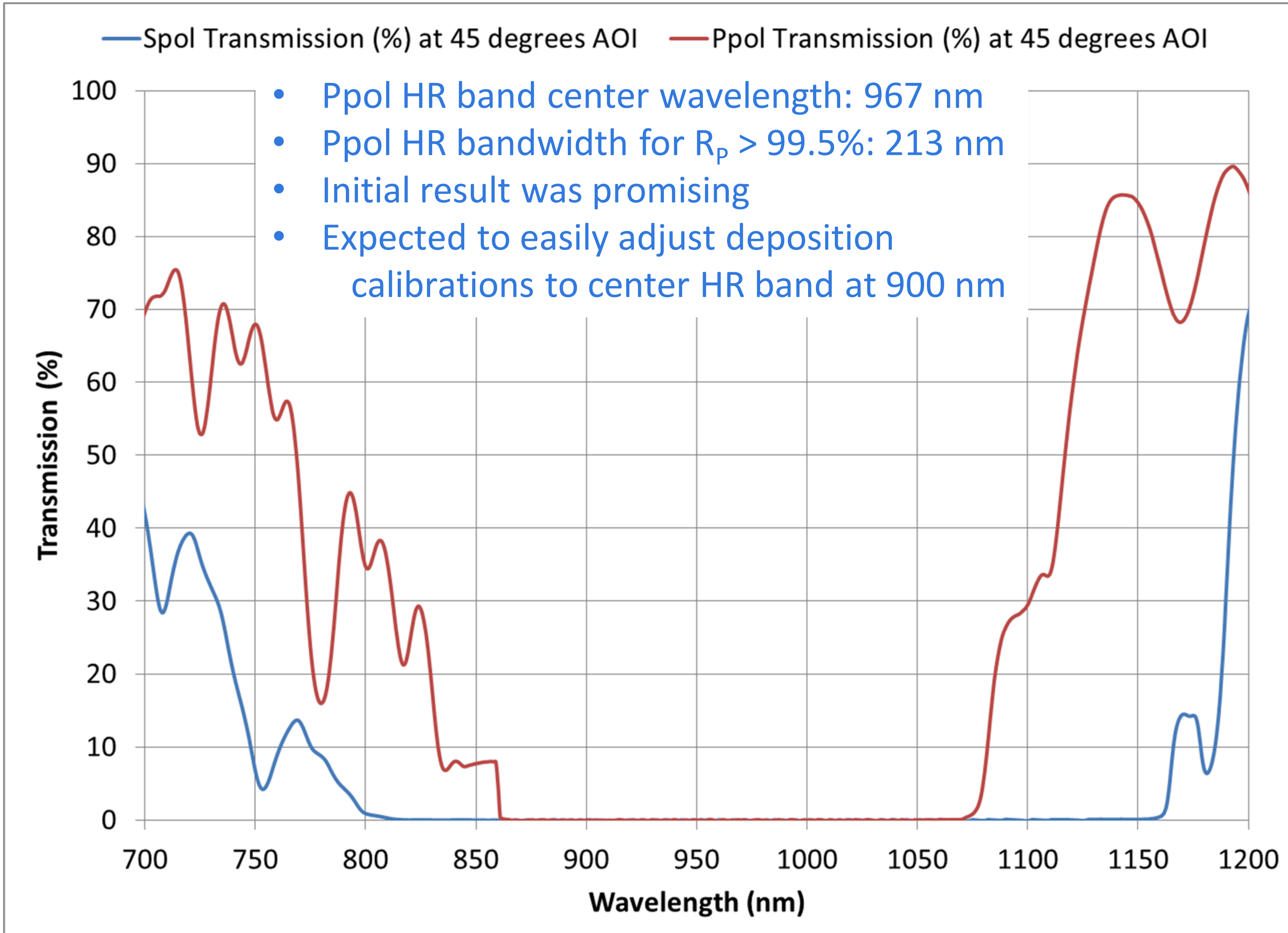
Measured Transmission at 45° AOI, P and S pol, from 700 nm to 1200 nm



- Ppol HR band center wavelength: 967 nm
- Ppol HR bandwidth for R_P > 99.5%: 213 nm
- Initial result was promising
- Expected to easily adjust deposition calibrations to center HR band at 900 nm

