



# The Impact of Contamination and Aging Effects on the Long Term Laser Damage Resistance of SiO<sub>2</sub>/HfO<sub>2</sub>/TiO<sub>2</sub> High Reflection Coatings for 1054 nm

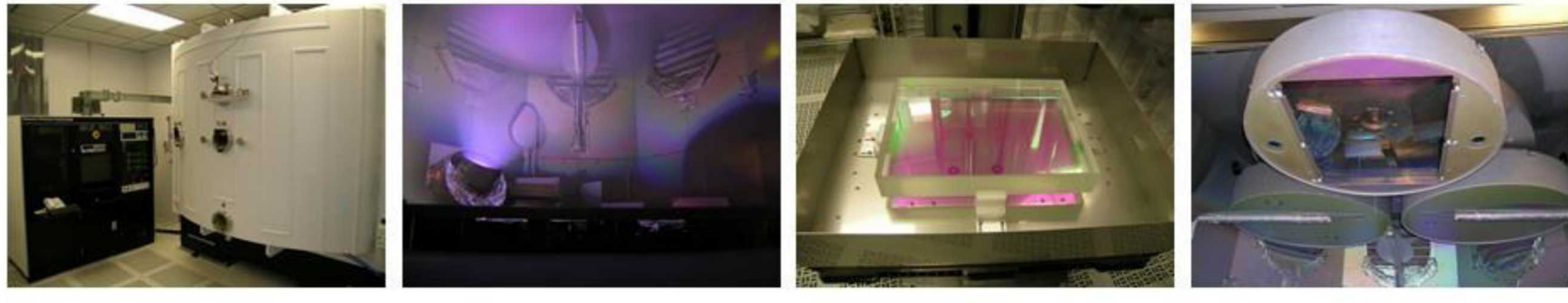
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SPIE Laser Damage, September 24, 2018

## Sandia's Large Optics Coating System

Provides [high laser damage resistant optical coatings](#) for large optics in support of Z-Backlighter terawatt/petawatt laser operations

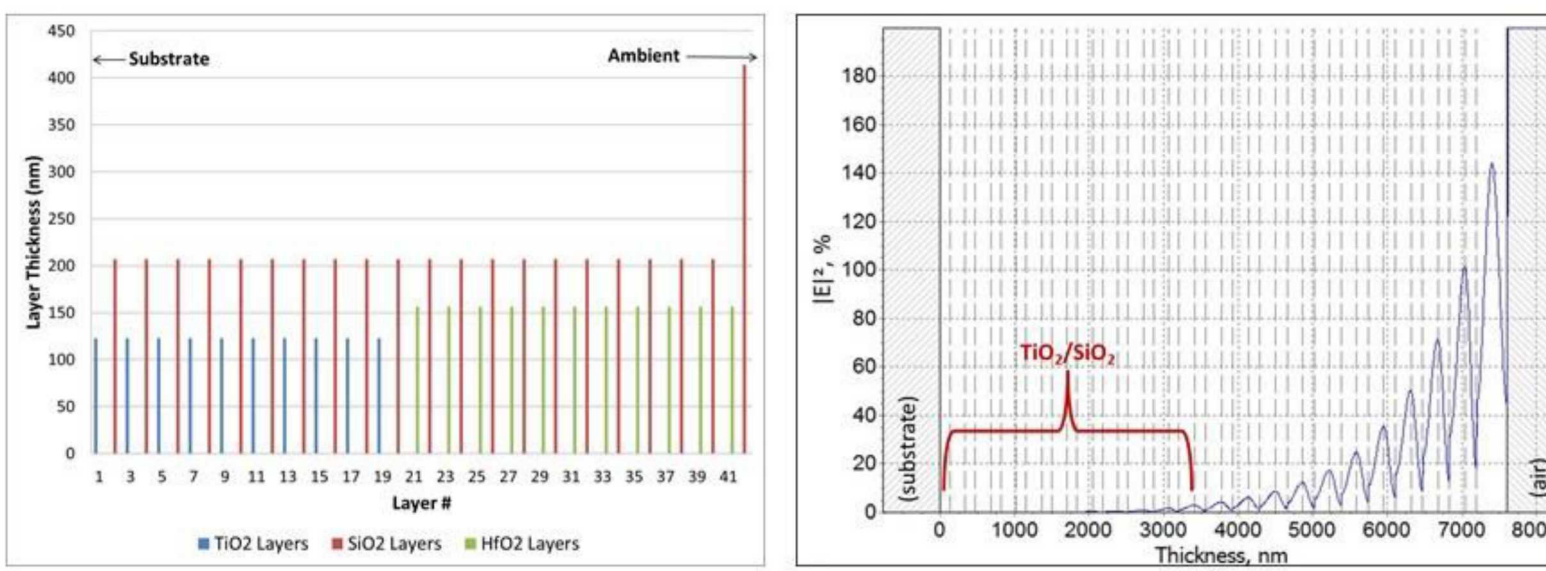
### Key Features:

- 2.3 m X 2.3 m X 1.8 m coating chamber in Class 100 clean room (94 – 120 cm optics)
- E-beam deposited coatings (mostly hafnia/silica layer pairs) with or without ion-assisted deposition (IAD)
- 3 e-beam sources for thin film materials
- Process control based on crystal sensor monitoring of thin film layers
- 50 – 100 anti-reflection (AR) coated debris shields & vacuum windows needed by backlighting operations per year, plus high reflection (HR) and polarizer coatings



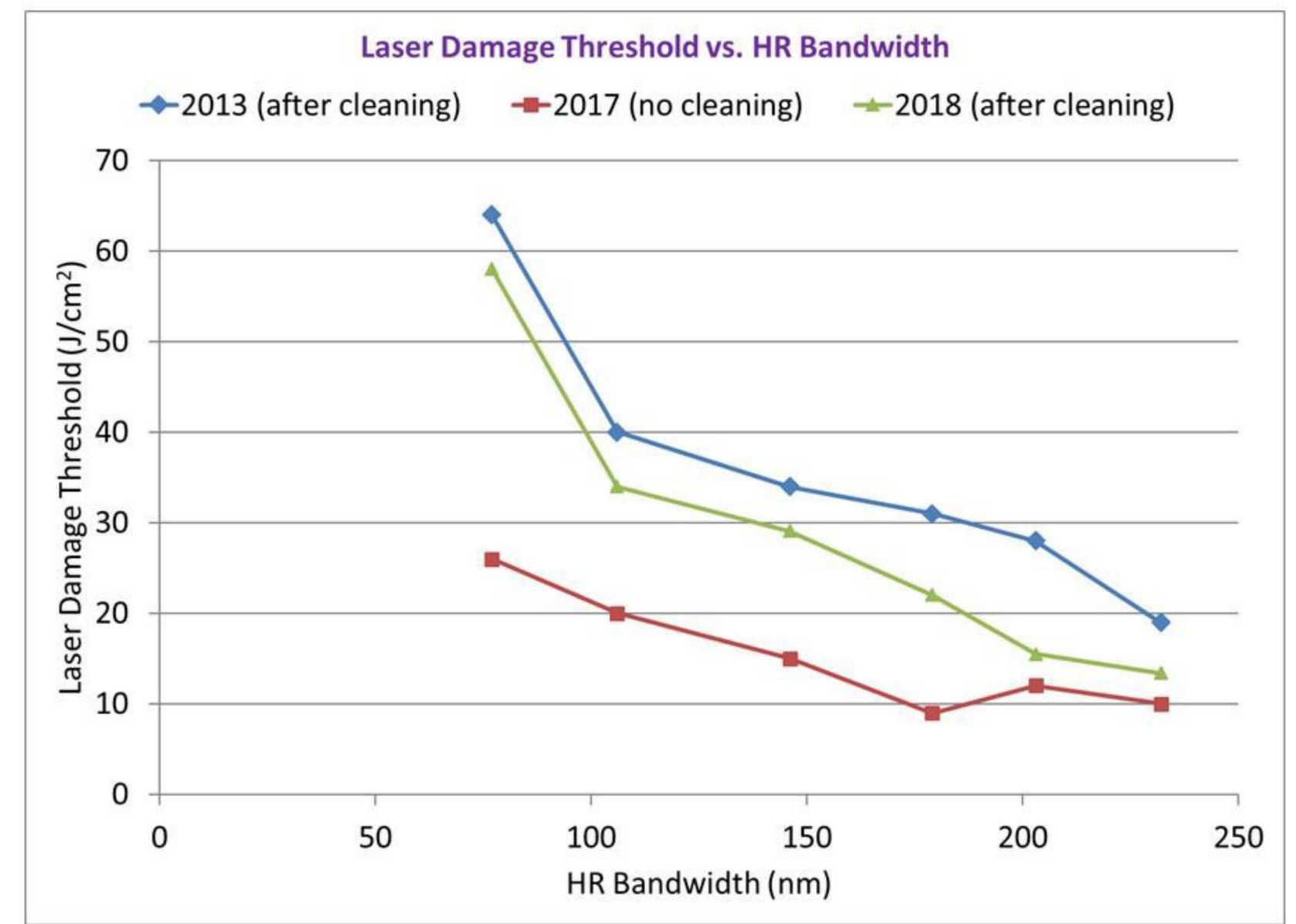
## Why Replace Inner HfO<sub>2</sub> Layers with TiO<sub>2</sub>

