SAND2009-6316C

Meeting Thin Film Design and Production Challenges for Laser Damage Resistant Optical Coatings at the Sandia Large Optics Coating Operation

Laser Damage Symposium XLI (Boulder), 9/21/2009

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Z Backlighter Laser Systems

Z Backlighter

Z Beamlet

- λ=527nm
- τ=0.3-8ns
  (1 - 2 ns common)
- ϕ~75μm spotsize
- E<2kJ
- I<10^{17} W/cm^2
- ~3 hr/shot
- 2 pulse MFB

2.5 – 10 J/cm2 across beams

Z Petawatt

- λ=1054nm
- τ=500fs min
- ϕ~30μm spotsize
- E<100J (<500J pending)
- I>10^{19} W/cm^2
- ~3 hr/shot
- Sub-ps probe
  @ 527nm, <20mJ

2.5 – 4 J/cm2 across beams

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Sandia Large Optics Coating Operation

90” X 90” X 72” chamber with planetary system

3 planet option holds up to a 94 cm ϕ optic per planet

Counter rotating planet option holds up to 1.2 m optic per planet

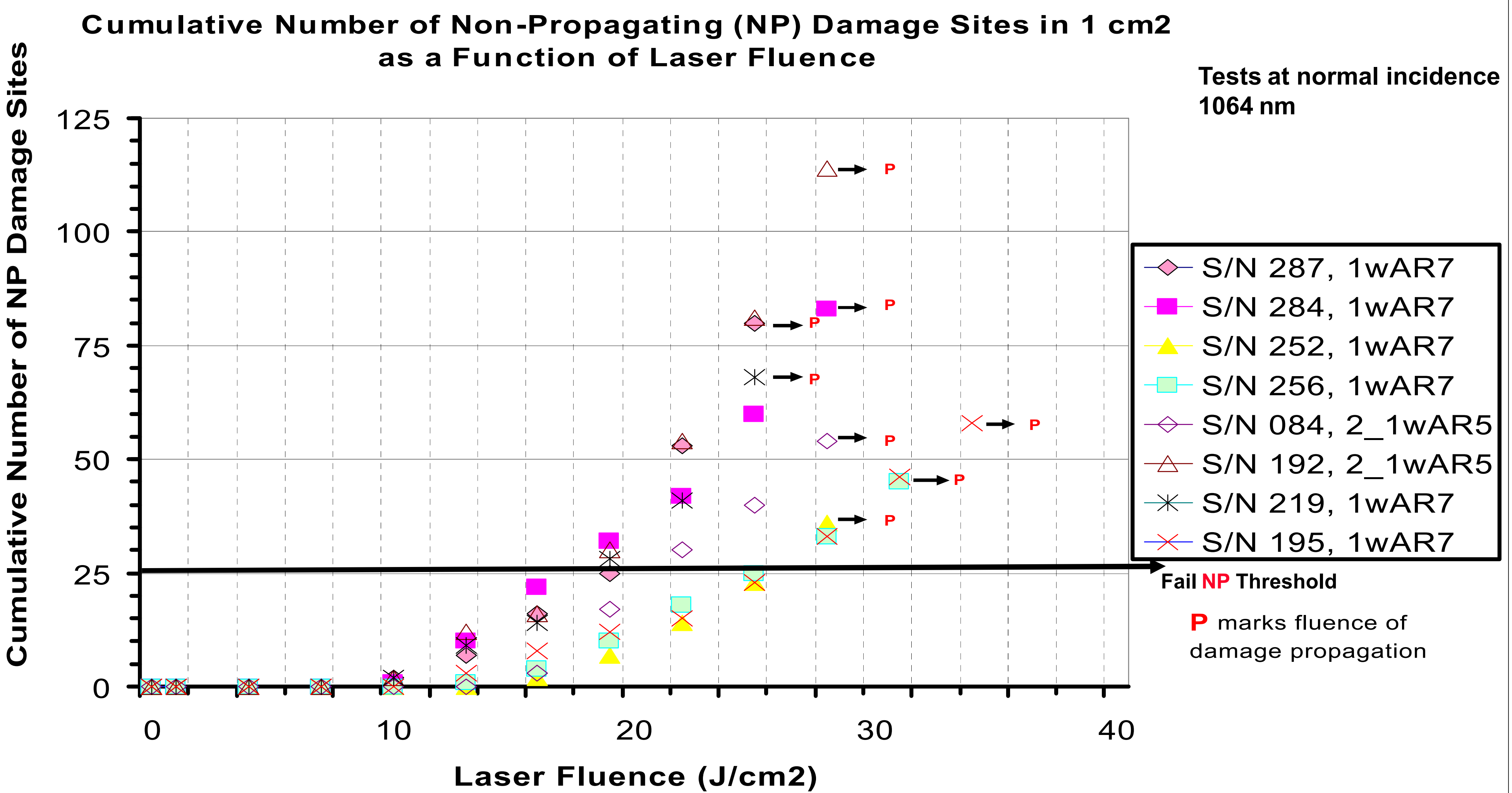
E-Beam deposited hafnia/silica coatings for high LIDT

