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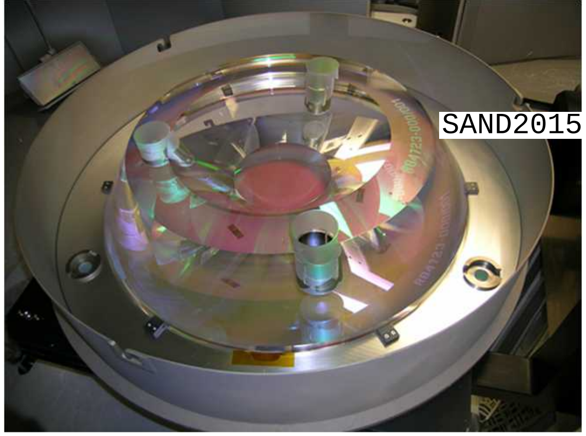
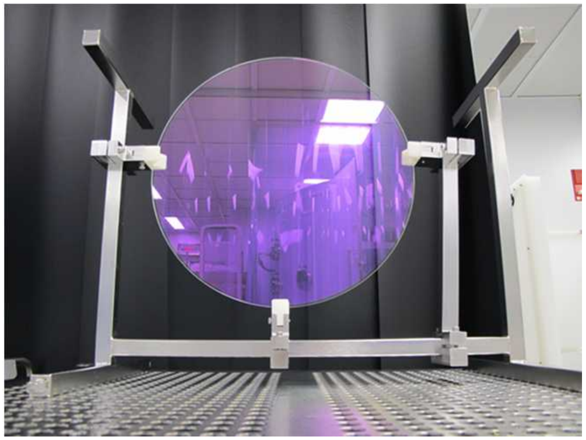


Cleaning protocols for increased laser damage resistance of antireflection coatings

Ella Field, John Bellum, Damon Kletecka

Presented at the Mini-Symposium on The Interaction of High Power Lasers with Optical Materials, University of New Mexico, Feb. 17, 2015



ZBacklighter

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Status of Cleaning Protocols

- **Challenges…**
  - There are no industry standards
  - Some protocols are proprietary
  - Non-automated protocols rely on skill of the worker: consistent results not always possible
  - Application specific: cleaning protocols suitable for one application may not be suitable for another
  - Contamination specific: cleaning protocols that effectively remove one type of contamination may not remove others
  - Many protocols exist, but arriving at the best one for a specific application can be a long trial-and-error process

- **Achieving high laser damage thresholds is dependent on proper cleaning, however…**
  - Many papers publish damage thresholds but not the cleaning methods

Cleaning optics for the Z-Backlighter lasers

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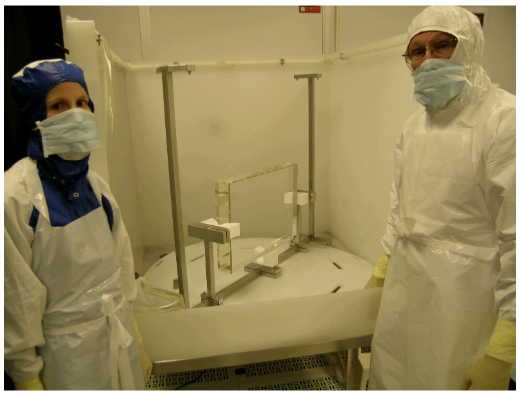
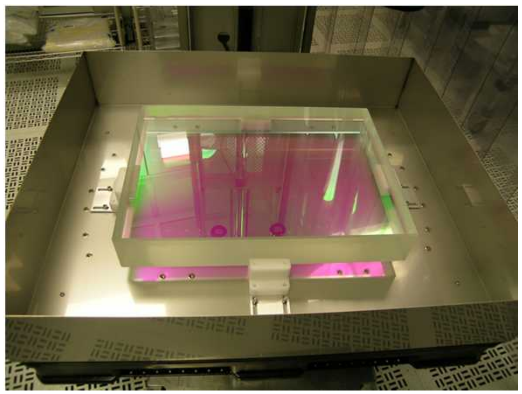
- **High fluence, high damage threshold:** The Z-Backlighter lasers at Sandia National Laboratories are kilojoule class, pulsed systems operating with ns pulse lengths at 527 nm (100 TW) and ns and sub-ps pulse lengths at 1054 nm (1 PW). The optical coatings must have high laser-induced damage thresholds (LIDT) to withstand the powerful fluences from the Z-Backlighter lasers.