- Electric field intensity is lower near the substrate:

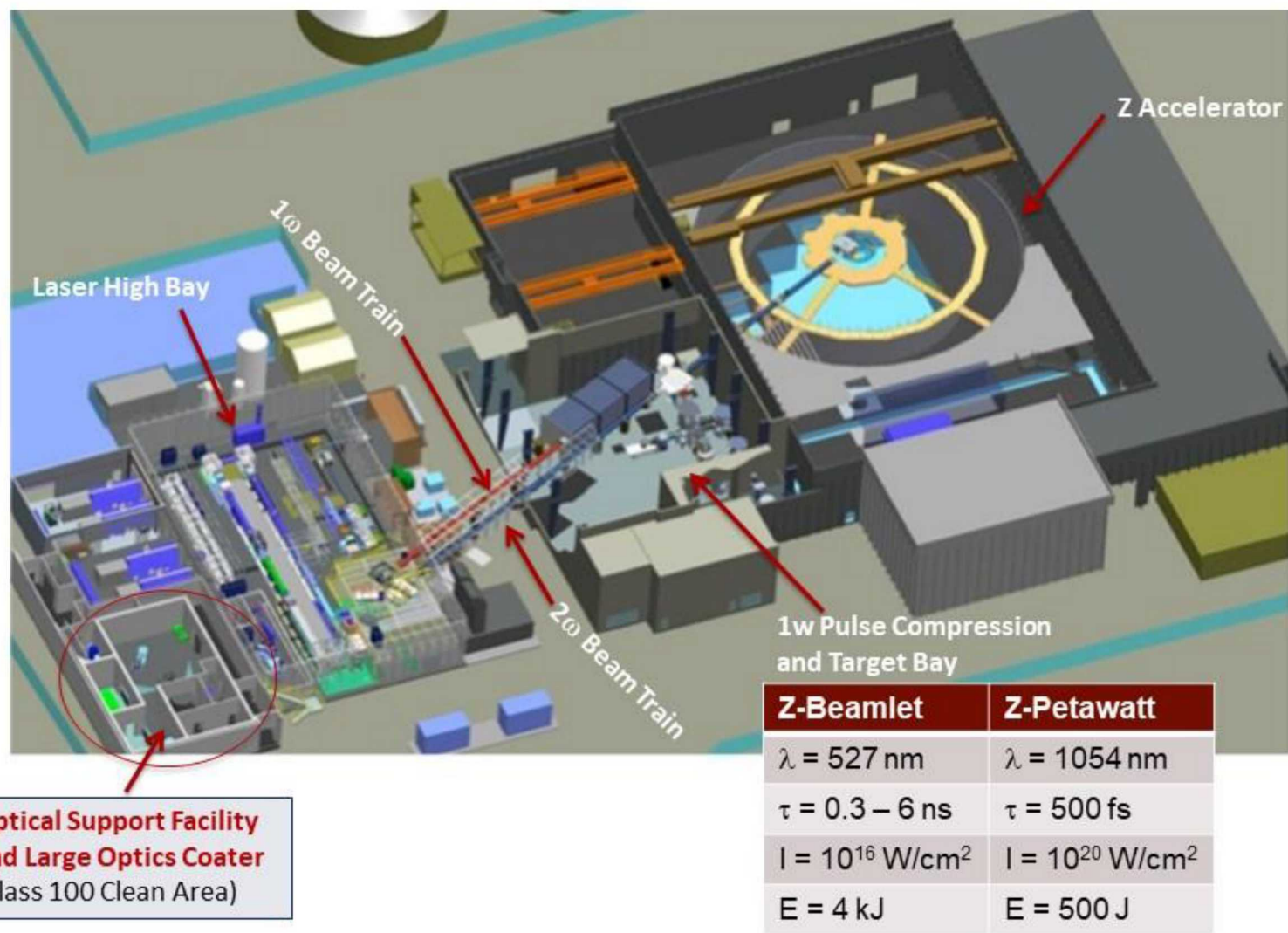


Layer thicknesses of 42-layer coating containing 10 TiO<sub>2</sub> inner layers.

Electric field intensity of coating containing 10 TiO<sub>2</sub> inner