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Evaluation of Biochromatic Coatings Designed for Pulsed Laser Fusion Applications

G. R. Wirtenson
J. B. Willis
E. A. Enemark

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EVALUATION OF BICHROMATIC COATINGS DESIGNED FOR PULSED LASER FUSION APPLICATIONS AT 0.53 AND 1.06 MICROMETERS

G. RICHARD WIRTENSON AND JAMES B. WILLIS
LAWRENCE LIVERMORE NATIONAL LABORATORY
UNIVERSITY OF CALIFORNIA
AND
E.A. ENEMARK
OPTICAL COATING LABORATORY, INC.

Various bichromatic coatings designed to operate at both 0.53 and 1.06 micrometers have been evaluated for spectral performance and laser damage threshold to determine the suitability of these coatings for 1 nanosecond pulse laser fusion experiments and to establish baseline data. Anti-reflection, partially transmitting high reflection, and maximum reflection coatings, consisting of titania and silica layers, were deposited onto BK-7 substrates. For each type of coating, two different designs were examined. Spectral measurements indicate the coatings met performance goals. Laser damage threshold values at 1.06 micrometers were similar to those of previous monochromatic production coatings, while damage levels at 0.53 micrometers were about one-half these 1.06 micrometer values.

Key words: Anti-reflection coatings, bichromatic, damage, high energy laser, laser damage, pulsed laser, reflectors, thin film.

1. Introduction

Laser fusion experiments have demonstrated more efficient ignition of the target as the wavelength of the incident laser radiation decreases. Additional experiments are planned which will study laser fusion reactions utilizing both 0.53 and 1.06 micrometer laser beams. The shorter wavelength will be obtained by inserting frequency doubling crystals into the 1.06 micrometer beams. The optical components following the frequency doubling stage will be used for both wavelengths. Consequently, the coatings on these optics must function at both wavelengths. In order to evaluate existing capability with regard to coatings proposed for these optics, the experiment reported here was undertaken.

2. Approach

For this initial experiment, the approach taken was in response to the hypothetical question - - what coatings might be supplied in response to an immediate need? Consequently, commonly used coating materials and existing coating processes were used. The coating designs were regarded as practical approaches consistent with the given spectral requirements.

Conventionally polished BK-7 substrates were coated with multi-layer designs consisting of titania and silica. Two different designs for each of three different types of coatings were deposited. The coating types were anti-reflectors, partially transmitting high reflectors, and maximum reflectors. The coated parts were evaluated for spectral performance, physical and environmental durability, and laser damage threshold at both 0.53 and 1.06 micrometers.

3. Coating Designs

The spectral requirements for the anti-reflection coatings were for reflectances less than 0.25% at both wavelengths with a goal of less than 0.1%. A major consideration was manufacturability. Because the eventual application is the coating of large area optics and because the coating thickness might vary by a few percent over the optical surface, the coating must provide for low reflectance for such a coating thickness variation.

Finally, laser damage considerations were important. For laser fusion systems in general, the weakest link in the optical train has been anti-reflection coatings. Increasing the damage threshold will allow for greater energy throughput and, thus, improved system performance.

Both theoretical designs for the anti-reflection coatings met the spectral specifications. The anticipated advantage for the simple (narrow band) design was that fewer layers might improve the coating's energy handling capabilities. Fewer layers meant less coating material and, thus, less absorption. For the complex (broad band) design, more layers resulted in broader regions of low reflectance. This thicker coating, however, might exhibit lower damage thresholds because of potentially greater absorption. The theoretical spectral performance curves for these anti-reflection coatings are shown in Figures 1 and 2.

Both reflector designs, the partial transmitter and the maximum reflector, compared a two-to-one stack to a two-stack design. "Stack" is merely a term for a set of coating layers consisting of alternating materials of high and low indices of refraction. The two designs are shown in Figure 3. The two-to-one design provides high reflectance at the two wavelengths of interest in one stack. The ensemble is a combination of one reflecting stack for one wavelength deposited over a reflecting stack at the other wavelength.