- **High volume:** Each year, we provide antireflection (AR) coatings for ~50 debris shields, in addition to other AR, high reflection (HR), and polarizer coatings for numerous other meter-class Z-Backlighter optics.
- **Manual effort:** Meter-class optics are manually cleaned before and after the optical coating is deposited – but cleaning optics manually is a time consuming process, and results may vary depending on who the washer is.

Multiple stages of cleaning

- Cleaning the optics **before** and **after** the optical coating is deposited to ensure:

- Contamination on the substrate is removed before the coating is deposited

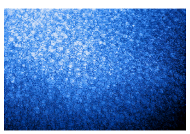
- Contamination on the optical coating is removed before the optic is installed in the beam train

This is the focus of our study

Our standard cleaning methods

- Before the substrate has been coated:

  1. **Rinse:** Clean each side of the substrate by first rinsing with deionized (DI) water while lightly wiping with a wiper (Texwipe model # TX1109) to remove large particles.
  2. **Detergent wash 1:** Vigorously wash each side of the substrate with a DI water soaked wiper and mild detergent (Micro 90, which is diluted to a ratio of roughly 10:1 by volume of DI water to detergent). Micro 90 removes organic, oily residue. Then rinse away the Micro 90 with DI water.



  3. **Slurry wash:** Vigorously wash both sides with a DI water soaked wiper and Baikalox. Baikalox is a slurry of <0.05 μm alumina particles that can remove particles left behind in the substrate surface microstructure from the glass polishing compound.
  4. **Detergent wash 2:** Rinse the substrate with DI water and vigorously wash both sides of the substrate again with Micro 90 and a DI water soaked wiper to remove any Baikalox that did not rinse away.
  5. **Final Rinse:** Scrub the substrate vigorously using a wiper with copious flow of just DI water to help remove any other particles and residues that remain.

- After the substrate has been coated:
  - Repeat the cleaning steps shown above, but omit steps 3 and 4 because Baikalox could mar the surface of the optical coating.

Comparing our standard cleaning method to others for coated optics;

We have compared the LIDTs of 4 coated optics that were cleaned using different methods

Experimental Setup:

- **Clean substrates:** prior to coating, all substrates were cleaned using our standard method
  - Substrates: 50 mm diameter, 10 mm thick fused silica
- **Coat substrates, side 1:** all substrates were coated at the same time with the same AR coating (1064 nm and normal angle of incidence) on both sides using e-beam evaporation of SiO_2 and HfO_2 (reactive evaporation of Hf and O_2)
- **Clean substrates, coat side 2:** after the first AR coating was deposited, the substrate was cleaned again using our standard method, and then side 2 was coated
- **Final cleaning tests:** each coated substrate was cleaned using a different final cleaning method
- **LIDT tests:** NIF-MEL protocol on side 1 and side 2
- **Effects of aging:** The original LIDT tests were performed in December, 2013. Afterward, the optics were stored in PETG containers. At the end of March 2014, we performed the final cleaning tests again, and tested the LIDT again in April 2014.