Initial Test Coating Run for BBHR Design

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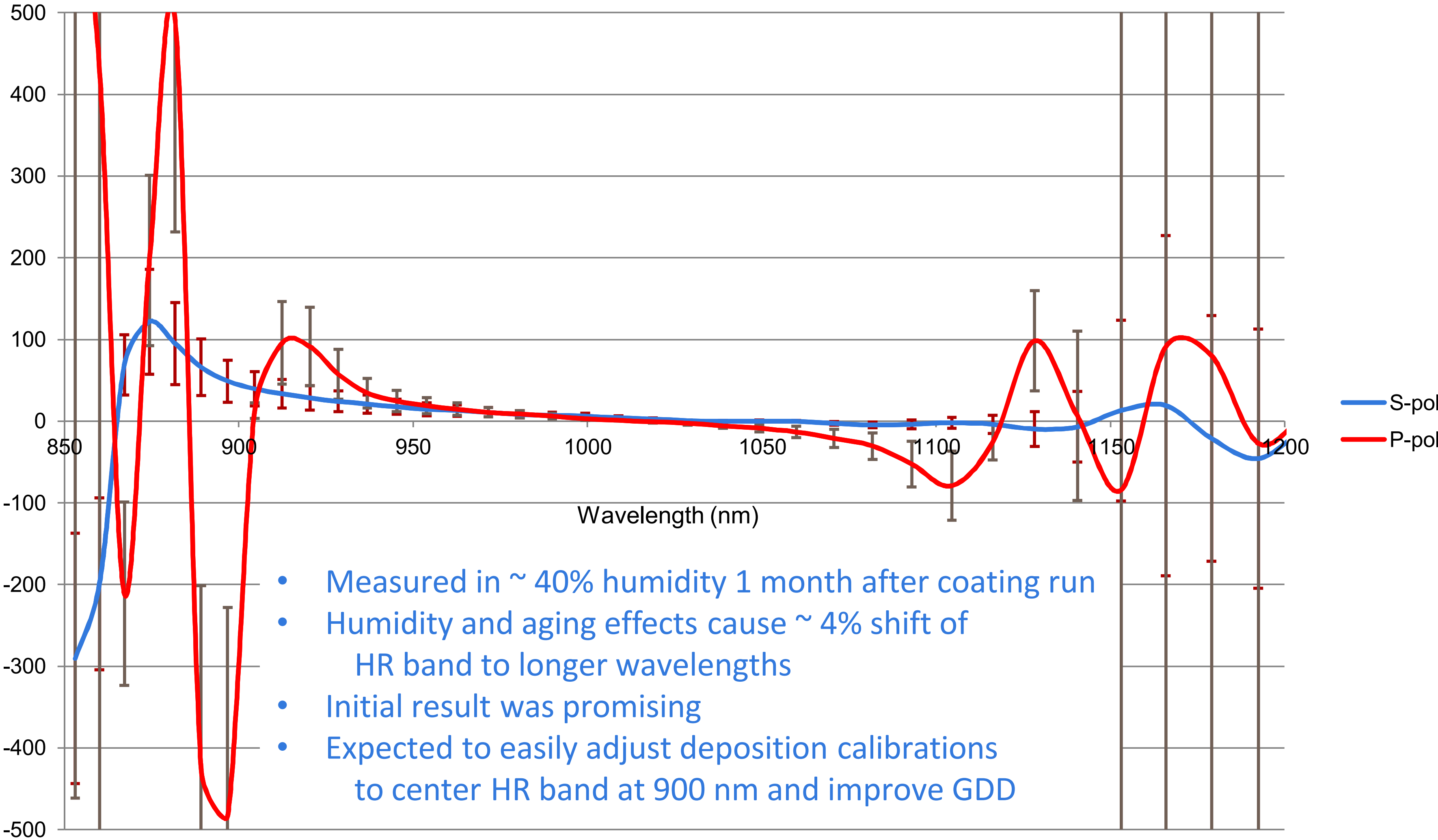
Measured GDD (fs^2) for Reflection at 45^o AOI, P and S pol, from 850 nm to 1200 nm



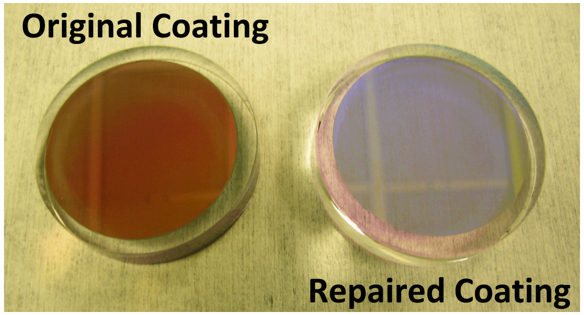
- Measured in ~ 40% humidity 1 month after coating run
- Humidity and aging effects cause ~ 4% shift of HR band to longer wavelengths
- Initial result was promising
- Expected to easily adjust deposition calibrations to center HR band at 900 nm and improve GDD