layers at 1054 nm, 45° AOI, P-pol. Vertical dashed lines indicate layer boundaries.



## 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



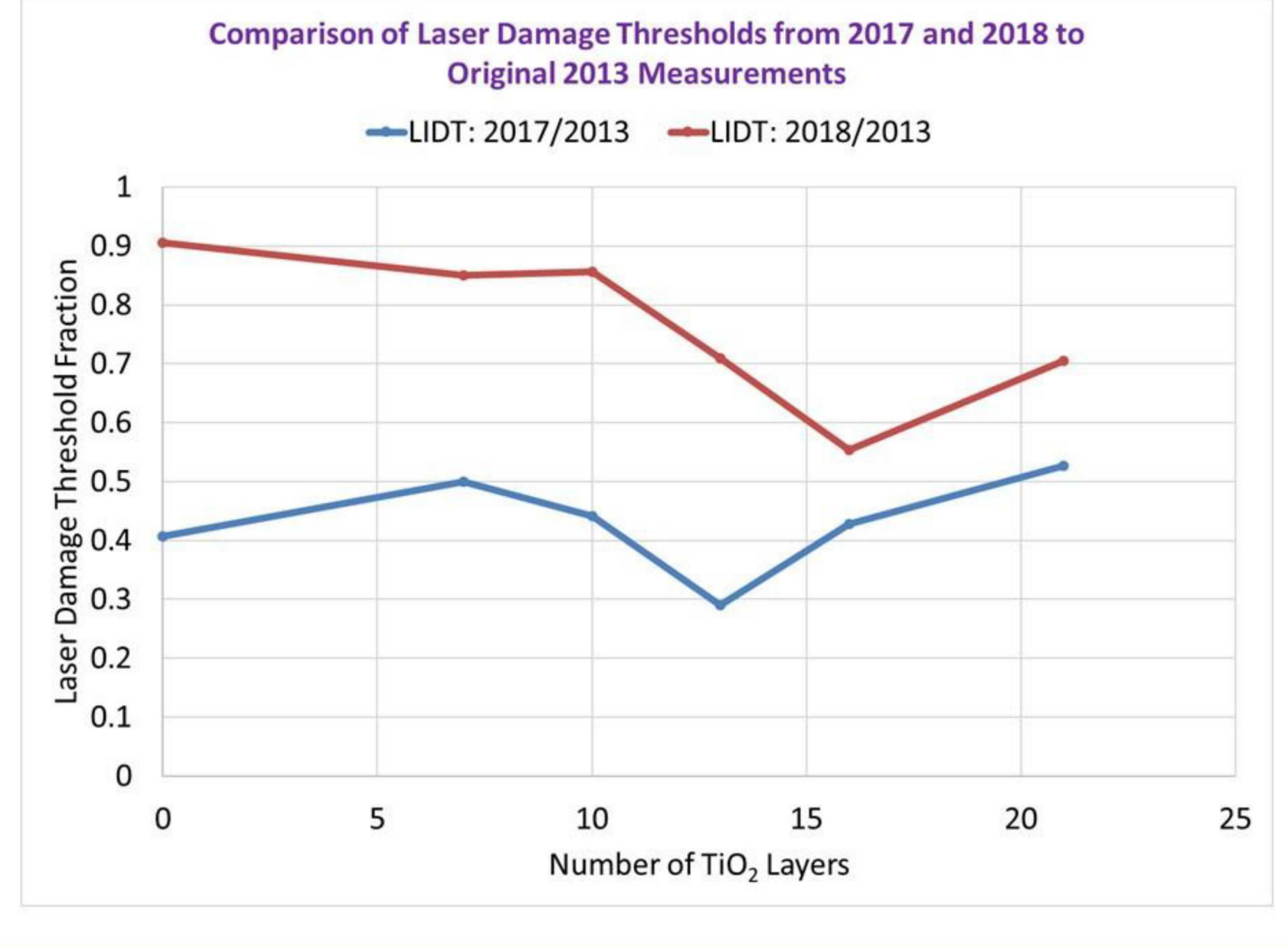
Optical Support Facility and Large Optics Coater (Class 100 Clean Area)