AR coating design: 1064 nm at normal incidence

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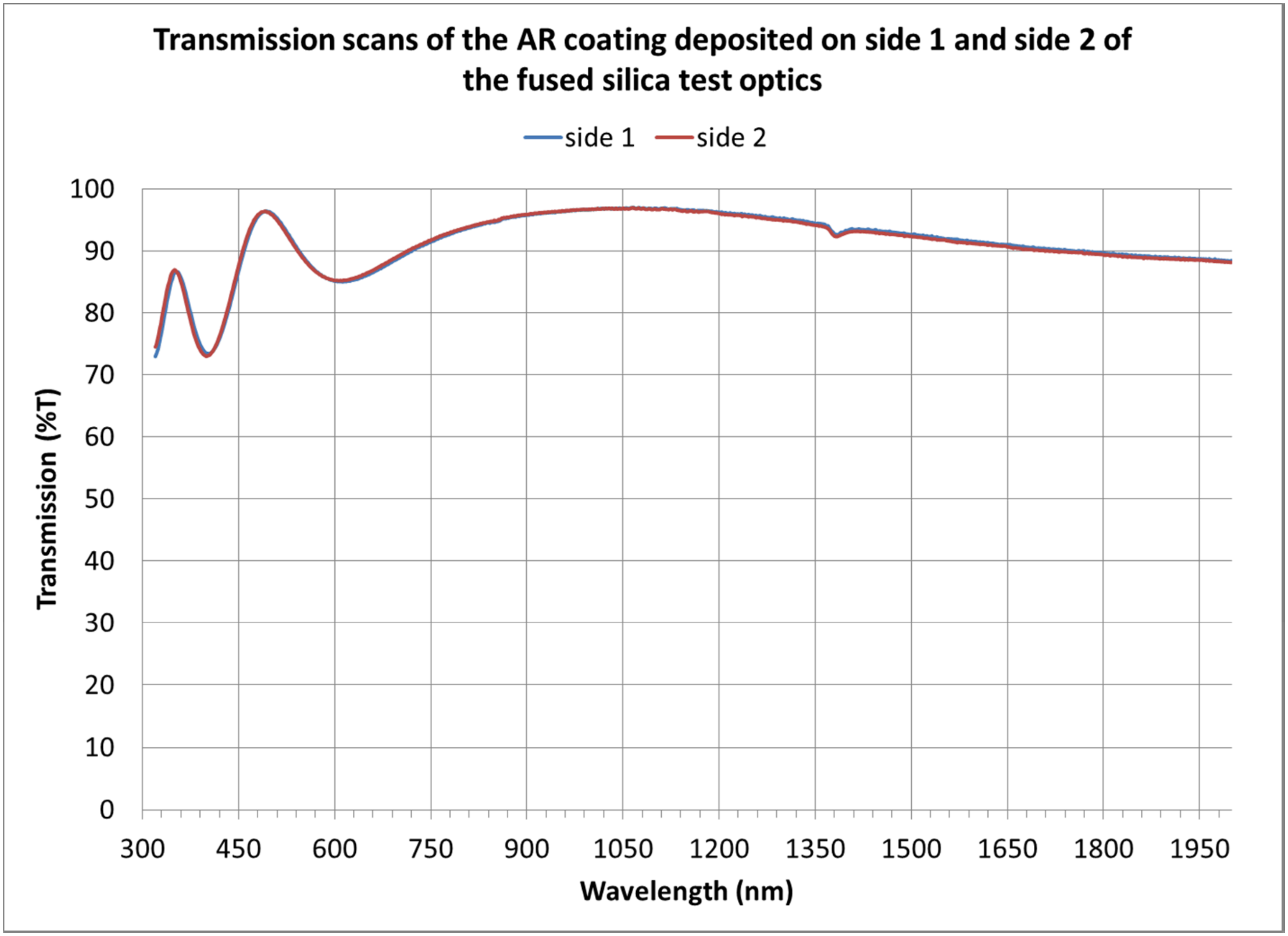