GDD measurements provided by J. Oliver and C. Smith, Laboratory for Laser Energetics

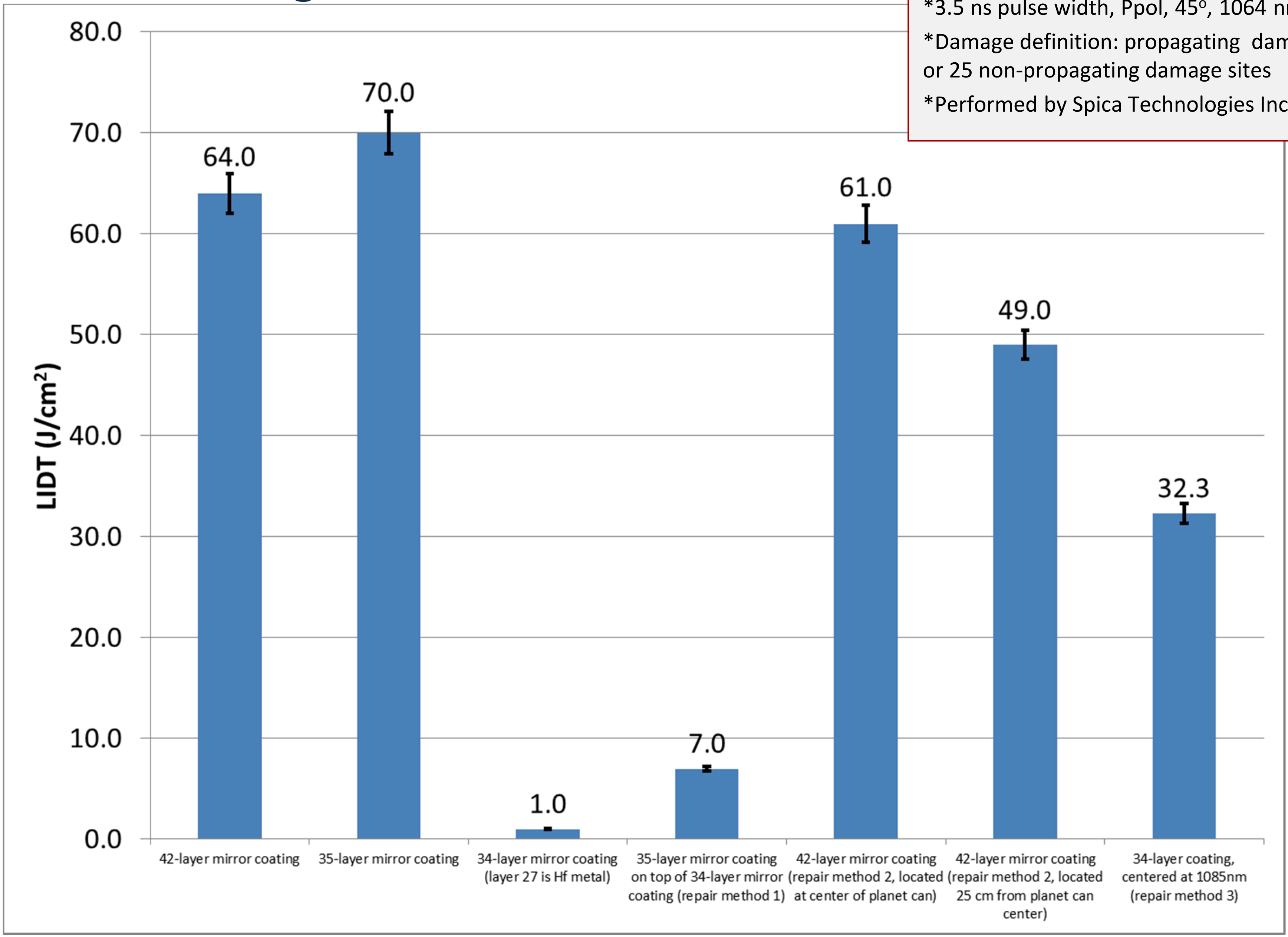
Exploring alternatives to removing or repairing high reflection coatings on large substrates

- **Alternative options that we tested:**
  1. **Deposit a new coating on top of the original coating –** the incorrect coating would be buried under the correct coating and therefore diminish the negative impact that the incorrect coating would have on the laser-induced damage threshold.
  2. **Remove the entire coating with ion milling –** recoat the optic with the correct coating following the complete removal of the incorrect coating.
  3. **Remove select layers from the coating with ion milling –** remove the outer layers through to the incorrect layer and recoat them correctly, leaving the underlying coating intact.

