Comparison of the Laser-Induced–Damage Threshold in Single-Layer Optical Films Measured at Different Facilities

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The laser-induced–damage thresholds (LIDT's) of two different coatings were measured in a round-robin experiment involving five well-equipped damage-testing facilities. Investigations were conducted at a wavelength of 1 μm in the subpicosecond-pulse–duration regime with different configurations in terms of polarization, angle of incidence, and environment (air versus vacuum). The results of this round-robin damage-testing effort revealed significant differences between facilities.

The standardization and comparison of laser-damage protocols and results are essential prerequisites for development and quality control of large optical components used in high-power laser facilities. This may be critical for the development of next-generation laser systems or even to improve the operational envelope of current-generation, large-aperture laser systems such as OMEGA EP[1] and PETAL.[2] Although the damage-initiation process is due to defects, and therefore the damage behavior of a material is best described by a damage probability curve, the damage threshold under subpicosecond laser excitation using a small area beam for testing is characterized by a narrow range of fluences in the transition from 0% to 100% probability for laser damage. This threshold behavior allows one to measure the damage threshold with great precision (which can be considered to be "deterministic"). This in turn simplifies a direct comparison of LIDT measurements from different facilities in order to explore how systematic factors in the measurement method can affect the result, aiding in the development of standardized damage-testing protocols.

The objective of this work was to compare results of LIDT testing of two dielectric materials, HfO_2 and SiO_2, in the form of single layers tested at five different laser facilities. The facilities utilized very similar characteristics such as similar wavelengths (around 1 μm), pulse duration (0.8 ps), and beam size. The tests were based on the protocol described by the ISO 21254 Standard.[3] The hafnia (HfO_2) and silica (SiO_2) single layers selected for these tests are common materials used in multilayer dielectric optical components employed in short-pulse laser systems as high- and low-refractive-index materials, respectively. All test substrates for a given coating type were produced during a single coating deposition (and therefore are considered identical) and have been deposited by electron-beam evaporation with ion assistance on BK7 substrates. Testing was performed in four configurations with respect to incidence angle and beam polarization (0° *p* polarization, 45° *p* polarization, 0° *s* polarization, and 45° *s* polarization). The layer thickness of the hafnia and silica layers was 149.9 and 194.3 nm, respectively. The results reported in this summary obtained from five different facilities (see author affiliations) are presented anonymously in the form Lab A, B, C, D, E (for laboratory A, B, C, D, and E). Following the presentation of the raw results of LIDT measurements, we examine the various parameters, which are hypothesized to be the sources for the observed discrepancies between these measurements.

The values of the refractive index and thickness were used to calculate the electric-field–intensity distribution within each single layer using OptiLayer software[4] and the maximum enhancement of the electric-field intensity (EFI_{max}) in the layer was determined for each testing configuration. This EFI_{max} value was used in combination with the measured LIDT ($LIDT_{exp}$) in each material and testing configuration to estimate the "intrinsic" LIDT ($LIDT_{int}$) for the two single layers using Eq. (1):

$$LIDT_{int} = LIDT_{exp} \times EFI_{max}. \tag{1}$$

Results are given in Table I for HfO_2 and SiO_2 single layers. Only results obtained in an air environment are compared since only two of the five testing facilities had the capability for testing in vacuum.

Table I: Intrinsic LIDT's ($LIDT_{int}$) for HfO_2 and SiO_2 monolayers estimated by means of relation (1) and raw damage test experimental data. Thresholds are given in terms of energy density (fluence) in J/cm^2.

	HfO_2 monolayer						SiO_2 monolayer					
	p polarization		*s* polarization		$LIDT_{int}$		*p* polarization		*s* polarization		$LIDT_{int}$	
	0°	45°	0°	45°	mean	σ	0°	45°	0°	45°	mean	σ
Lab A	1.94	2.06	–	2.04	2.01	0.04	3.03	2.99	–	2.93	2.99	0.03
Lab B	2.13	1.87	2.17	out of range	2.06	0.09	2.96	out of range	3.09	out of range	3.02	0.07
Lab C	1.54	1.37	1.41	1.36	1.42	0.04	2.00	2.15	2.01	2.05	2.05	0.04
Lab D	1.63	1.39	–	1.60	1.54	0.07	2.03	2.18	–	2.15	2.12	0.05
Lab E	1.64	1.48	–	1.48	1.53	0.09	Not tested					

The round-robin LIDT measurements of two dielectric single layers showed significant differences. Deviations of the order of 21% were obtained, much greater than the absolute measurement uncertainties on the facilities estimated to be at least 10%. This is an unexpected and highly undesirable result. LIDT determination in this pulse-length regime should be straightforward, and results should be comparable. An analysis of the various contributors involved in the measurement of damage thresholds shows, however, that differences of 20% are nevertheless plausible. The hypothesized principal mechanism to explain such deviations must be explored in future work to resolve this difficulty in determining damage-threshold measurements in the short-pulse regime. We suggest that it is of fundamental importance to pay increased attention to specific metrology:

- Acquire accurate beam spatial-profile measurements with special attention to the sensor noise determination in the case of a small beam on a large sensor window.

- The problem of nonlinear beam propagation affecting the experimental measurements, mainly the beam profile, must be considered.

- Experimental conditions must be perfectly known and controlled as, for example, hygrometry and/or environment.

- Precise knowledge of the temporal intensity profile is also imperative.

This material is based in part upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856, the University of Rochester, and the New York State Energy Research and Development Authority. Part of this work was performed under the auspices of the U.S. Department of Energy (DOE) by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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