The test optics were coated at the same time as a Z-Backlighter lens

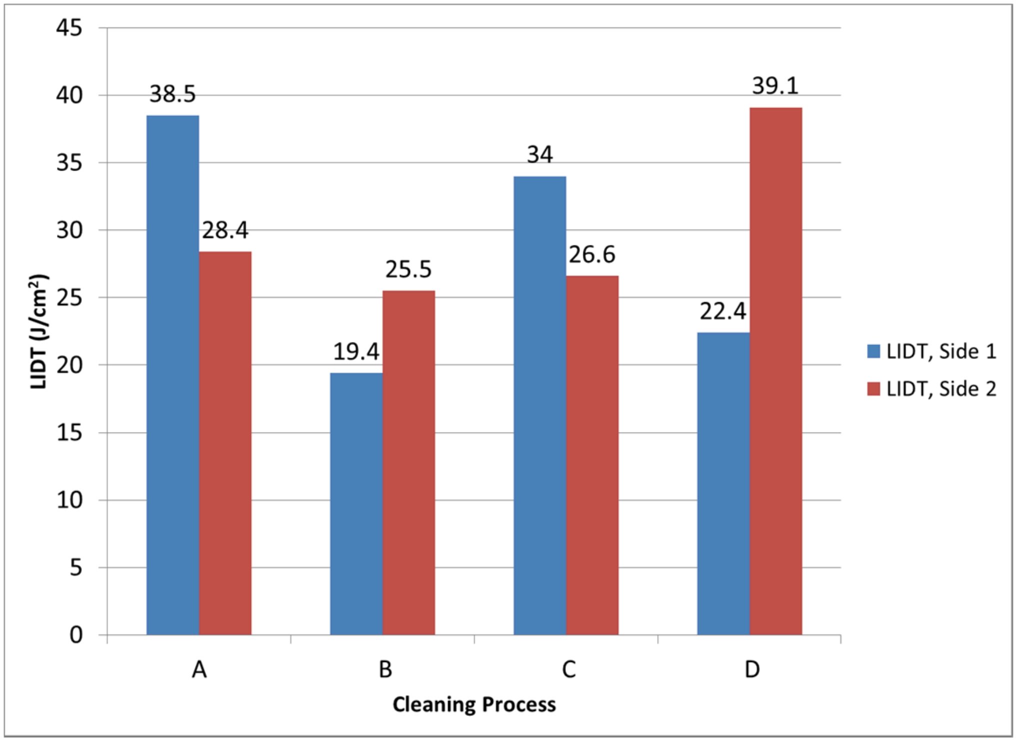
Final cleaning tests on the coated optics

A	B	C	D
Our standard cleaning method: clean optic vigorously with Micro 90 detergent and deionized water	No cleaning	Soak optic in a 1:1 by volume mixture of ethyl alcohol and deionized water*	Soak optic in a 1:1 by volume mixture of ethyl alcohol and deionized water*, and then finish by cleaning the optic vigorously with Micro 90 detergent and deionized water

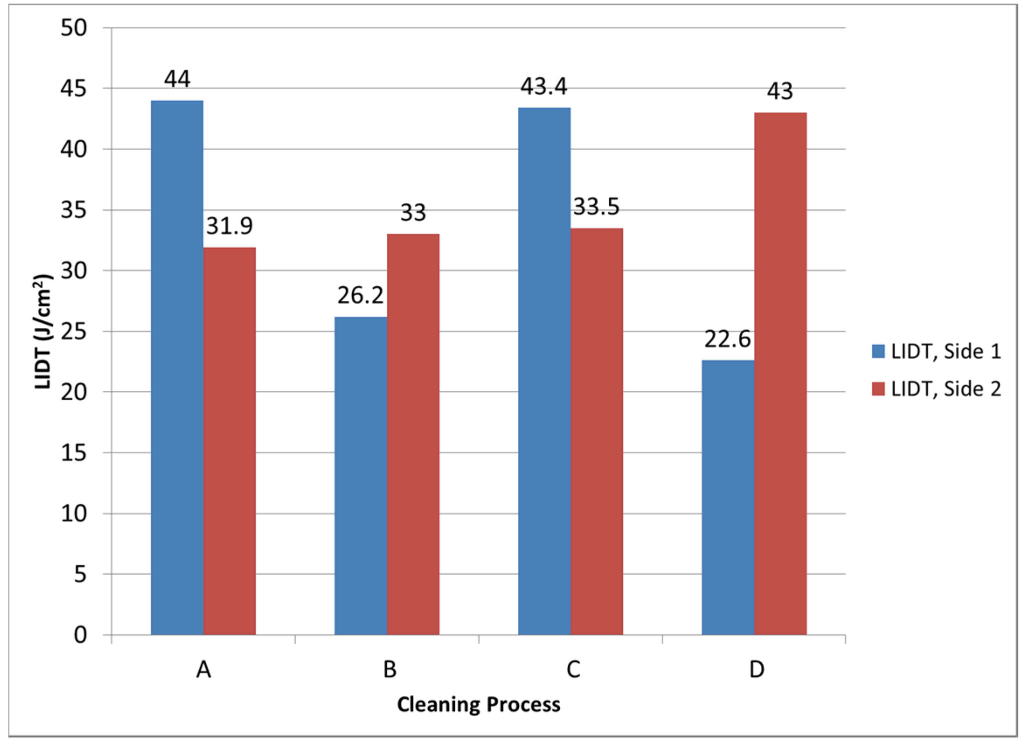
* **This method is based on the work by H. Murakami and T. Jitsuno, et al, which helps to remove oil contamination from coated optics.**
H. Murakami, et al, "Influences of oil-contamination on LIDT and optical properties in dielectric coatings," Proc. of SPIE Vol. 8530 853024-1, 2012.