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

## Experimental Setup

- Substrate preparation:
  - 2" diameter X 0.5" thick optically polished fused silica substrates cleaned with Micro 90 detergent, Baikolox alumina slurry, and deionized water
  - Our standard cleaning process: Field, et al, "Impact of different cleaning processes on the laser damage threshold of antireflection coatings for Z-Backlighter optics at Sandia National Laboratories" Opt. Eng. 53 (12) 122516 (2014).
- Ion-Assisted Deposition process:

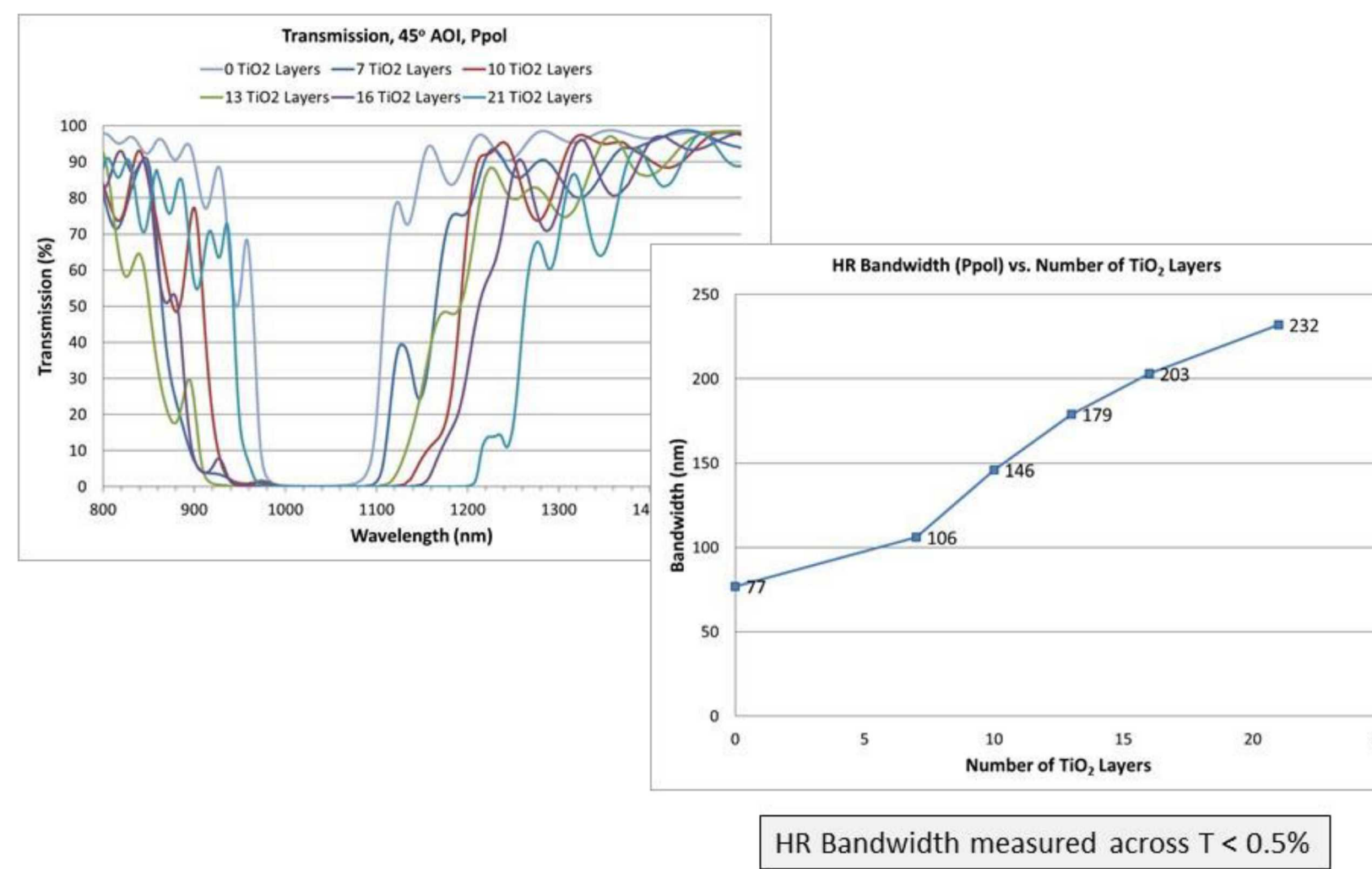
	Starting material	Deposition rate (Å/s)	Ion beam current (mA)	Ion beam voltage (V)	Ar neutralizer flow (sccm)	Ar flow (sccm)	O <sub>2</sub> flow (sccm)
SiO <sub>2</sub>	1-3 mm granules	7	425	400	6	25	25
HfO <sub>2</sub>	Hf Shavings	3	600	400	7	0	45
TiO <sub>2</sub>	Ti 2-3 mm granules	3	600	400	7	0	45