Ion-Assisted Deposition (IAD) available

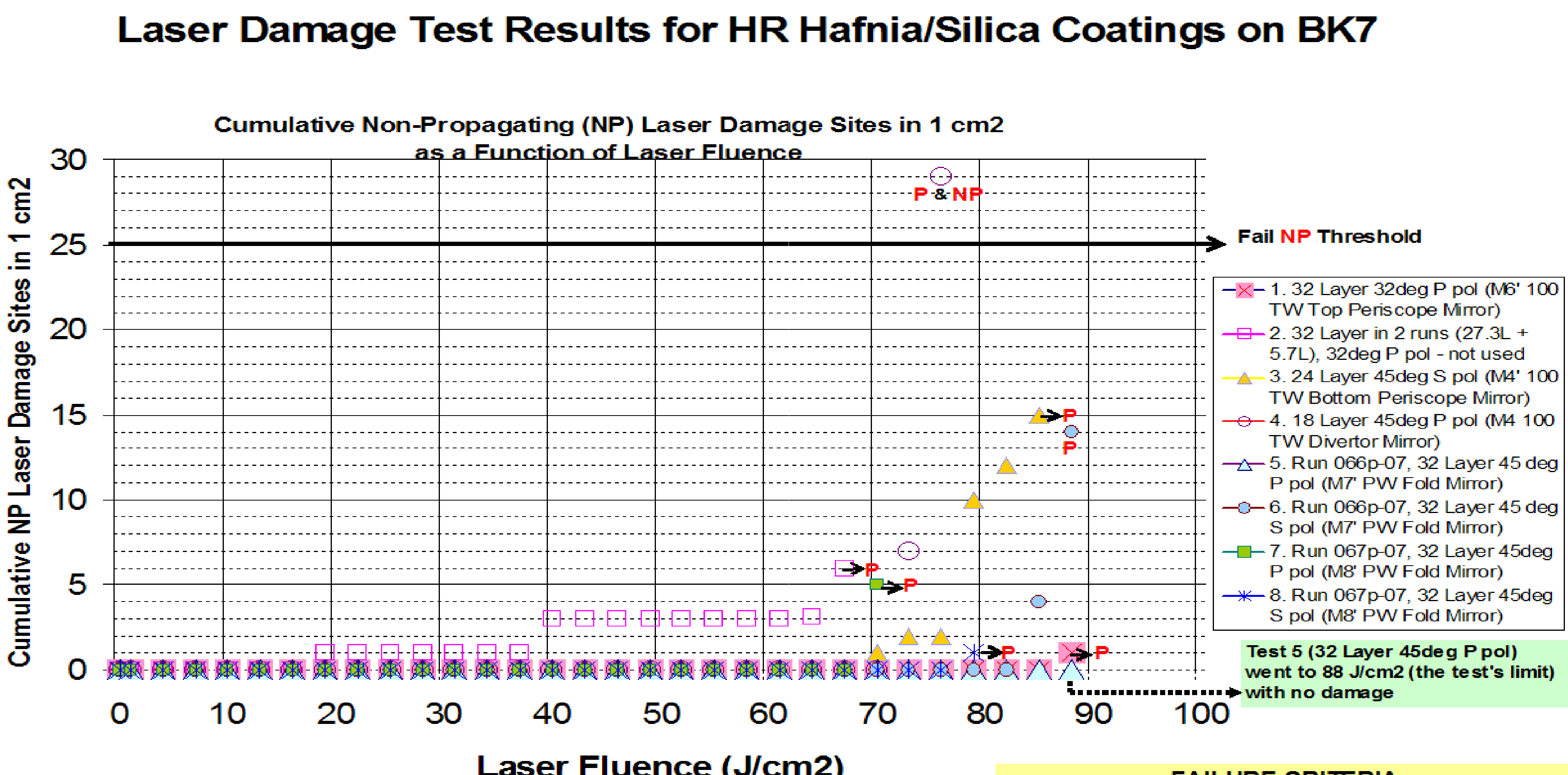
Backlighting operations require a continuous supply of AR coated debris shields

Recent efforts have focused on Z Petawatt needs, including 94 cm ϕ truncated fold mirrors and 75 cm ϕ final optics assembly (FOA) mirrors

Typical Damage Test Results for AR Coatings: Non-IAD on Fused Silica with Chamber at 200º C



Typical Damage Test Results for HR Coatings: Non-IAD on BK7 with Chamber at 200° C



