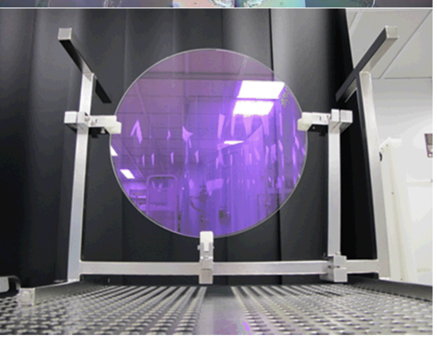

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SAND2015-3881C

Analysis of Laser Damage Tests on a Coating for Broad Bandwidth High Reflection of Femtosecond Pulses

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SPIE/SIOM Pacific Rim Laser Damage 2015, May 20, 2015, Shanghai, China

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Petawatt (PW) class laser pulse regimes and broad bandwidth high reflection (BBHR) requirements

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pulse duration ($\Delta\tau$) versus frequency range ($\Delta\nu$) and bandwidth ($\Delta\lambda$)

$$\Delta\tau = 1/\Delta\nu \qquad \Delta\lambda = (\lambda^2/c)\Delta\nu \qquad \text{(c = speed of light)}$$

Example for λ = 900 nm:

$\Delta\tau$	$\Delta\nu$ (10^9Hz)	$\Delta\lambda$ (nm)
1 ns	1	0.0027 nm
100 ps	10	0.027 nm
10 ps	100	0.27 nm
1 ps	1000	2.7 nm
100 fs	10000	27 nm
10 fs	100000	270 nm

Range of pulse durations for high intensity PW lasers (100 fs – 10 fs)

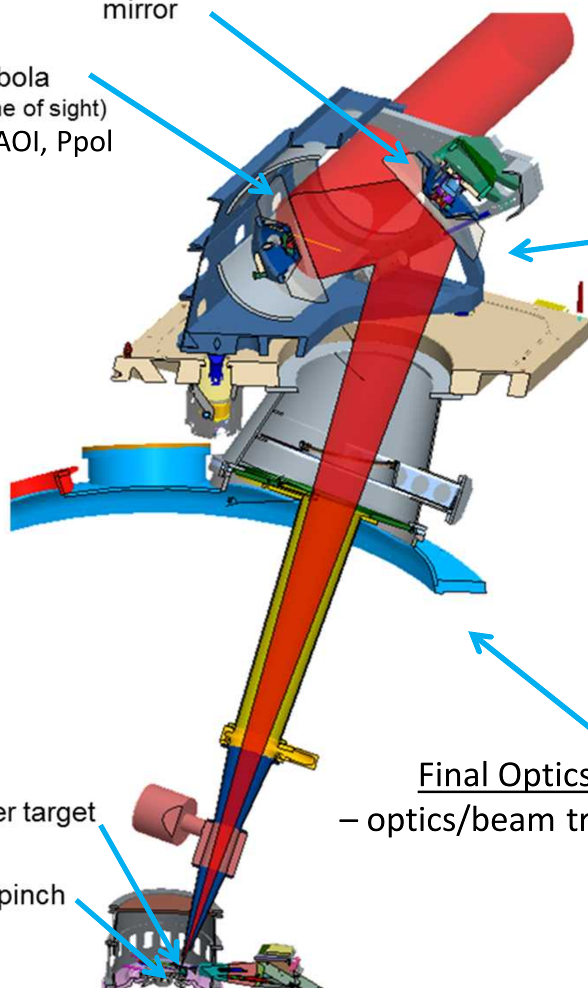
BBHR of this study: 200 nm HR bandwidth centered at 900 nm (← 270 nm)

Use laser and BBHR mirror environments for fs PW pulses

Example: Sandia's ZPW laser (~ 500 fs pulses @ 1054 nm)

24° – 47° AOI, Ppol
steering
mirror

parabola
(no line of sight)
32° AOI, Ppol



foil laser target

Z pinch

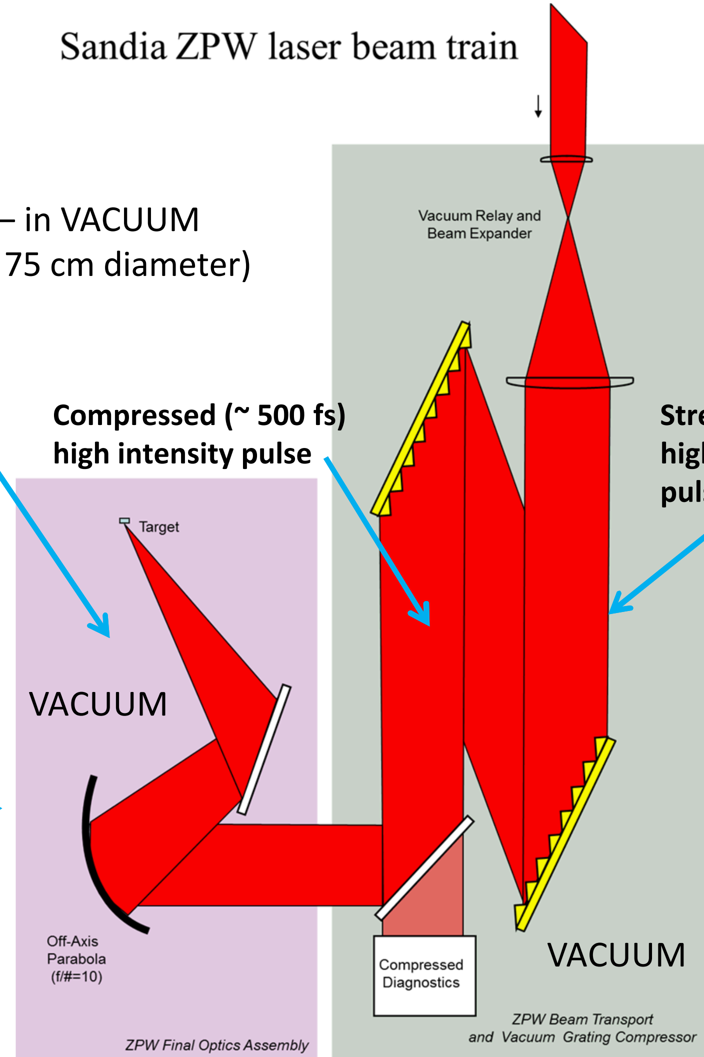
BBHR mirrors – in VACUUM
(meter class – 75 cm diameter)

Final Optics Assembly
– optics/beam train in VACUUM

Sandia ZPW laser beam train

Compressed (~ 500 fs)
high intensity pulse

Stretched (~ 1 ns)
high intensity
pulse



Ambient environments that most closely match the vacuum use laser environment are those at 0% relative humidity (RH)

Coating for BBHR of this study – designed to reflect pulses of tens of fs duration and 900 nm center wavelength

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Coating design goals:

- Reflectivity → R > 99.5% for 45° AOI, Ppol
- Operational Bandwidth → 800 – 1000 nm
- Laser Induced Damage Threshold (LIDT) → > 800 mJ/cm^2
- Group Delay Dispersion (GDD) → < 20 fs^2 over the operational bandwidth