- **Evaluation Criteria:**
  - LIDT
  - Spectral requirements



Laser damage results



NIF-MEL Damage testing protocol:

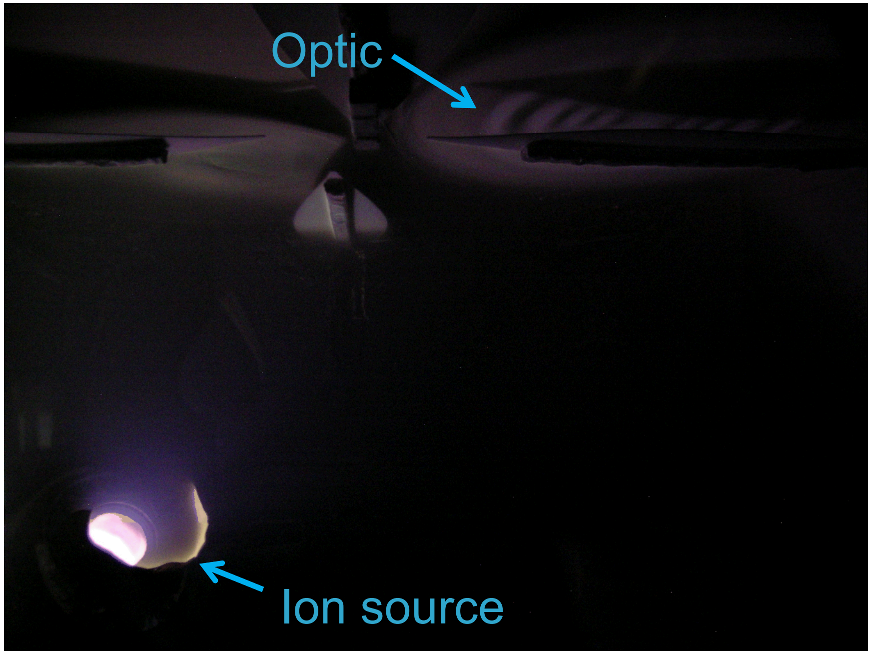
*3.5 ns pulse width, Ppol, 45°, 1064 nm

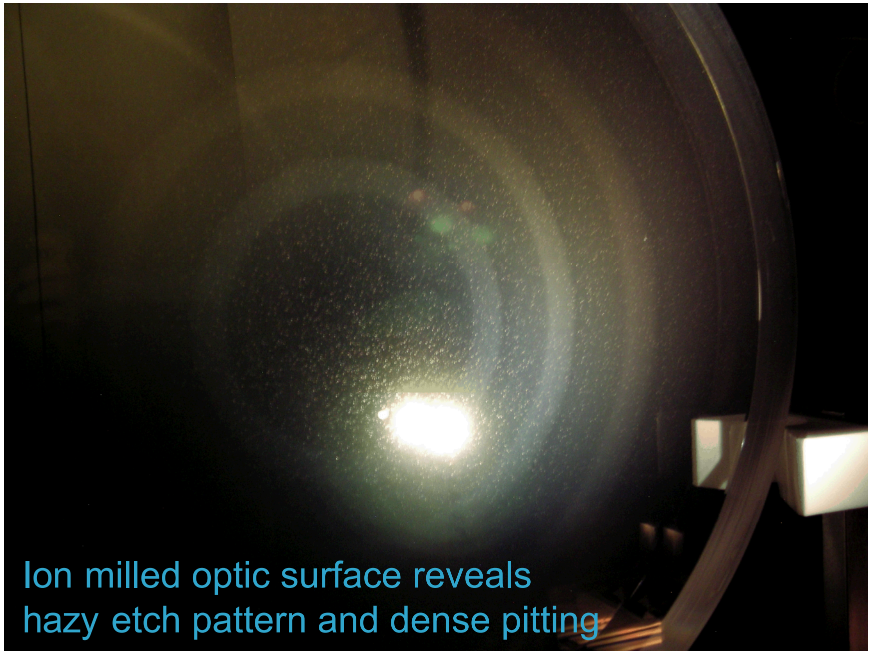
*Damage definition: propagating damage, or 25 non-propagating damage sites

*Performed by Spica Technologies Inc.