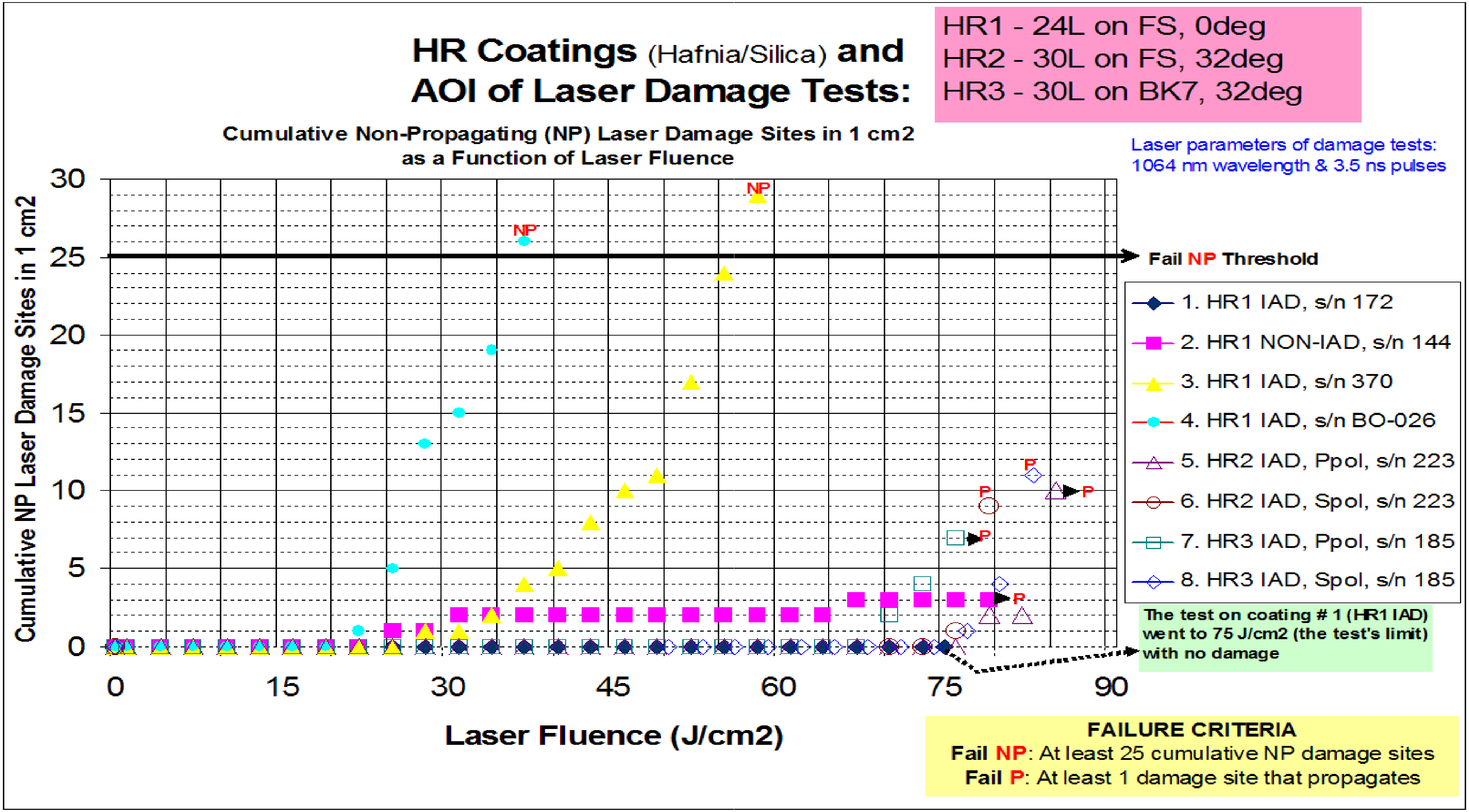
FAILURE CRITERIA

Fail NP: At least 25 cumulative NP damage sites

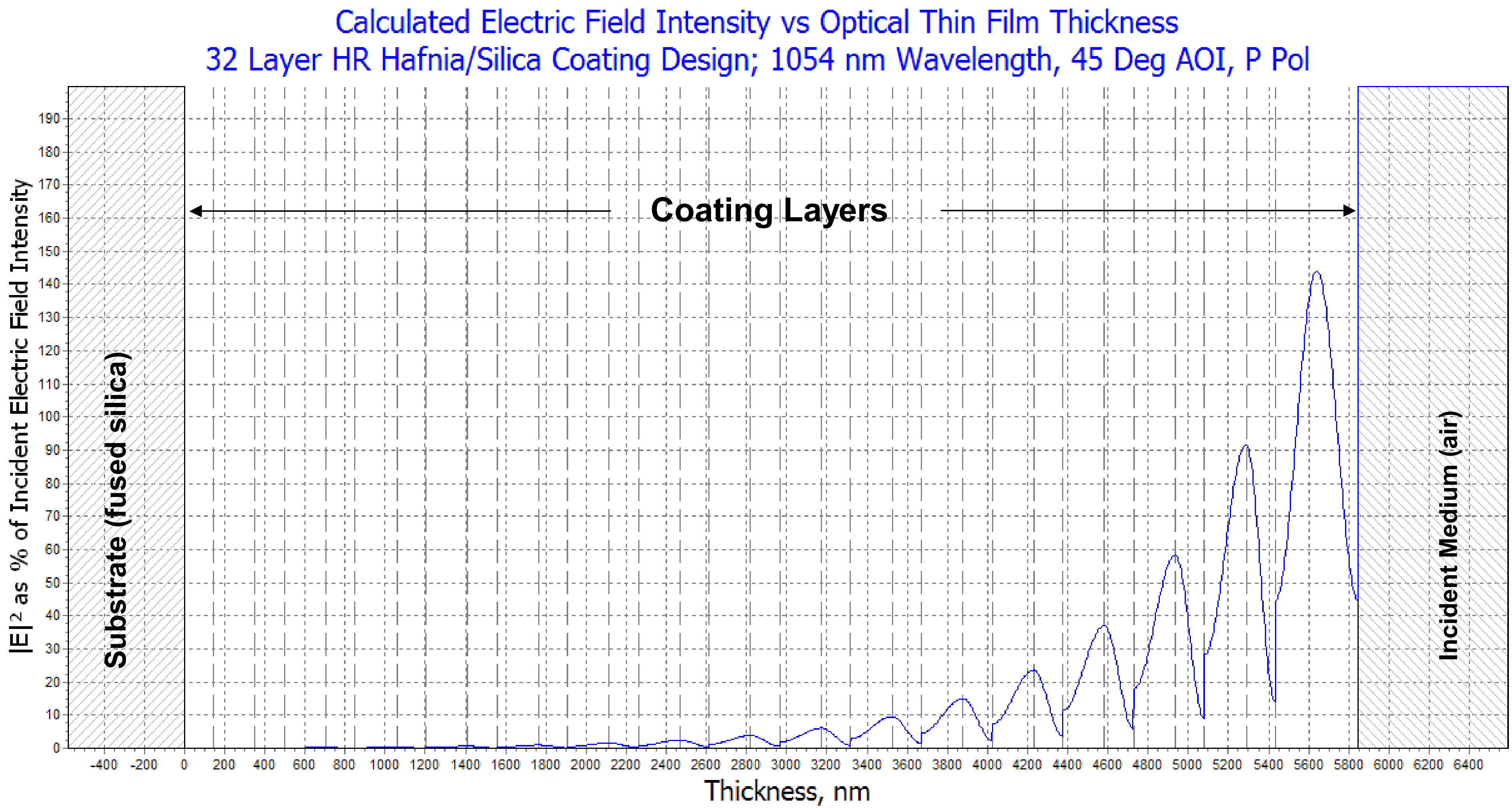
Fail P: At least 1 damage site that propagates

Laser parameters of damage tests:
1064 nm wavelength & 3.5 ns pulses

Typical Damage Test Results for HR IAD Coatings: Chamber at 70° C



Example of Optical E Field Behavior in High LIDT Coatings



IAD vs Non-IAD HR Coatings and De-lamination Risk

- **BK7: Non-IAD coatings at ~ 200^o C chamber temperature offer low de-lamination risk**
  – BK7 provides compressive stress in either ambient air or in vacuum

  – Non-IAD coatings are relatively less dense but smooth

- **Fused Silica: IAD coatings are required to reduce de-lamination risk in vacuum environments**
  – IAD coatings are denser but tend to have higher surface roughness