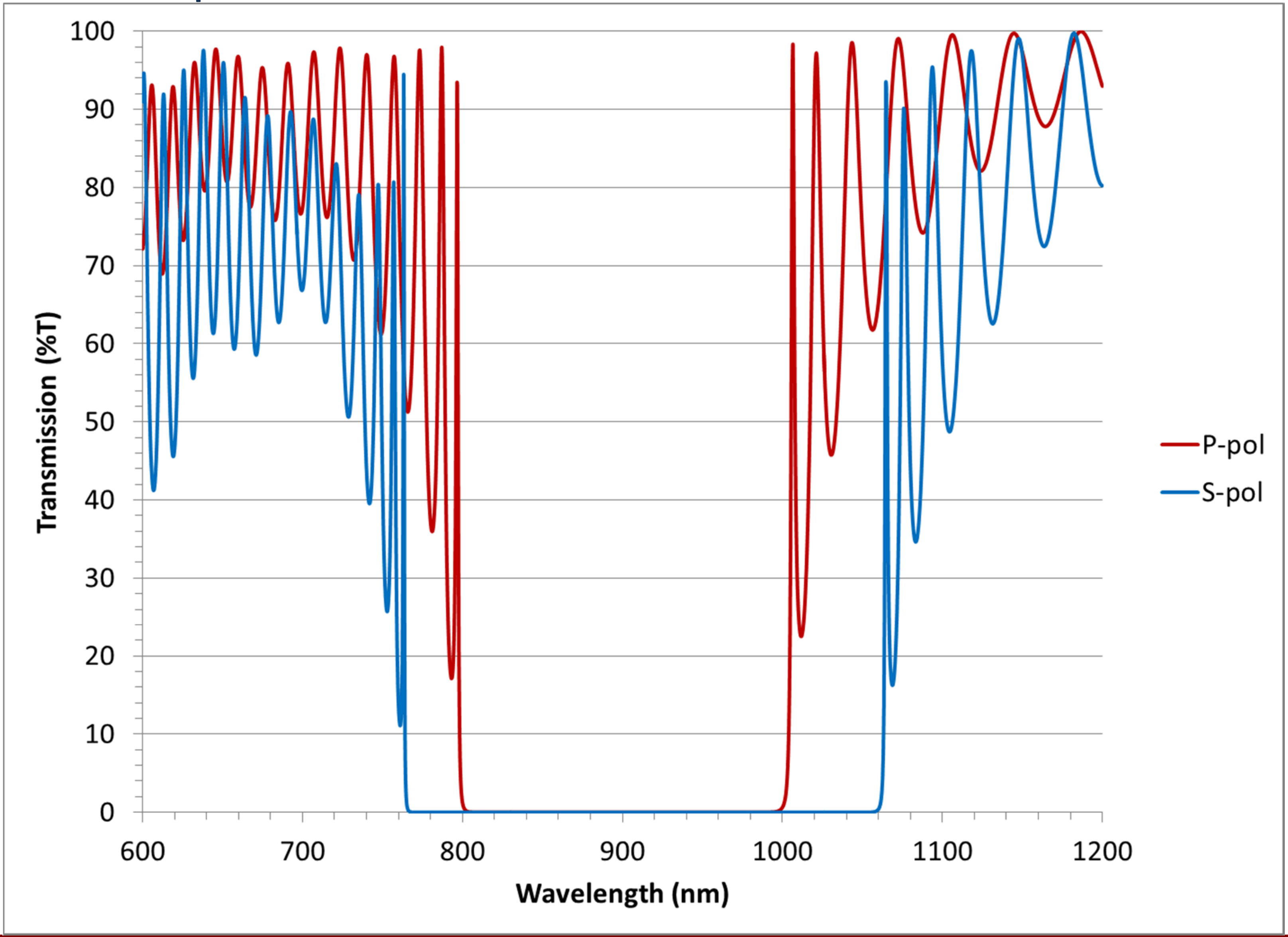
To meet these goals, we designed and produced an all-dielectric multilayer, quarter wave type BBHR coating

- based on TiO_2/SiO_2 layer pairs

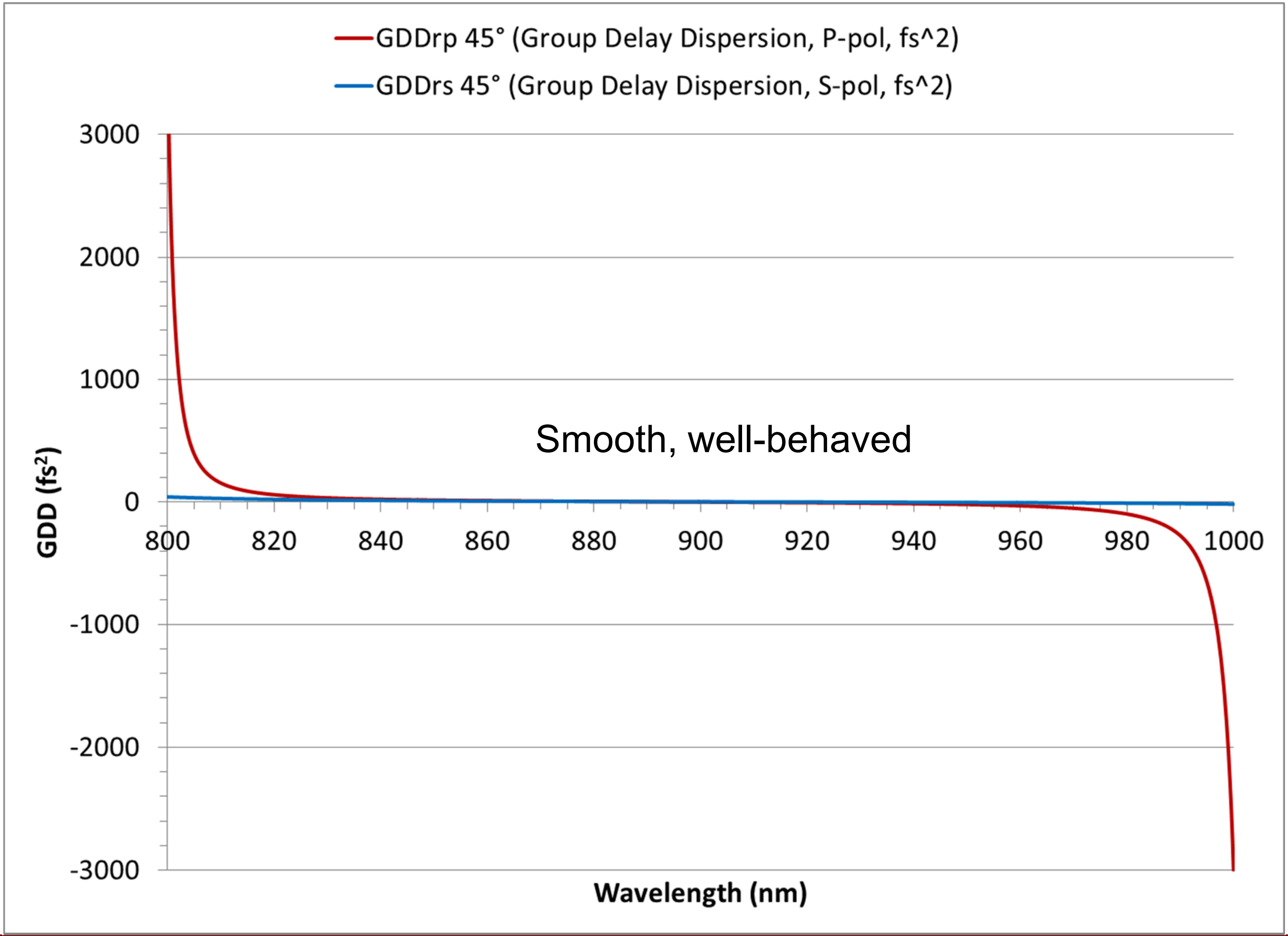
- based on opposite (reversed) chirped TiO_2 versus SiO_2 layer thicknesses from outer to inner layers