Laser damage test results

December 2013



April 2014

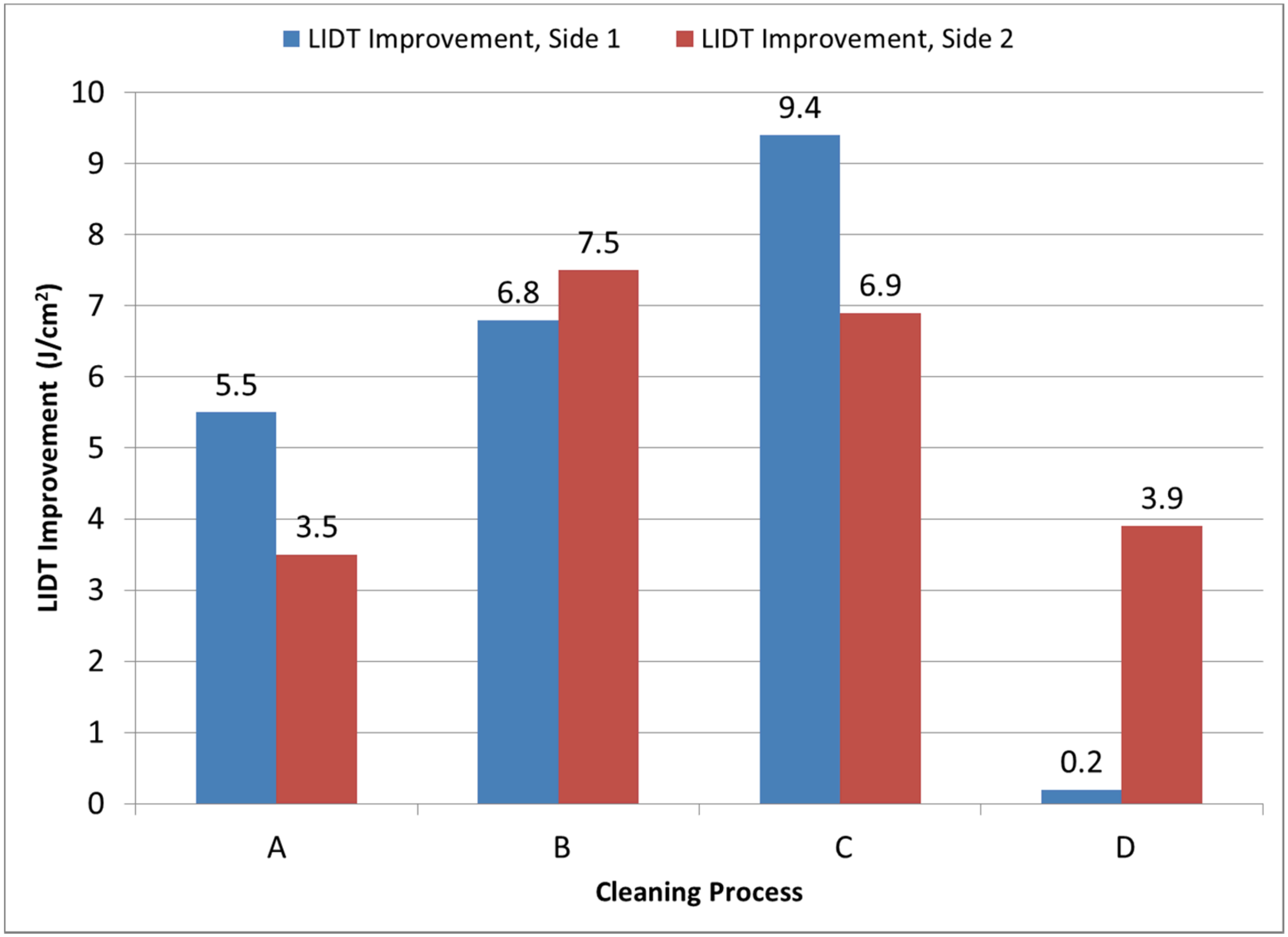


- Highest LIDTs obtained for optics cleaned with Micro 90 detergent and/or alcohol/deionized water
- Side 1 of optic D had defects that lowered the damage threshold. These defects caused propagating damage on side 1 during the LIDT test of side 2 in