  – Fused Silica and Non-IAD coatings exhibit stress mismatch regardless of chamber temperature, leaving the coatings at high risk for de-lamination in vacuum*

  – IAD increases coating density enough to remove or at least reduce coating/substrate stress mismatch, and thus is necessary for coatings on Fused Silica in vacuum*

* In air, moisture can make coatings more compressive

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Microscope Images of IAD Coatings Indicate Elevated Chamber Temperature and Ion Beam (Ib) Off Between Layers Reduces Surface Roughness

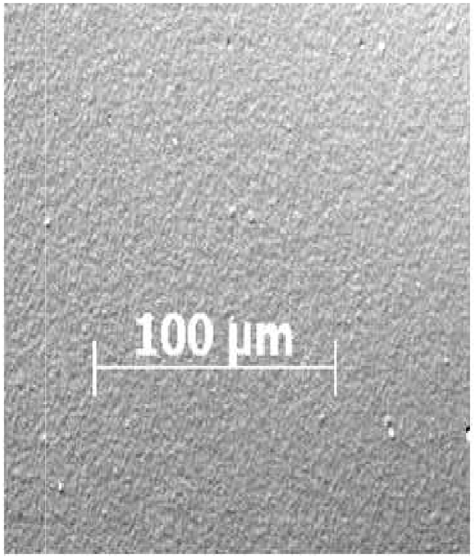
Coating A shows more surface roughness than coating B

QUESTIONS

Is this from higher temperature or from Ib OFF as opposed to ON?

How do the 2 coatings differ in LIDT?

Microscope images of two identical 32 layer HR45P IAD coatings on BK7



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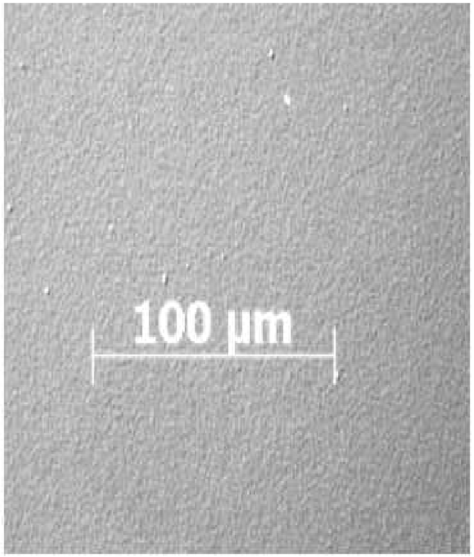
A. 70 °C chamber temperature