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

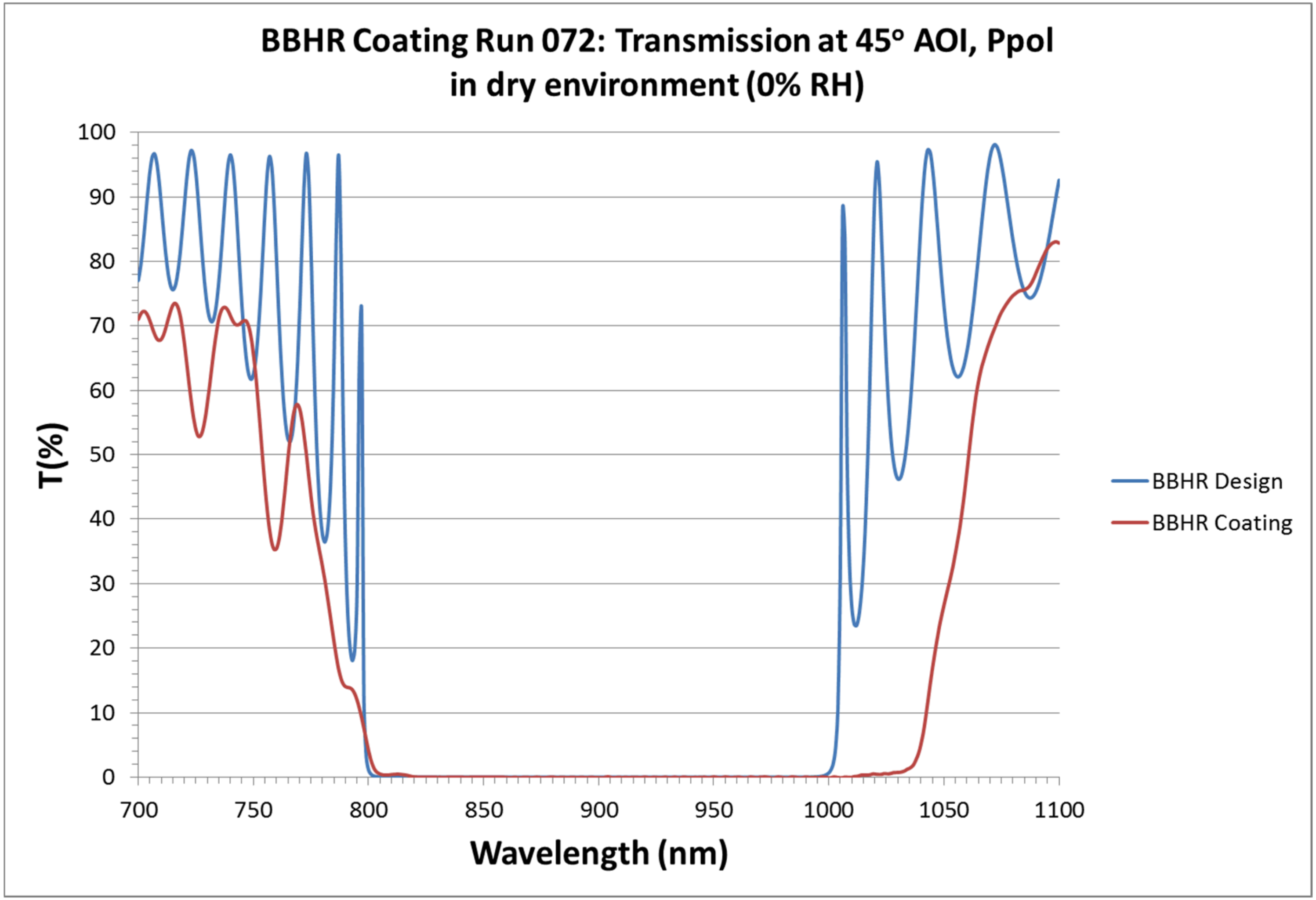
R_p > 99.5%, 801 – 999 nm (198 nm bandwidth)



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



The BBHR coating deposited for use in vacuum: design and deposited coating transmissions match well



Dilemma in LIDT testing of BBHR coatings

- Available LIDT test lasers and test environments often do not match the use laser and use environment
  - Use environment is dry/vacuum
  - LIDT test environment is typically ambient/humid
  - The spectra of multilayer dielectric BBHR coatings shift significantly due to absorption of moisture in humid environments
  - LIDT test laser center wavelengths and spectral bandwidths often don’t match those of the use laser <u>or</u> the BBHR coating

Pulse and spectral issues – Use laser versus LIDT test lasers

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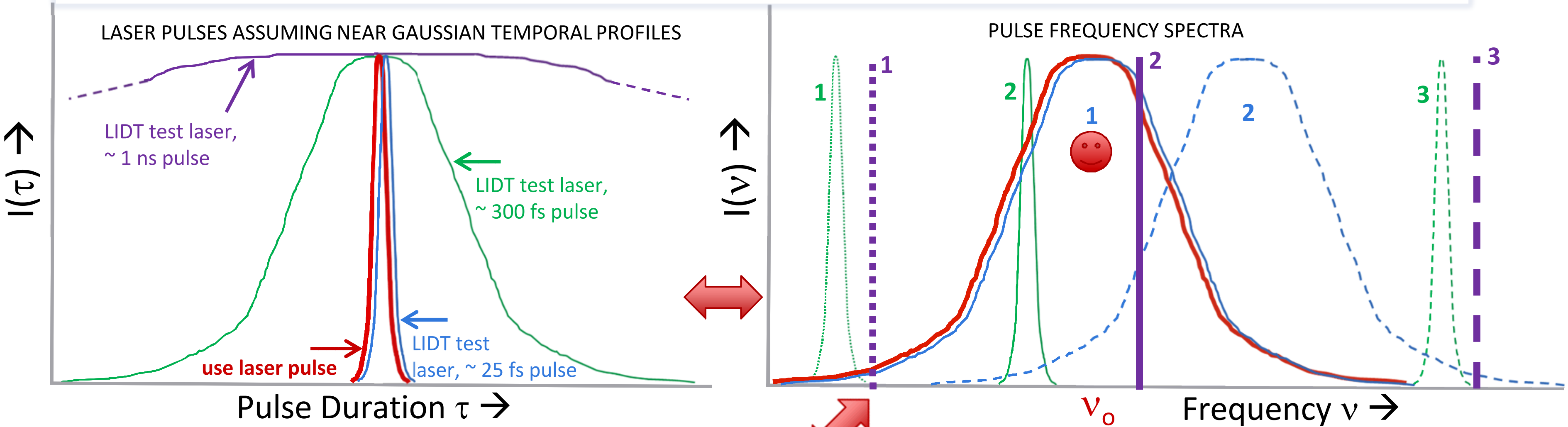
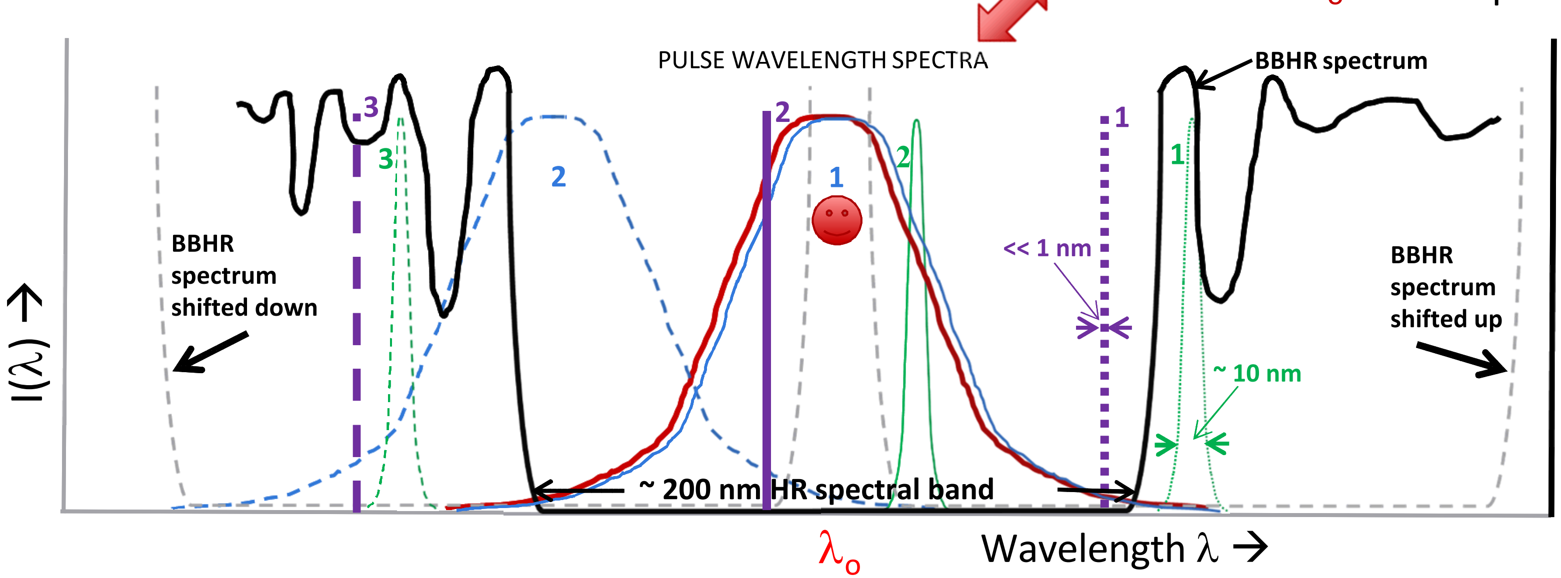
Scenario: **Use laser -** **~ 25 fs pulse, n_o center frequency & λ_o center wavelength**

LIDT test lasers - **~ 25 fs pulse, ~ 300 fs pulse, ~ 1 ns pulse with differing ν_o/λ_o**





Can we shift the BBHR spectral band to overlap other LIDT test laser pulse spectra?