Ion milling concerns: non-uniform etch rate

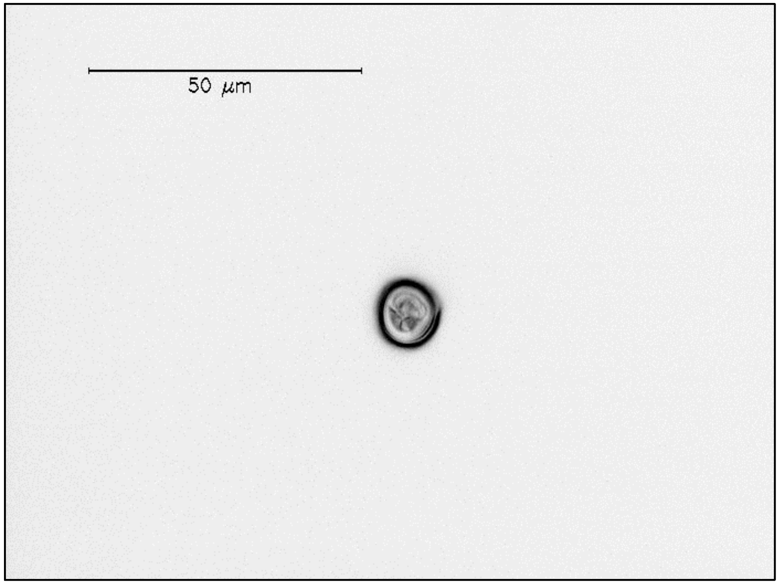
- Not a problem for small optics (~12 cm diameter)
- Faster etch rate at the center of the optic means the coating was completely removed from the center before the edges were finished. This means the bare substrate was etched as well, giving it slight curvature. At worst, we estimate the substrate radius of curvature to be 32 km.

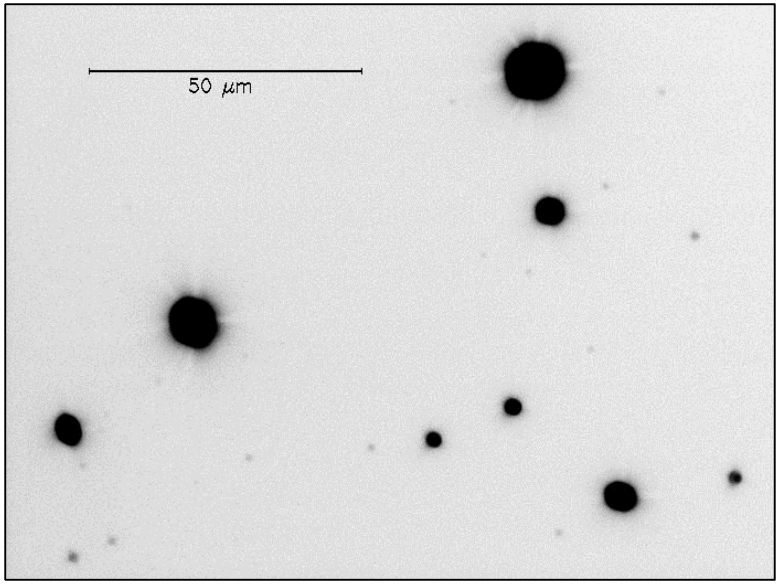




Ion milling concerns: pitting on substrate surface

- 5 – 10 micron pits appear over entire optic surface
- Consider trying lower ion energies to reduce pitting, though this will increase the etch time
- Despite dense pitting, high LIDTs still maintained, repaired optic is functioning well in beam train





Sandia's Large Optics Coating Operation - Summary

- Successfully meets debris shield and vacuum window AR coating production goals
- Provides high LIDT coatings for large optics required for Z-Backlighter TW and PW lasers
- Advances year by year in state-of-the-art high LIDT coating designs and production for large, meter-class optics

New Capabilities:

- High index coating materials → TiO_2, Nb_2O_5, and Ta_2O_5
- BBHR coating design for fs-class laser pulses at 45^o AOI, Ppol
- Ion milling (etching) to remove unusable coatings

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

Thank you!

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