Ib ON = ion beam **on** during pause in deposition between layers



055p-08

B. 120 °C chamber temperature

Ib OFF = ion beam **off** during pause in deposition between layers

Tests of Surface Roughness and LIDT of IAD Coatings Depending on Ib ON/OFF and Chamber Temperature

Test Conditions

- Same 32 Layer Coating Design for all Coatings – for HR at 45° AOI, Ppol & 1054 nm
- 1 Non-IAD Coating (on BK7) at 200 °C Chamber Temperature
- 6 IAD Coatings (on Fused Silica)

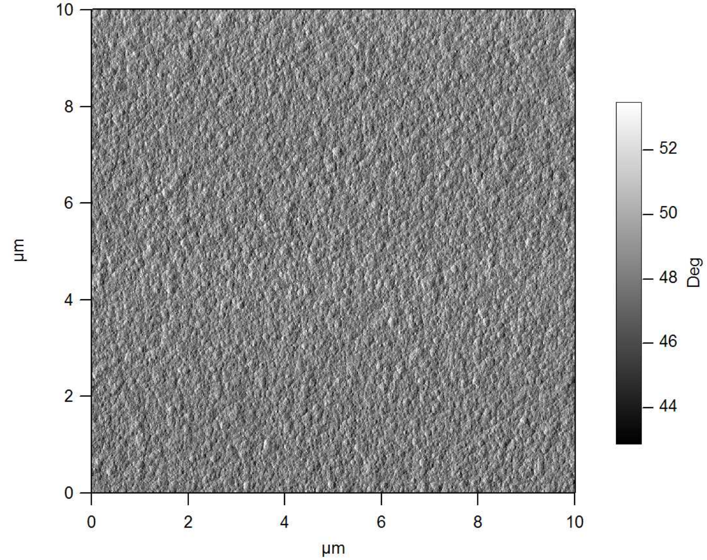
•Chamber Temperatures (°C)	Ion Beam Status During Pause in Deposition Between Layers		
•70	Ib ON	&	Ib OFF
•95	Ib ON	&	Ib OFF
•120	Ib ON	&	Ib OFF

- Atomic Force Microscope (AFM) Measurement of RMS Surface Roughness
- Reflectometer Measurement of R at 45° AOI, Ppol & 1054 nm
- LIDT Test for Each Coating

AFM Measurements

(Advance Materials Laboratory, University of New Mexico and Sandia)

ASYLUM MFP-3D Bio AFM



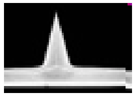
Scanning Parameters:

Scan size: 10x10 um, 1024x1024 points
Scan rate: 1 Hz
Free air amplitude: 2V (~200nm)
Tapping mode amplitude: 1.5 V
Tuning Freq.: -10% off peak

Typical Scanning Phase Image

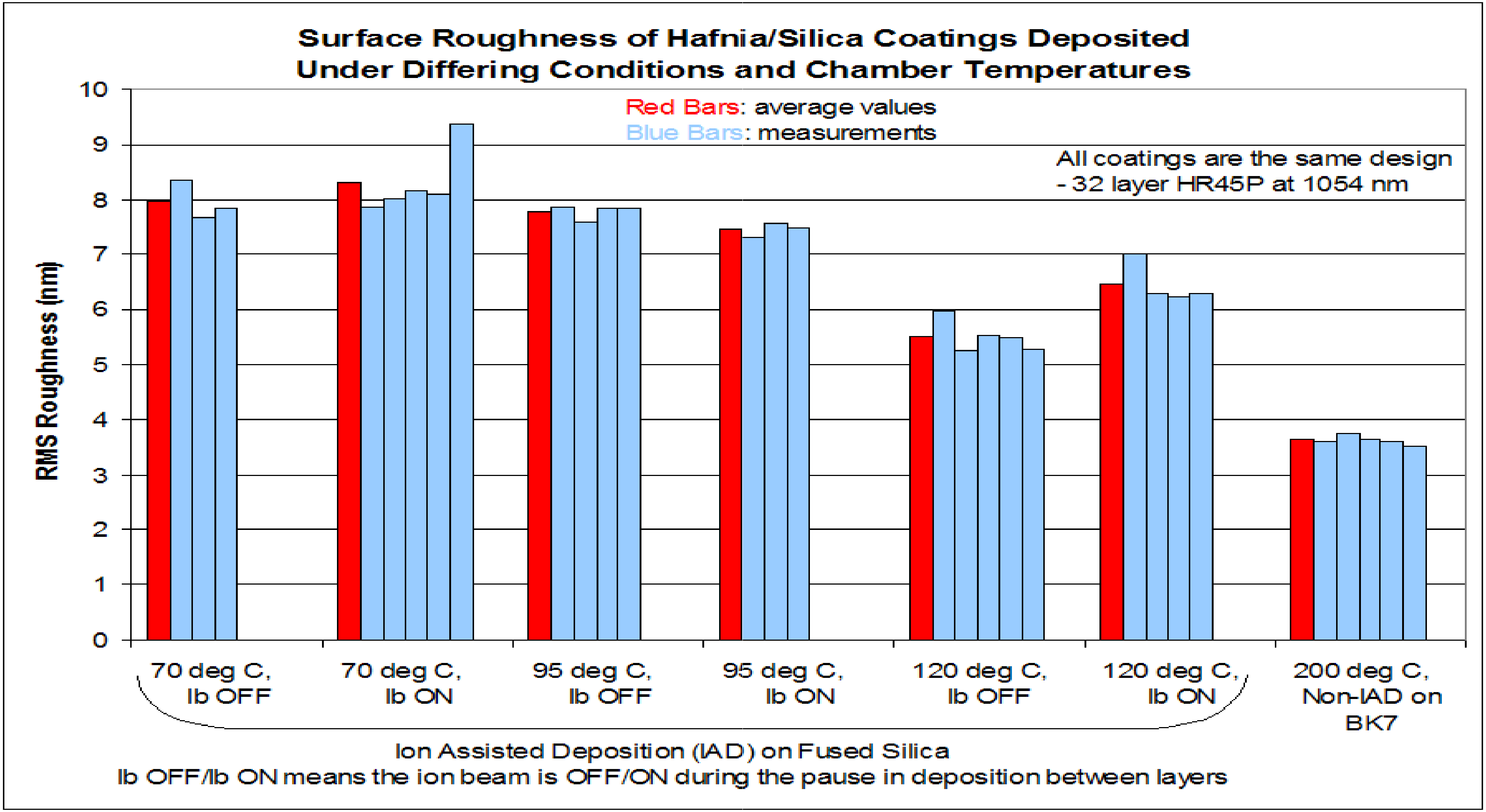
The phase of the cantilever was <90° for all images, indicating absence of contact/off-contact switching