Will LIDT tests with shifted BBHR bands and other LIDT test laser pulse spectra be valid?

Questions and Answers

- **Can we shift BBHR spectral bands to overlap other LIDT test laser pulse spectra?**
  - Yes, by controlling humidity and AOI to "tune" the HR band to overlap the LIDT test laser pulse spectrum.
    - As humidity increases, the BBHR spectral band shifts to higher wavelength.
    - As AOI increases, the BBHR spectral band shifts to shorter wavelength.

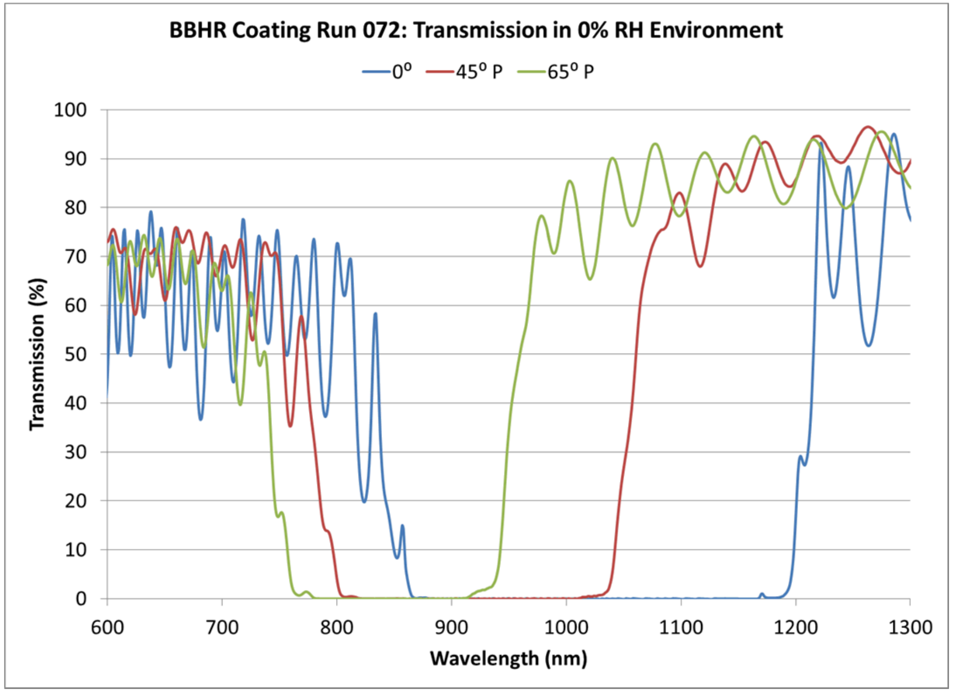
- **Will LIDT tests with shifted BBHR bands and other LIDT test laser pulse spectra be valid?**

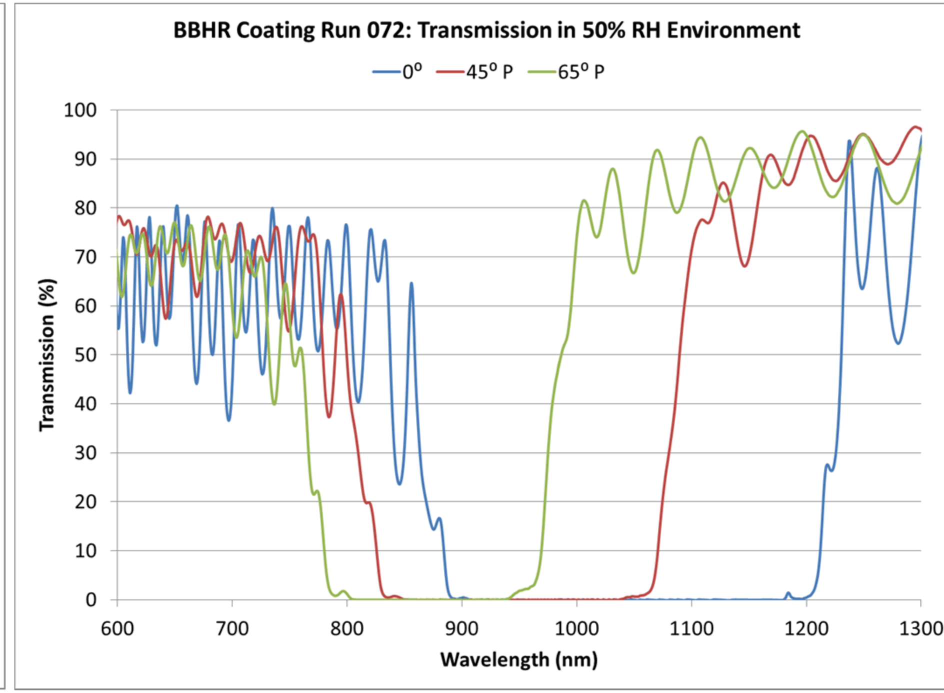
- Do LIDT tests of BBHR coatings with longer (sub-ps, ps, ns) pulses have value?
  - Yes, because LIDTs with longer pulses can indicate fs pulse LIDT behavior based on LIDT trends with pulse duration.
- Do LIDT tests at other AOIs (different from the use AOI) have value?
  - Yes, because the E-fields at wavelengths within the BBHR band at other AOIs behave similarly to the E-fields at the use AOI.
  - Yes, because, as AOI increases, projected fluence on coating layers decreases, favoring higher LIDT, while optical path in coating layers increases, favoring lower LIDT, and vice versa.
    - The two effects on LIDT tend to balance each other out as AOI increases or decreases from the use AOI.

- Do LIDTs at BBHR bands different from the use BBHR band have value?
  - Yes, based on the similar E-field behaviors, but band-gap related intrinsic laser damage may be higher (lower) for BBHR bands below (above) the use BBHR band.

- If the use environment is vacuum (dry), do LIDT tests in humid/ambient environments have value?
  - Yes, since the presence of water in coatings has little effect on LIDT.

BBHR coating run 072: transmission spectral shifts with AOI and RH





Δλ for R > 99.5%

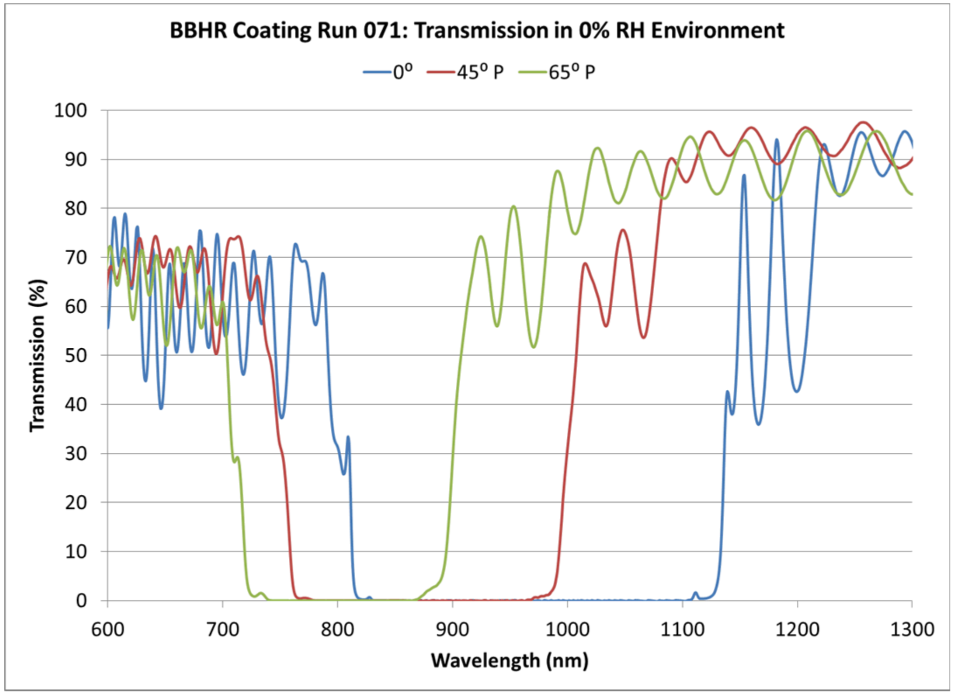
0°:	303 nm (866 – 1169 nm)
45° P:	213 nm (805 – 1018 nm)
65° P:	137 nm (779 – 916 nm)

