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LASER DAMAGE TESTING OF COATED REFLECTORS AT EXCIMER LASER WAVELENGTHS*

by

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ABSTRACT

An important parameter in the design of large-scale ultraviolet lasers - such as those envisioned for Inertial Confinement Fusion and Molecular Laser Isotope Separation - is the resistance to optical damage of windows, AR-coatings, and coated reflectors. In addressing the problem of evaluating and optimizing highly reflective dielectric stacks, we have measured the damage thresholds of a variety of 248-nm, 308-nm, and 351-nm reflectors. The coatings were composed of quarterwave stacks of oxide and/or fluoride films deposited on Suprasil 2 substrates. Testing was accomplished at 35 Hz with nominal 10-ns pulses focused to a mean $1/e^2$ diameter of 0.5 - 0.6 mm. Damage threshold - defined as the highest fluence at which 10/10 sites survived 1000 shots - ranged from 1 - 5 J/cm^2, with a strong dependence upon laser wavelength and reflector coating materials.

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Introduction

We have undertaken a program intended to evaluate and optimize highly reflective dielectric coatings at excimer laser wavelengths. The existing data base is limited due to the relatively recent advent of high power, scalable ultraviolet lasers. It is the intent of this effort to expand the existing data base, identify coatings with high potential damage resistance, and optimize the most promising reflectors.

Test Conditions

Figure 1 is a schematic diagram of the experimental arrangement utilized in these tests. Although described in detail elsewhere[1] a few important points are worthy of review: determination of peak laser fluence; the method whereby the effective test spotsize is increased; and the importance of multiple-shot testing.

The conventional independent variable in laser damage testing is the peak laser fluence (J/cm^2) at a specified pulsewidth. A variety of techniques for determining peak fluence are in general use, but the method employed here is simple and absolute. It is implemented by measuring transmitted energy through a small pinhole. When due consideration is given to potential sources of error such as beam wander and pinhole averaging, this method is unexcelled in making fast, accurate fluence measurements.

In order to have access to high energy densities in the smooth spatial profiles required for these tests, it is necessary to focus to a small spot. The mean $1/e^2$ diameter of the rectangular beam used here is about 0.5 mm. It is conceivable that uncertainties could be introduced as a consequence of sampling a small area, so the effective test area was increased by irradiating ten sites at each fluence. In addition, another technique has been developed to verify the damage threshold as determined by the standard ten-site tests. At levels slightly above and below the threshold fluence, the beam is scanned across roughly 10 mm^2 of the surface in a search for "weak" spots. In every case the higher level produced damage and the lower level did not, thus resolving the spotsize question in the standard tests.

Each test site was irradiated for 1000 shots at 35 pps. This evaluates the sample under more realistic conditions than the more typical single shot tests, and our observation that on some materials, damage is delayed for as much as 900 shots, points out the value of multiple shot testing.

Table I summarizes applicable laser and test conditions.

TABLE I

OPERATING CONDITIONS

Laser - Lumonics 861 Multigas Excimer System operating at pressure, voltage and mixture specified by manufacturer.

Excimer -	KrF	XeCl	XeF
Wavelength (nm) -	248	308	351
Pulse repetition frequency - 35 Hz - all tests			
Pulse length (ns FWHM)	12	10	10
Mean spot diameter (mm at I_0/e^2)	0.62	0.66	0.47

<u>Damage Morphology</u>

Laser-induced damage was observed visually under 25-50 x magnification. The general manifestation was an increase in white-light scatter, ranging from enlargement of already-present small (5 - 25 μm) defects to catastrophic burning or rupturing of the coating. Figures 2 and 3 are electron micrographs which illustrate these last two categories. In Fig. 2, a ZrO_2/SiO_2 reflector has been subjected to burning and melting of the coating layer under 248 nm irradiation. Individual layer edges are visible. Figure 3 is an example of coating rupture in a ThF_4/cryolite reflector at 308 nm. Further discussion of these and other coating materials is deferred to a later section.

Test Results

For each reflector tested, a plot similar to Fig. 4 was produced. Linear regression fits to the data were generally quite good and yielded the damage threshold (0% intercept) and a quantity, at the 100% intercept, which we term the "upper limit" of the reflector. Since some test sites survived at levels up to the upper limit, this quantity indicates the potential performance of a given reflector design while the slope of the fitted line is a measure of the degree to which a reflector approached its potential.

Table II is a listing of previously reported[1] results at 248 nm and 308 nm. Table III contains recent test results on 351 nm reflectors.[2]

Discussion

The two predominant influences on laser damage thresholds in these tests were laser wavelength and reflector coating materials. It should be reiterated that spotsize and pulsewidth were, to the extent possible, held constant throughout the course of this program.