Cantilever Used: AC160TS, purchased from ASYLUM; Tip radius <10 nm



AFM results

Surface roughness lowest with Ib OFF at 120 °C



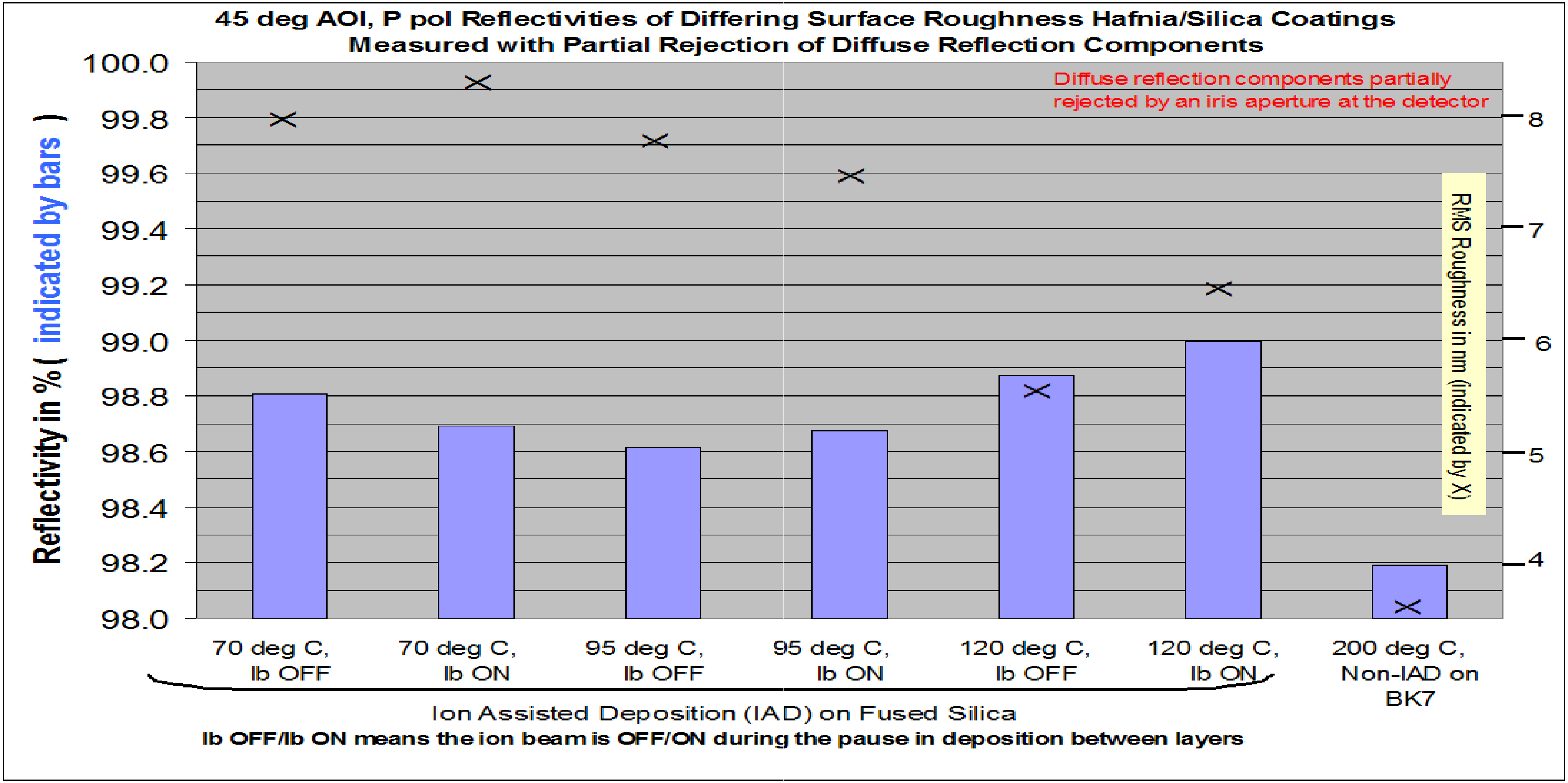
Z Backlighter

Sandia National Laboratories

Reflectometer Results

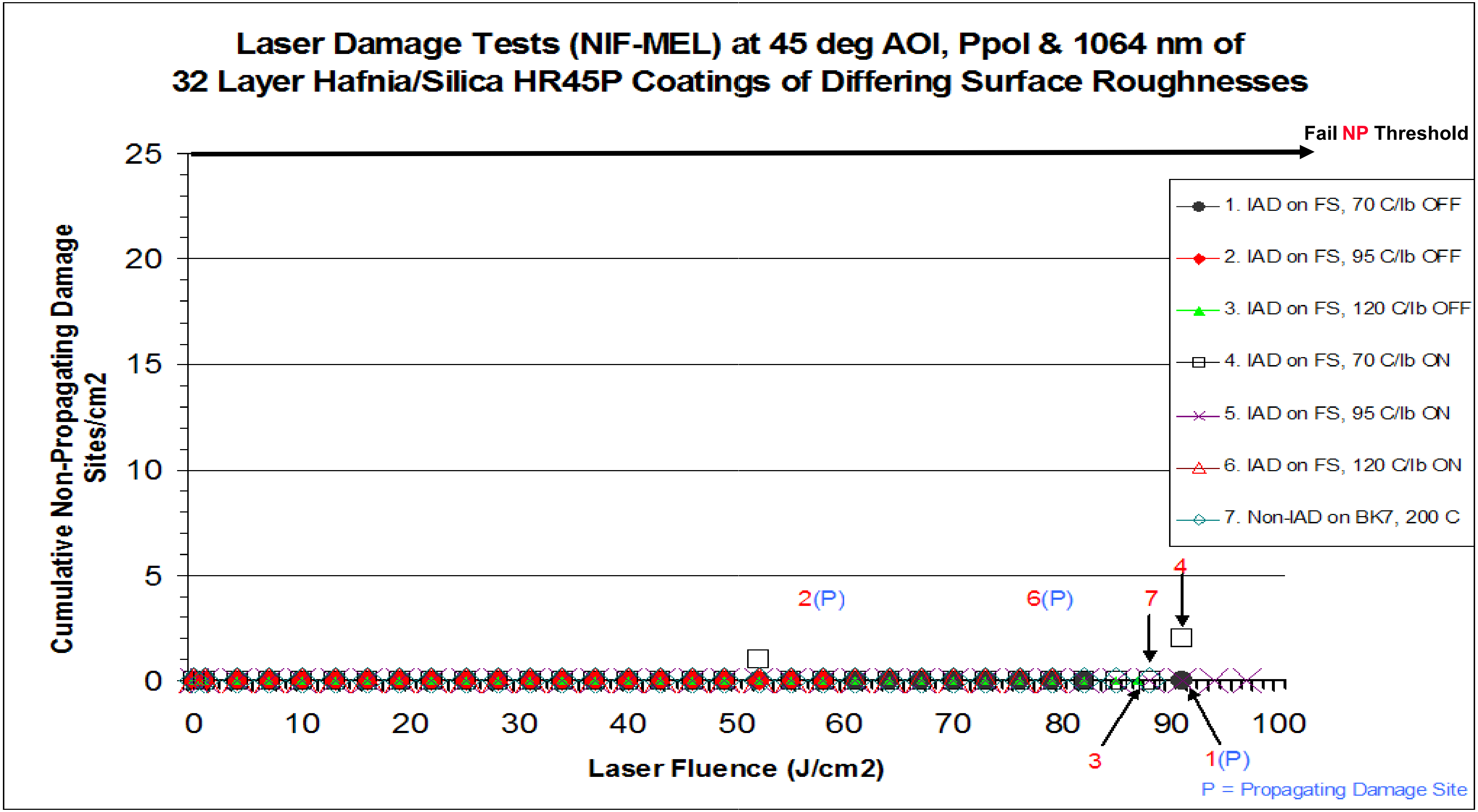
Normal Detection: 1" ϕ detection aperture 10.5" from Point of Incidence

Modified Arrangement: ¼" ϕ iris aperture reduces cone angle of light accepted by detector



Laser Damage Test Results

LIDT of IAD coatings is not affected by chamber temperature or Ib ON or OFF



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The Petawatt Final Optics Assembly (PW FOA) Steering Mirror - a High Reflection, High LIDT Coating Design Challenge