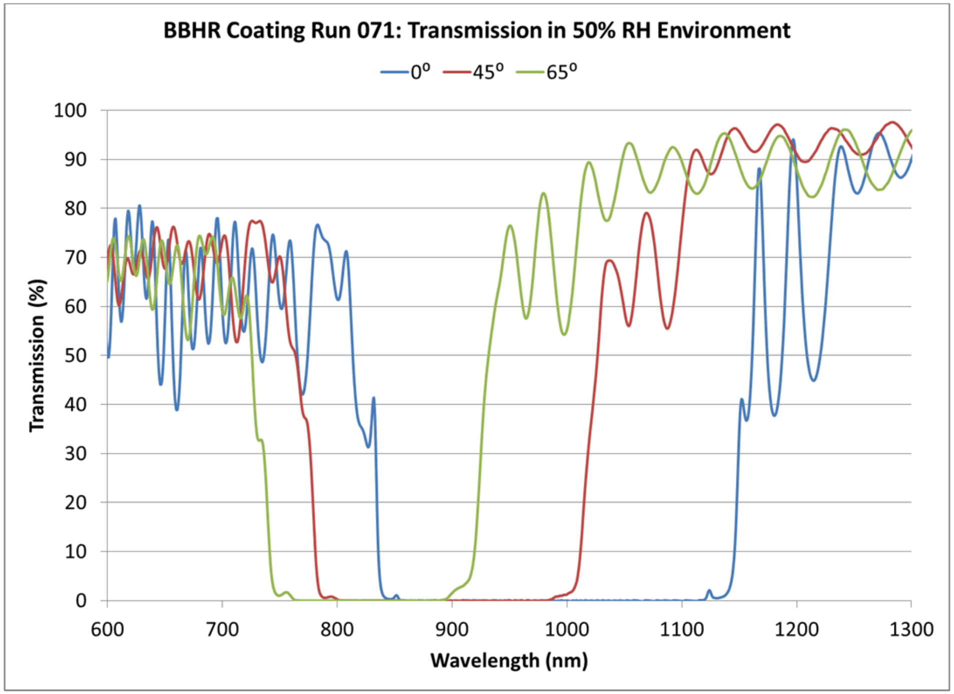
Δλ for R > 99.5%

0°:	291 nm (891 – 1182 nm)
45° P:	196 nm (846 – 1042 nm)
65° P:	139 nm (803 – 942 nm)

Δλ for R > 99.5% decreases as AOI increases

BBHR coating run 071: transmission spectral shifts with AOI and RH





Δλ for R > 99.5% (0% RH)

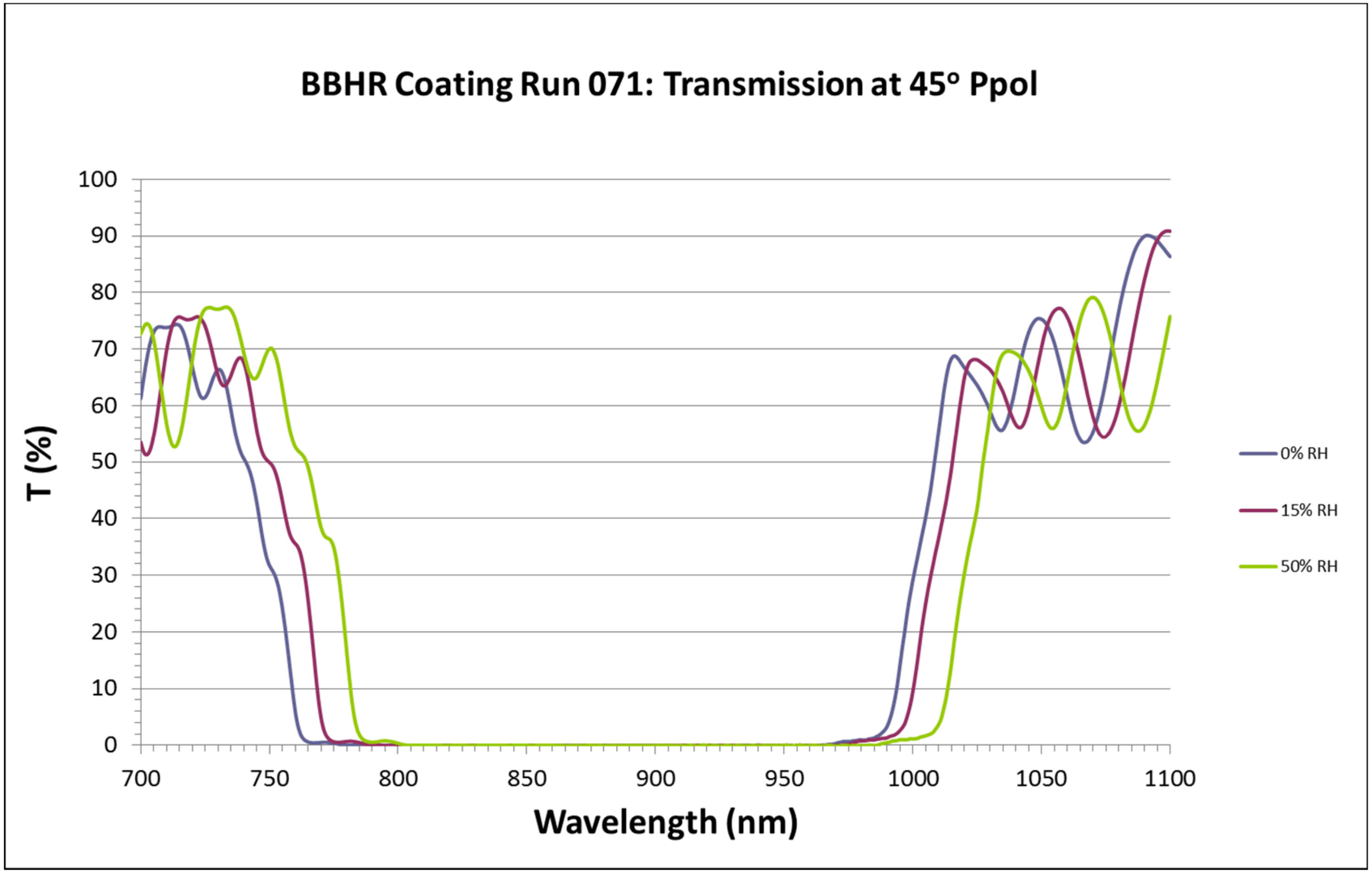
0°: 289 nm (819 – 1108 nm)
45° P: 196 nm (774 – 970 nm)
65° P: 132 nm (739 – 871 nm)

Δλ for R > 99.5% (50% RH)

0°: 266 nm (854 – 1120 nm)
45° P: 188 nm (799 – 987 nm)
65° P: 133 nm (762 – 895 nm)

Δλ for R > 99.5% decreases as AOI increases

BBHR coating run 071: transmission spectral shifts with RH at 45° AOI, Ppol



RH is difficult to control. Tuning spectral shifts is easier by means of AOI tuning.