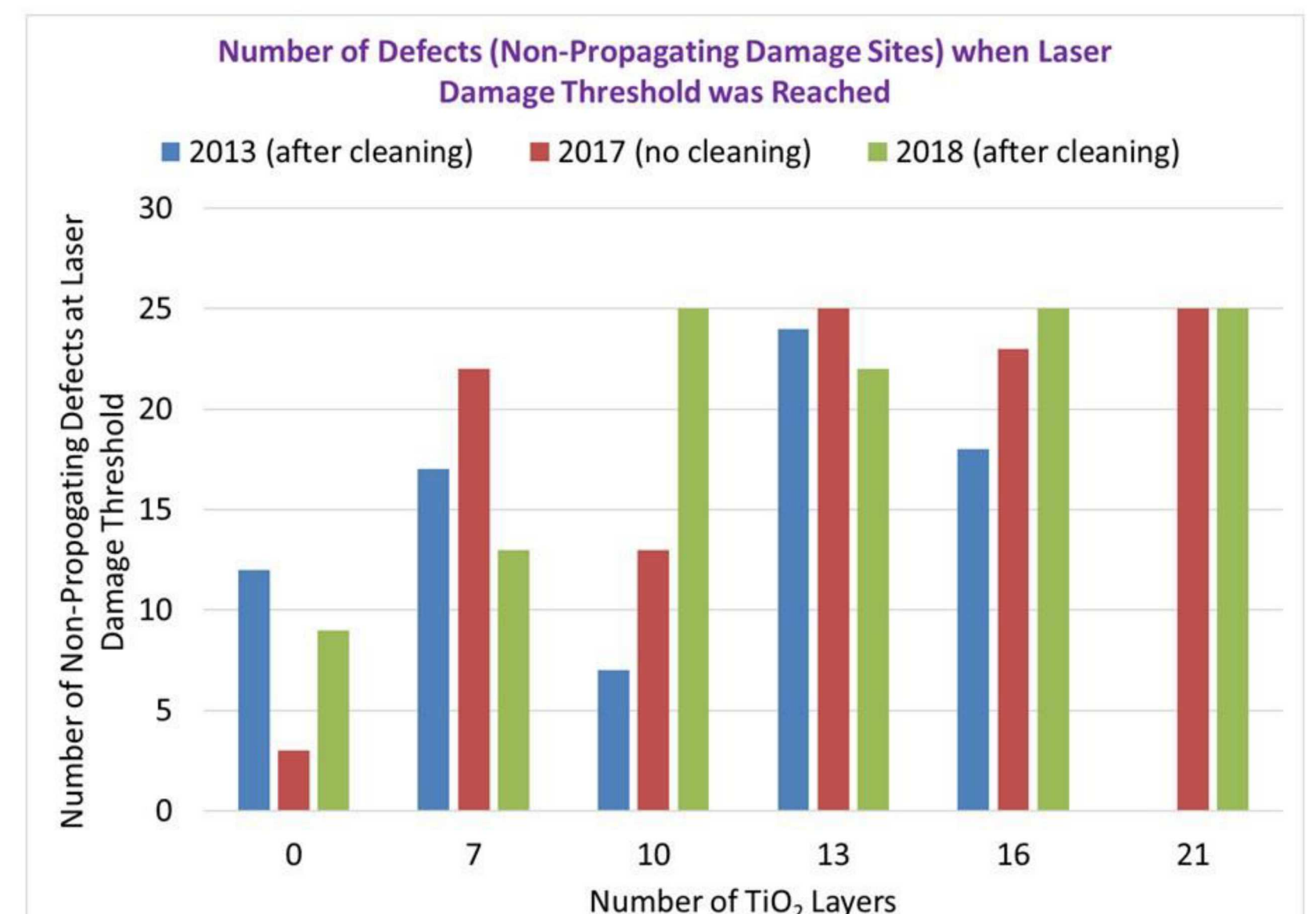
## History of Hafnia/Titania/Silica Optical Coatings at Sandia