April. In accordance with NIF-MEL protocol, the LIDT test was discontinued. The LIDT of side 2 is likely higher than reported.

NIF-MEL LIDT test protocol:

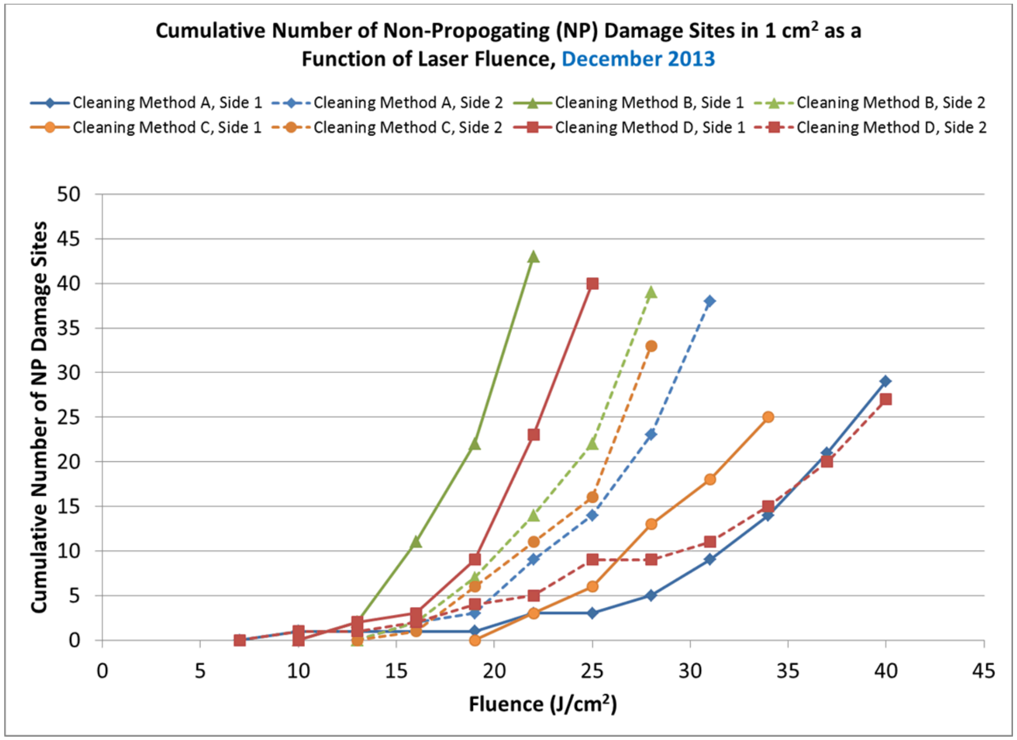
- 3.5 ns pulse width, normal incidence
- Damage definition: propagating damage, or 25 non-propagating damage sites
- Performed by Spica Technologies, Inc.