LIDT tests for BBHR coating run 072

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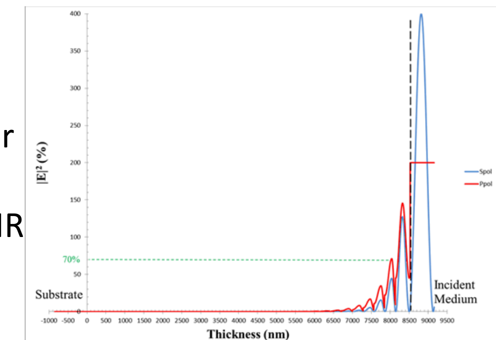
ISO 11254-1 protocol at 1053 nm with 675 fs pulses performed at CEA-CESTA, France

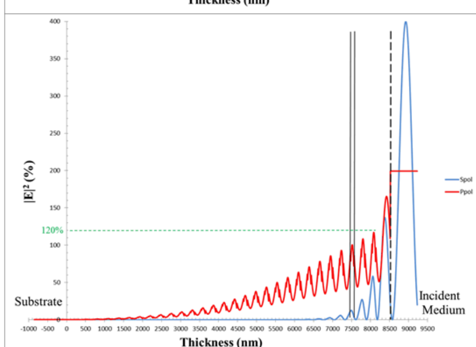
Test environment – low humidity (~ 10% RH)

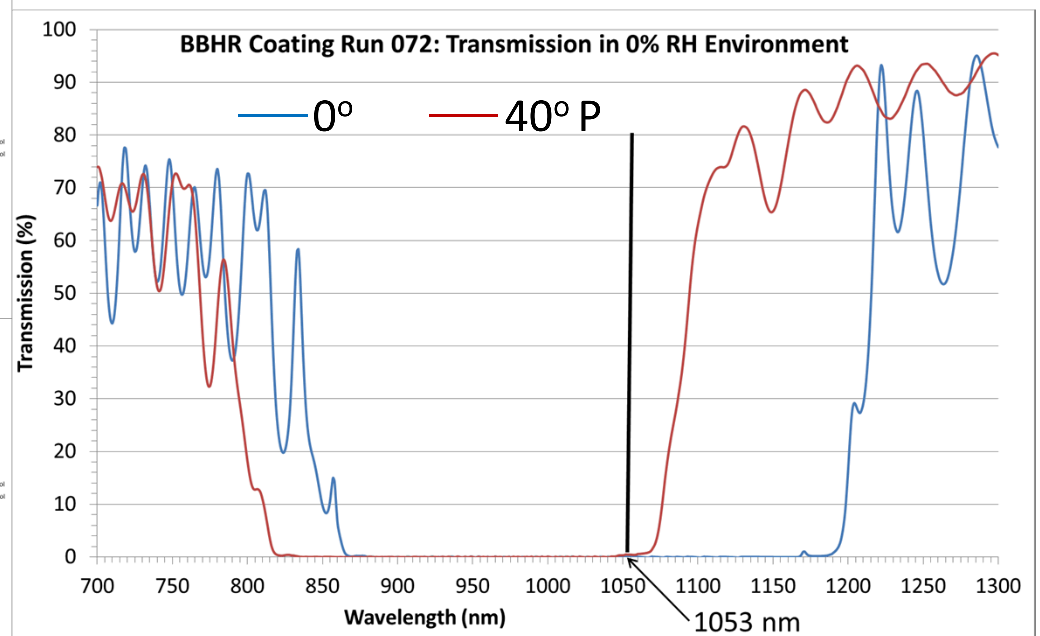
Test AOIs and polarization – 0° and 40° Ppol

E-field behavior in the HR band and not near HR band edge

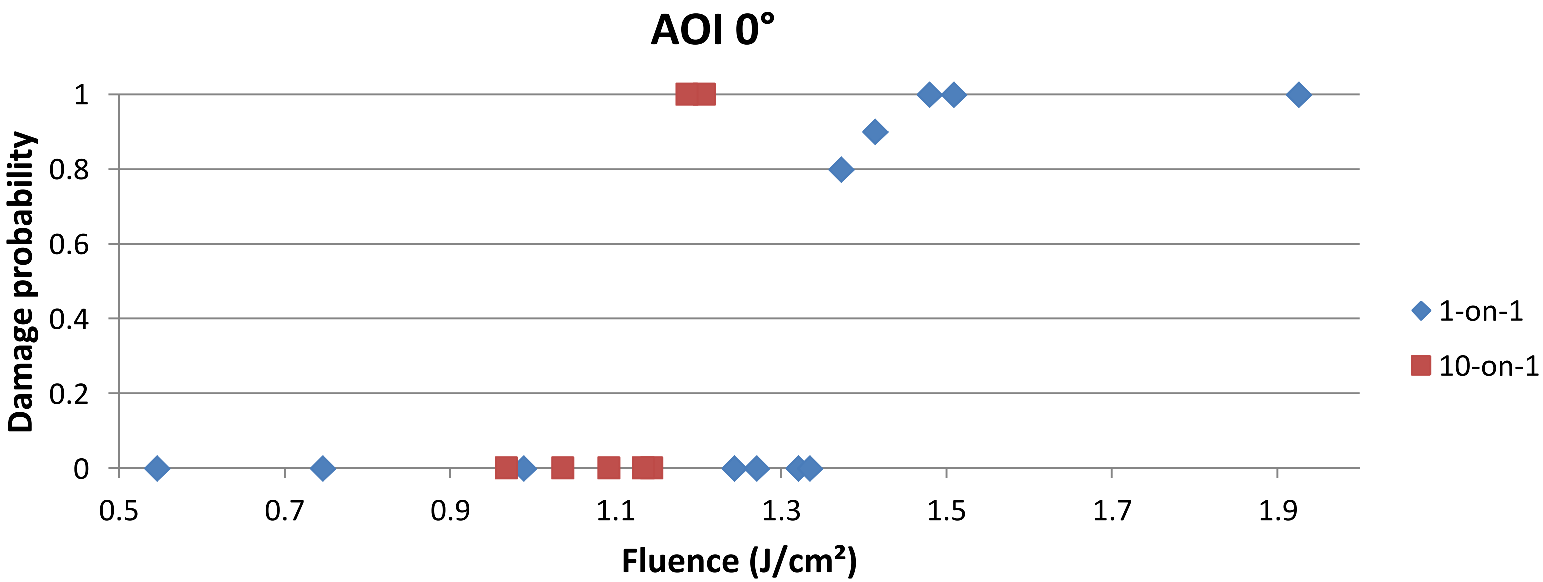


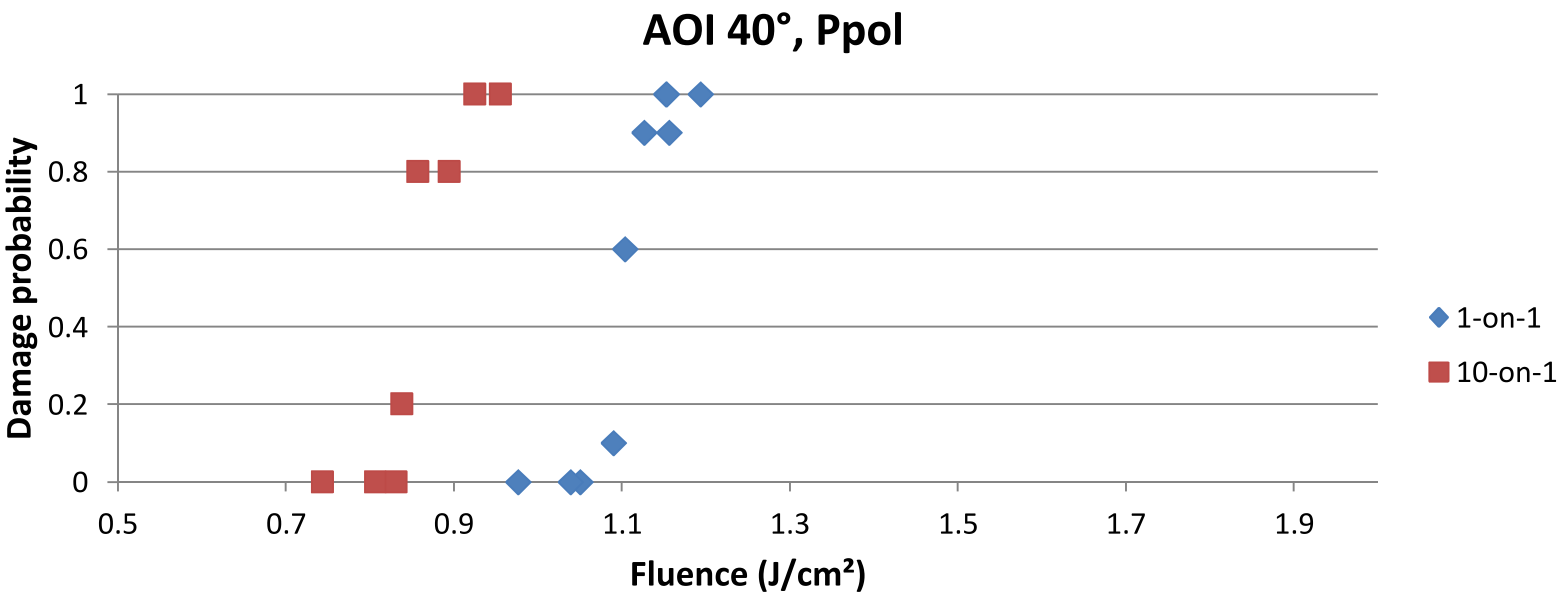
E-field behavior in the HR band and near HR band edge