It has been previously reported[3] that the damage threshold (J/cm^2) increases with laser wavelength approximately as λ^4. A careful study of wavelength scaling has not been undertaken here, but in the few cases where comparisons are possible, the aforementioned scaling relationship is verified.

In addition, rough averages of these results (1, 2, and 4 J/cm^2 at 248, 308, and 351 nm, respectively) clearly demonstrate a λ^4 trend.

At a given wavelength and pulsewidth, damage resistance is most strongly affected by the materials chosen to implement the reflective dielectric stack. This ignores the possibility of non-stoichiometric or highly absorbing deposition of otherwise good materials. Tables II and III have indicated some promising materials which will be pursued in future tests: Al_2O_3, Sc_2O_3 and ThF_4. Of note are results for two widely used production coatings: ZrO_2/SiO_2 and HfO_2/SiO_2. The former, while promising at 351 nm is not useful at 248 nm due to the proximity of the ZrO_2 bandedge. The location of the PbF_2 bandedge is problematic at shorter wavelengths also. There are indications[1] that HfO_2 may be approaching its maximum potential damage resistance in these tests; further efforts to optimize this coating will not be attempted.

Conclusions

These tests are an important beginning in the current program to improve uv optics. We now know the readily attainable thresholds for dielectric reflectors, which materials look promising, and what the trends are in wavelength scaling. There remain, however, many unanswered questions. Little data exists, for example, on damage properties of window materials, AR coatings and partial reflectors for the ultraviolet.

Future efforts here will be directed at new materials as well as alternative deposition methods and deposition parameter studies for promising candidates.

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References

1. S. R. Foltyn and B. E. Newnam, "Ultraviolet Damage Resistance of Dielectric Reflectors Under Multiple-Shot Irradiation," IEEE J. Quant. Elect., QE-17, Special Issue on Laser Materials Interactions, to be published Sept., 1981.

2. Reflectors produced as part of a coating development program of Optical Coating Labs, Inc., with the Naval Weapons Center, China Lake, CA. Samples were tested under contract at Los Alamos National Laboratory.

3. B. E. Newnam and D. H. Gill, "Ultraviolet Damage Resistance of Laser Coatings," NBS Spec. Publ. 541, pp. 190-201, 1978.

TABLE II

MULTIPLE-SHOT DAMAGE THRESHOLDS OF
ULTRAVIOLET REFLECTORS: 248 nm AND 308 nm

Coating Materials	Number of Coatings Tested	Reflectance (Wavelength - nm)		Damage Threshold (J/cm^2)	Upper Limit (J/cm^2)
PbF_2/Na_3AlF_2	1	0.74	(248)	0.03	--
plated Al	2	0.80, 0.85	(248)	0.1, 0.2	0.1, 0.2
ZrO_2/SiO_2	1	0.99	(248)	0.2	0.4
HfO_2/SiO_2	4	0.94-0.98	(248)	0.4-1.0	0.5-1.4
Al_2O_3/NaF	6	0.92-0.97	(248)	1.0-1.7	2.2-2.7
Al_2O_3/Na_3AlF_6	2	0.99	(248)	1.4, 1.5	2.2, 2.5
BeO/SiO_2	1	--	(248)	1.7	2.0
Sc_2O_3/MgF	2	0.97, 0.98	(248)	1.7, 1.8	2.5, 2.8
ThF_4/Na_3AlF_6	2	0.95, 0.96	(248)	2.8, 3.0	3.5-4.0
HfO_2/SiO_2	3	0.96-0.98	(308)	1.6-2.2	2.5-3.7

TABLE III

MULTIPLE-SPOT DAMAGE THRESHOLDS
OF ULTRAVIOLET REFLECTORS: 351 nm

Coating Materials	Number of Coatings Tested	Reflectance	Damage Threshold (J/cm^2)	Upper Limit (J/cm^2)
ZrO_2/SiO_2	8	0.95-0.99	3.9-5.1	6.1-7.5
Al_2O_3/NaF	4	0.97-0.98	3.8-5.2	6.1-6.6

Figure Captions

Figure 1. Schematic diagram of the experimental arrangement used in these tests.

Figure 2. Electron micrograph of a damaged ZrO_2/SiO_2 coating.

Figure 3. Electron micrograph of a ruptured ThF_4/cryolite coating.

Figure 4. Results of a standard test on a 248 nm Sc_2O_3/MgF reflector.