- Our usual coatings contain HfO<sub>2</sub> and SiO<sub>2</sub> layers; TiO<sub>2</sub> introduced in 2013 to address new coating challenges:
  - Increase the high reflection bandwidth of mirrors to improve angle-of-incidence flexibility, and compensate for spectral shift due to water absorption
  - Create mirrors for fs-pulses
- The laser damage threshold of TiO<sub>2</sub> can degrade over time:
  - "...the damage thresholds of three identical SiO<sub>2</sub>/TiO<sub>2</sub> HR coatings were measured soon after coating and again after storage for 1 year in a normal laboratory environment. The thresholds of two of these coatings had decreased by one-half after aging but were restored to the original value by baking at 275° C for 4 h. The threshold of the third sample was not changed by aging nor was it improved by baking." – W.H. Lowdermilk, et al, "Optical Coatings for Laser Fusion Applications" *Thin Solid Films*, 73 (1980).
- Due to laser damage degradation concerns, in 2017 we re-measured the laser damage thresholds of HfO<sub>2</sub>/TiO<sub>2</sub>/SiO<sub>2</sub> coatings that we produced in 2013 to compare aging effects between HfO<sub>2</sub> and TiO<sub>2</sub>. In 2018, the coatings were washed and laser damage thresholds were measured again.