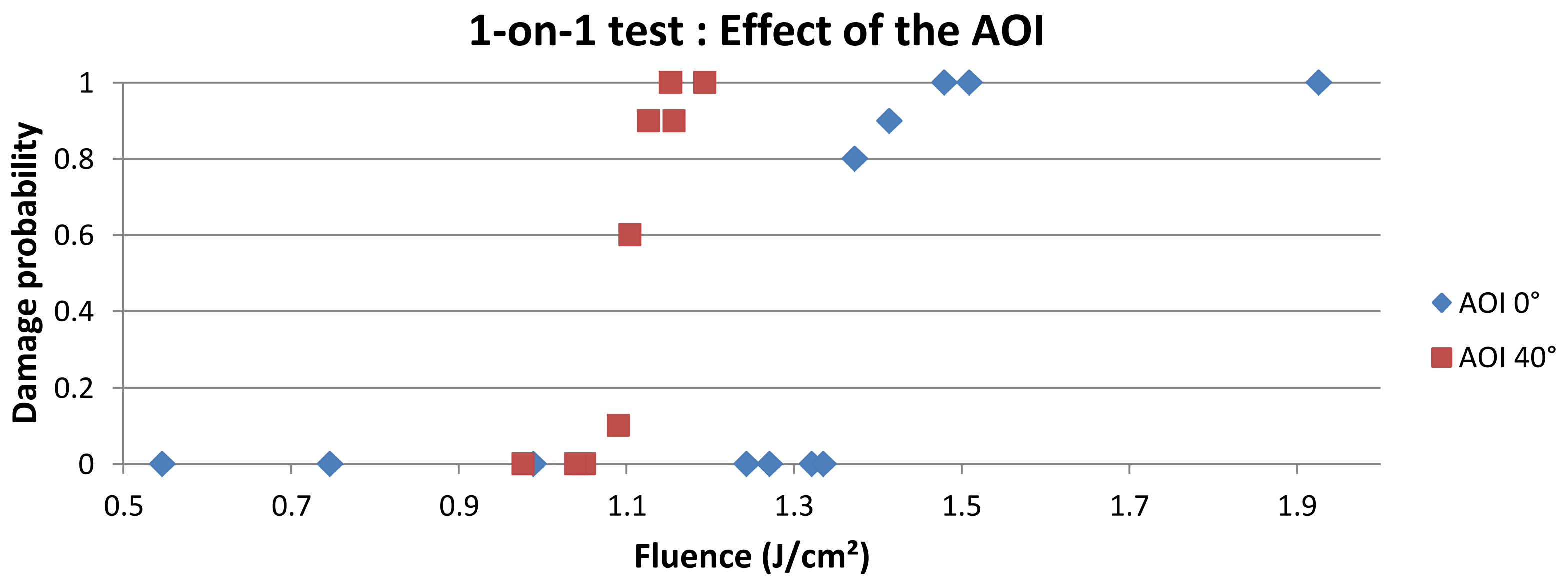


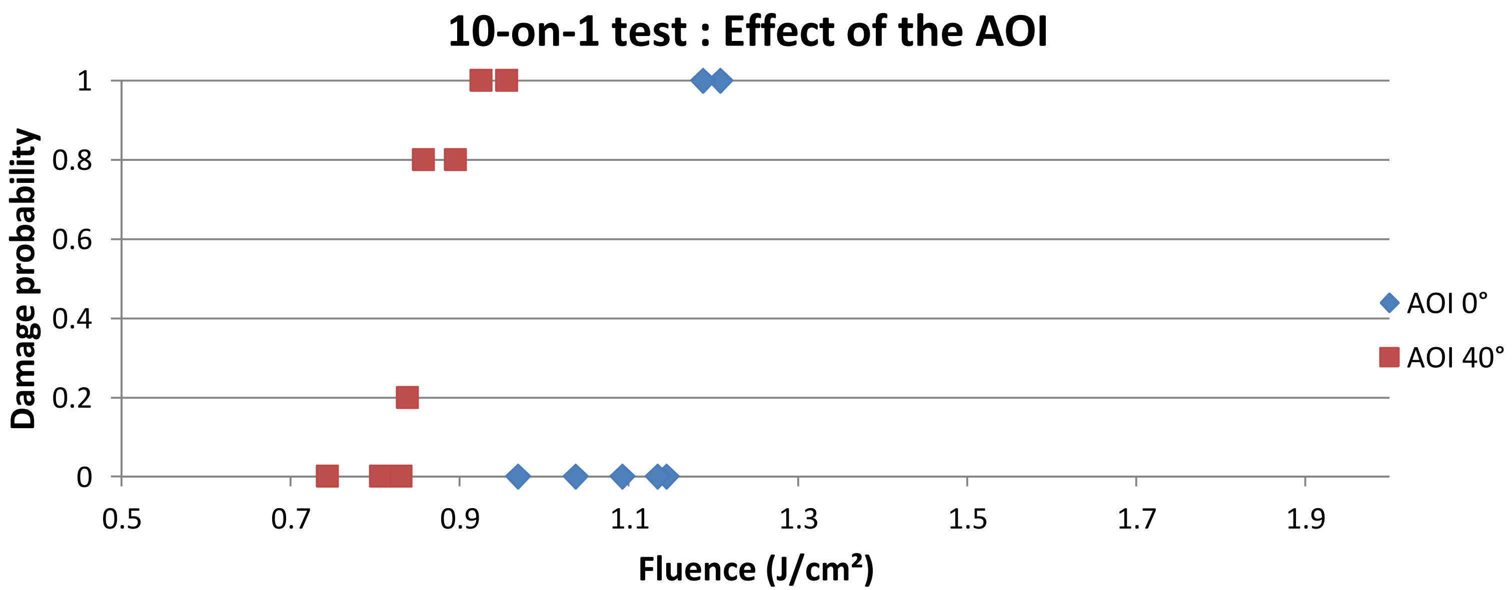
CEA LIDT tests for BBHR coating run 072: comparison of 1-on-1 and 10-on-1 tests





CEA LIDT tests for BBHR coating run 072: comparison of 0º AOI and 40º AOI, Ppol tests





LIDT Tests for BBHR coating run 071

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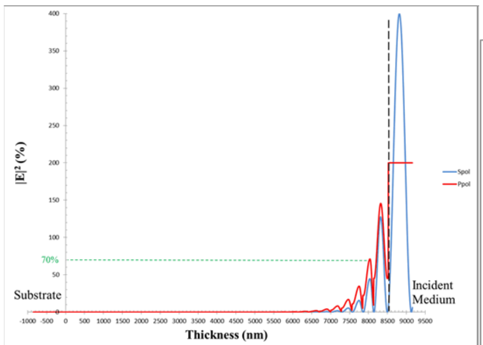
NIF-MEL protocol at 1064 nm with 800 ps and 8 ps pulses performed by Spica Technologies, Inc.