COATING REQUIREMENTS

- Dual Wavelength, Large Range of Angles of Incidence (AOIs), Both S & P Polarizations:

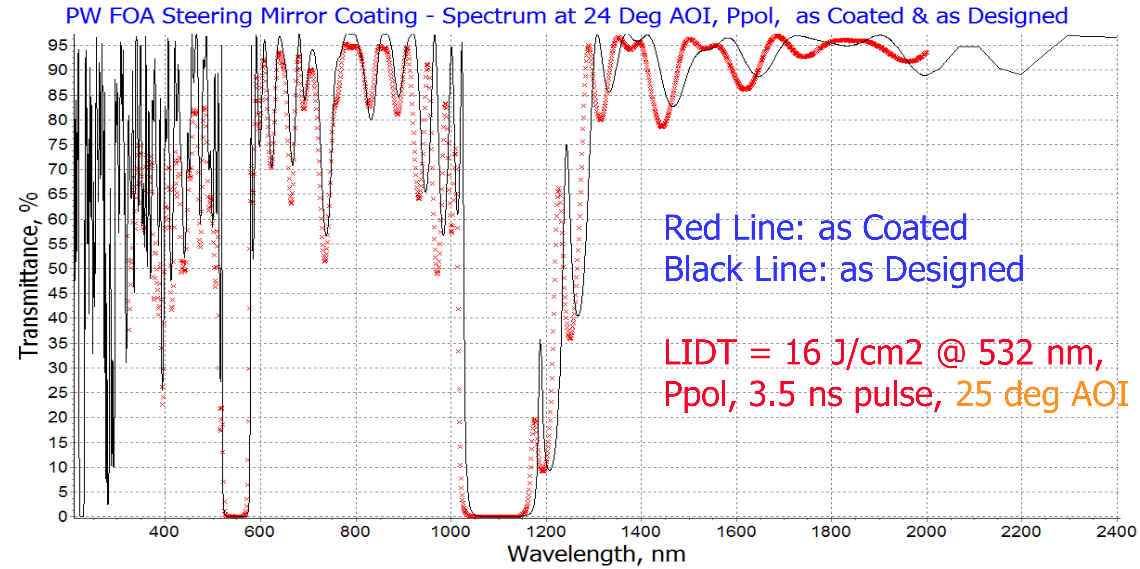
  RSpol & RPpol > 99.6%
  @ 1054nm +/- 6nm (1w)
  & @ 527nm +/- 3nm (2w)
  & AOIs from 24 to 47 degrees

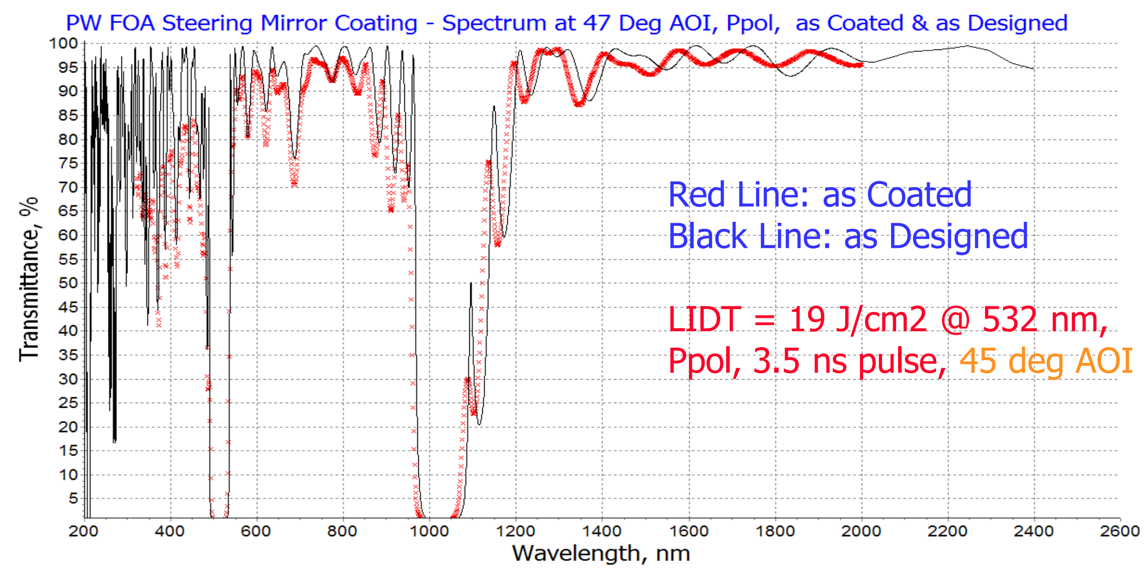
- High LIDTs:

  LIDT > 2 J/cm2 for sub ps pulses @ 1w & > 10 J/cm2 for ns pulses @ 2w

- Success Achieved with a 50 Layer Coating Design

- Sub ps Laser Damage Results are Positive (see Poster 7504-45, 10:40 – 11:40 AM on Tuesday)





PW FOA Steering Mirror, as Coated

- **Very high Dollar, 75 cm diameter Fused Silica substrate**

  - optic weight ~ 200 lb

  - sculpted back surface

- **50 layer IAD coating**