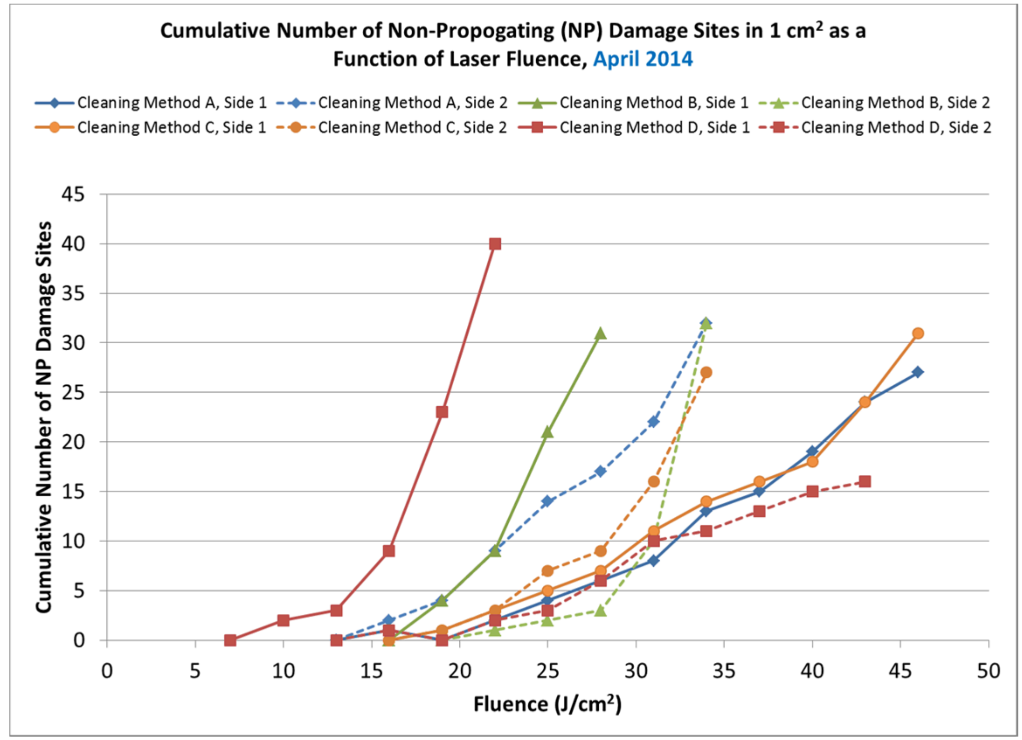
LIDTs improve as coatings age



LIDT Improvement = LIDT (Apr. 2014) – LIDT (Dec. 2013)

Number of damage sites vs. laser fluence





- None of the coatings reached their LIDT due to propagating damage sites, except for the flawed side 1 of optic D
- Damage that propagates tends to be intrinsic, governed by how the laser field interacts directly with the coating molecules, rather than contamination. Therefore, cleanliness of the optics and/or nodules/pits in the coatings directly affected the LIDTs of the coatings presented here
  - Improving the cleanliness and/or quality of the coatings should result in even higher LIDT results

The importance of cleaning…

- **The LIDTs are highest** for cleaning with the alcohol/deionized water soak and/or Micro 90 detergent
    - **Comparable results obtained from completely different cleaning methods.** Cleaning with alcohol/deionized water can lead to similar increase in LIDT as cleaning with detergent. However, the highest LIDTs can be obtained by applying both cleaning methods to the same optic.
- **The LIDTs are lowest** for skipping the final cleaning step
- All LIDTs improved as the coatings aged over 4 months
- This work reported in:

Field, Bellum, Kletecka, "Impact of different cleaning processes on the laser damage threshold of antireflection coatings for Z-Backlighter optics at Sandia National Laboratories" *Optical Engineering* 53 (12), 2014

Thank you!

- Questions?