Raster scan over 1 cm^2 with adjacent Gaussian beam spots overlapping at 90% of their maximum intensities

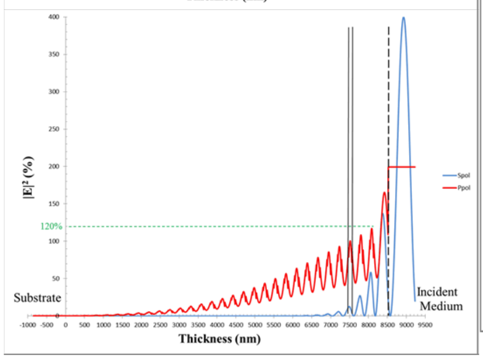
Test environment – dry nitrogen (0% RH)

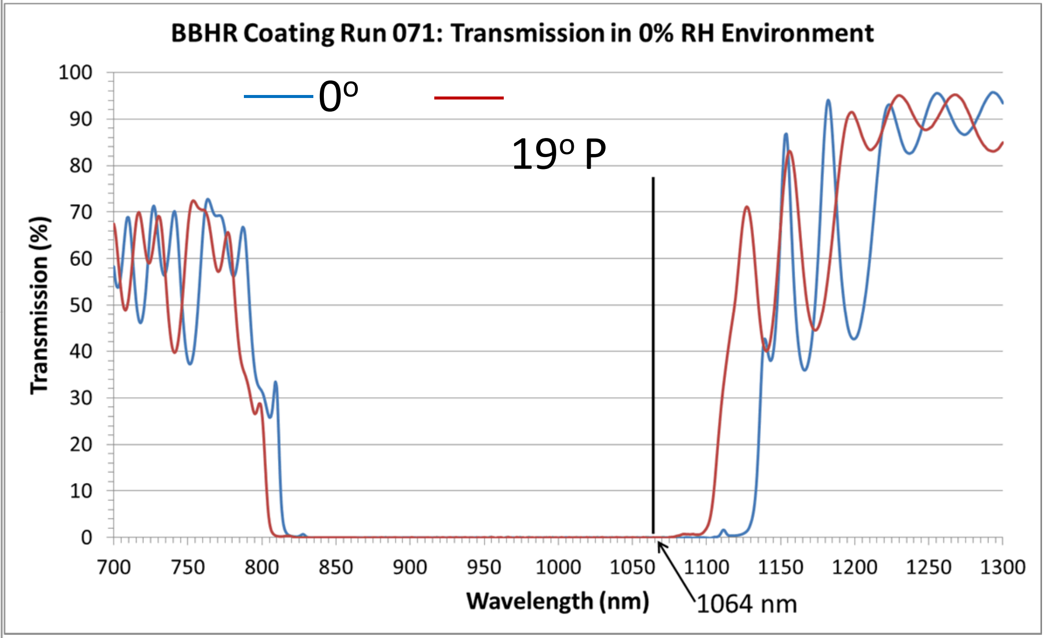
Test AOIs and polarization – 0^o and 19^o Ppol

E-field behavior in the HR band and not near HR band edge

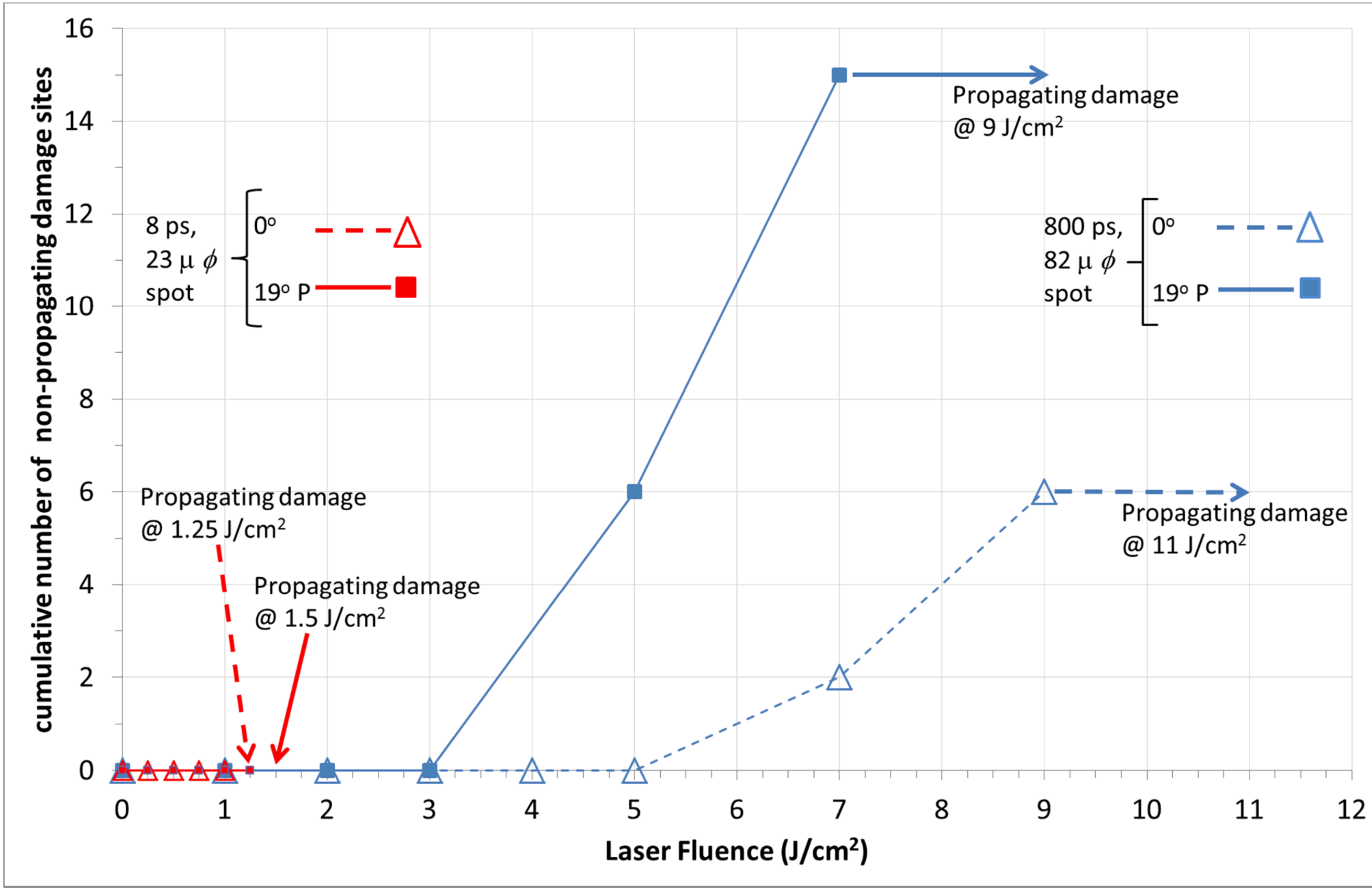


E-field behavior in the HR band and near HR band edge





NIF-MEL LIDT tests with 800 ps and 8 ps pulses for BBHR coating run 071



Summary and proposal

- We designed and produced a coating for BBHR at 45º AOI, Ppol having a 200 nm HR bandwidth centered at 900 nm and low GDD for reflection of fs PW laser pulses
- We highlight dilemmas in LIDT testing of BBHR coatings arising from differences between LIDT test lasers/environments and fs PW use lasers/environment
- We argue the validity of LIDT tests of BBHR coatings with AOI and RH shifts of the HR spectral band to make it match the spectra of fs – to – ns LIDT test lasers
- We present LIDT results for our BBHR coating with shifted HR bands allowing LIDT tests with a 675 fs, 1053 nm laser, and 8 ps and 800 ps, 1064 nm lasers
- Tuning of the AOI for the BBHR coating allowed our LIDT tests to probe laser damage behaviors within and near the edge of the HR band
- We propose the use of a tunable, 350 fs laser for LIDT tests of our BBHR coating in ~ 10 nm bands from 800 nm to 1000 nm