## Transmission Measurements

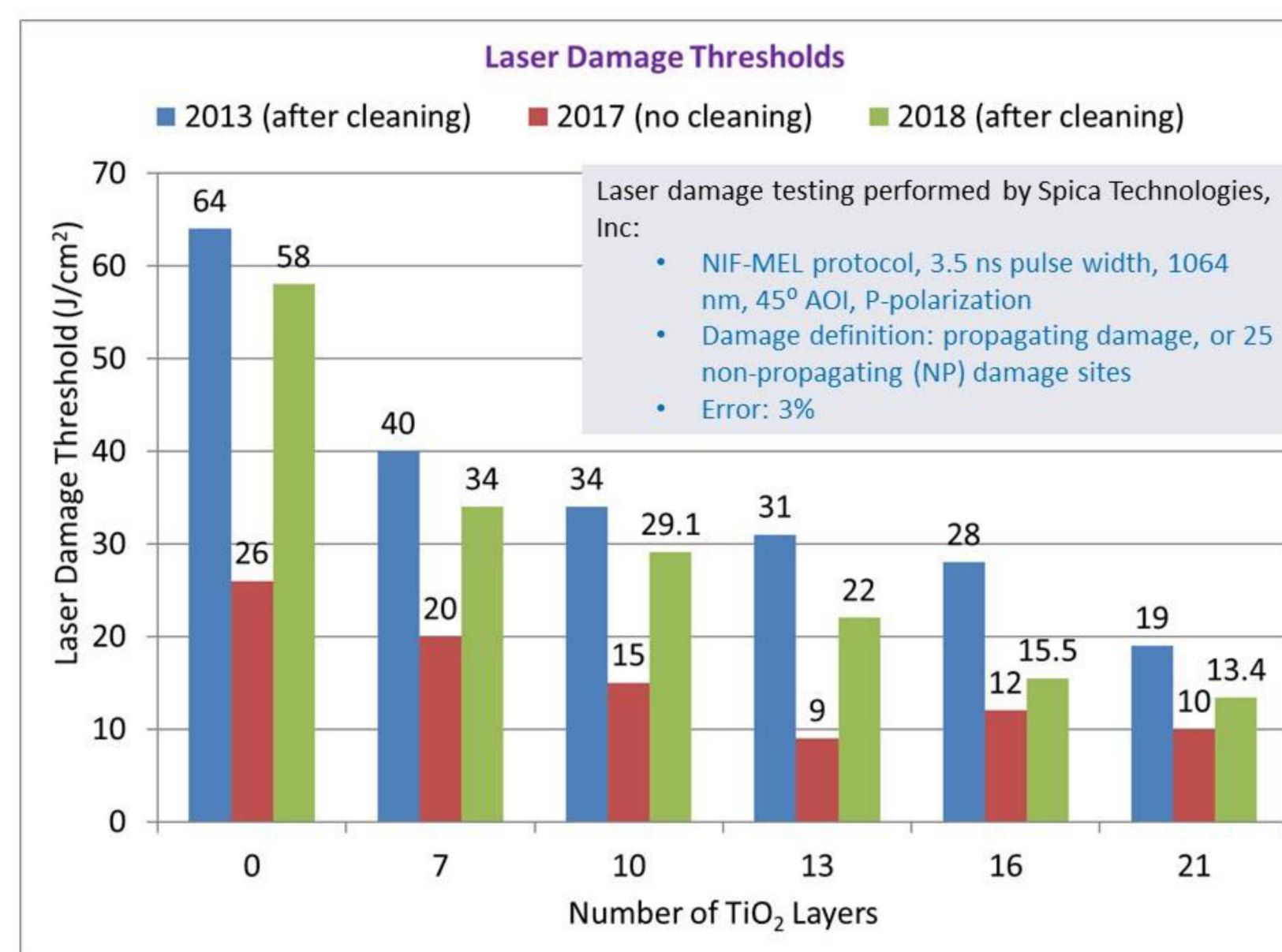


HR Bandwidth measured across T < 0.5%



## HfO<sub>2</sub>/TiO<sub>2</sub>/SiO<sub>2</sub> Coating Designs

- 42-layer quarter wave stack design
  - 1054 nm
  - 45° AOI
  - P-polarization
  - Outer layer is 1/2 wave SiO<sub>2</sub> for improved resistance to laser damage
- Started with HfO<sub>2</sub>/SiO<sub>2</sub> coating and replaced some inner HfO<sub>2</sub> layers with TiO<sub>2</sub>:
  - Coatings contain 0, 7, 10, 13, 16 and 21 TiO<sub>2</sub> layers
  - TiO<sub>2</sub> layers: higher index, lower band gap increases HR bandwidth but decreases LIDT
  - HfO<sub>2</sub> layers: lower index, higher band gap increases LIDT but decreases HR bandwidth



## Conclusions

- The laser damage threshold specifications for optics depends on more than just the laser energy involved. In this case, it also depends on how the coatings age.
  - The cause of the degradation may depend on a number of factors, including the coating technology, optics storage, and cleaning methods.
  - A higher laser damage threshold specification is required to compensate for degradation
- Cleaning the optics in 2018 did not fully restore the laser damage thresholds to their original values, however the coatings containing a higher proportion of HfO<sub>2</sub> layers suffered the least amount of degradation.