The two-to-one stack used fewer layers. However, the regions of maximum reflectance are not as broad as those for the ensemble design. For the ensemble, a choice had to be made as to which stack was to be deposited first. In either case, radiation reflected by the first deposited reflector would of necessity pass through the second deposited reflector. Since the 0.53 micrometer reflector was half the thickness of the 1.06 micrometer reflector and, thus, probably less absorbing, the choice was to deposit the 1.06 micrometer reflector first and then the 0.53 micrometer reflector. See Figure 3.

Theoretical performance curves for these designs are shown in Figures 4, 5, 6, and 7. The two-stack design provides greater manufacturing tolerances because of broader regions of high reflectance. The partial transmitters were to pass approximately 3% of the incident radiation.

4. Results

All coating designs were successfully deposited. The measured spectral curves are shown in Figures 1 and 2, and 4 through 7 for comparison to theory. The coatings passed the adhesion, hardness, and humidity tests of MIL-M-13508.

Damage threshold data are presented in Table I. Both the 0.53 and 1.06 micrometer data were obtained using comparative damage test techniques[1]. All damage testing was performed at UC/LLNL.

5. Discussions

The coatings met the spectral and environmental requirements. However, the damage test results were lower than desired, especially at 0.53 micrometers for the anti-reflection coatings. Previous samples of the broad band design had been found to damage at higher energy levels. See Table II.

There is no clear explanation for the variation in damage results for the reflector coatings. Again, the 0.53 micrometer data was not as high as hoped. In addition, one design concept for the reflectors did not clearly excel with regard to energy survivability. In some cases, the two-to-one design was more damage resistant while the two-stack design was better in others.

The possibility does exist that the titania is damaging more readily at the shorter wavelength because of increased absorption. The absorption edge occurs at about 0.35 micrometers. It could be that the absorption decreases very slowly with increasing wavelength and that we are seeing a manifestation of this at 0.53 micrometers. This must remain as conjecture, however, until additional experiments are performed.

REFERENCES:

1. Milam, D., Willis, J.B., Rainer, F., and Wirtenson, G.R., "Determination of Laser Damage Thresholds by Comparison with an Absolute Laser Damage Standard", UCRL-84830 preprint, (Accepted for Publication), Applied Physics Letters.

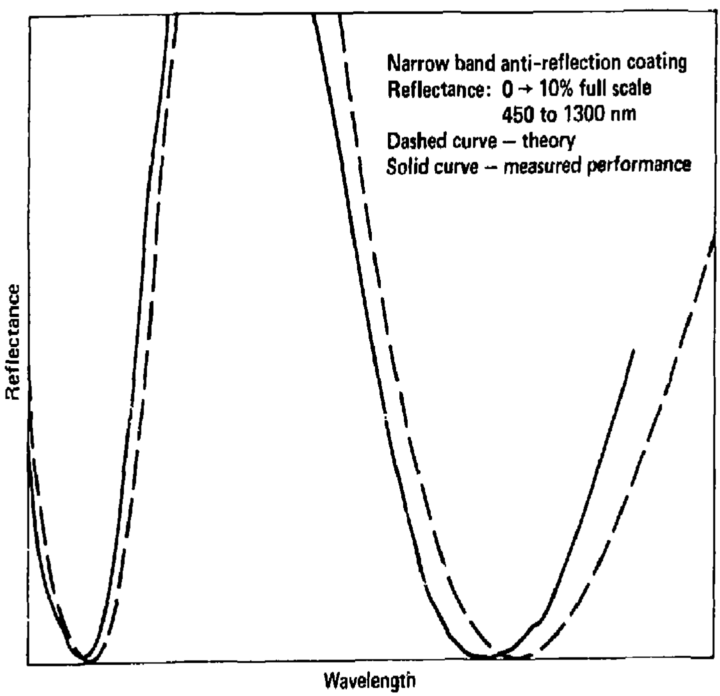

Narrow band anti-reflection coating
Reflectance: 0 → 10% full scale
450 to 1300 nm
Dashed curve – theory
Solid curve – measured performance
Reflectance
Wavelength

Figure 1

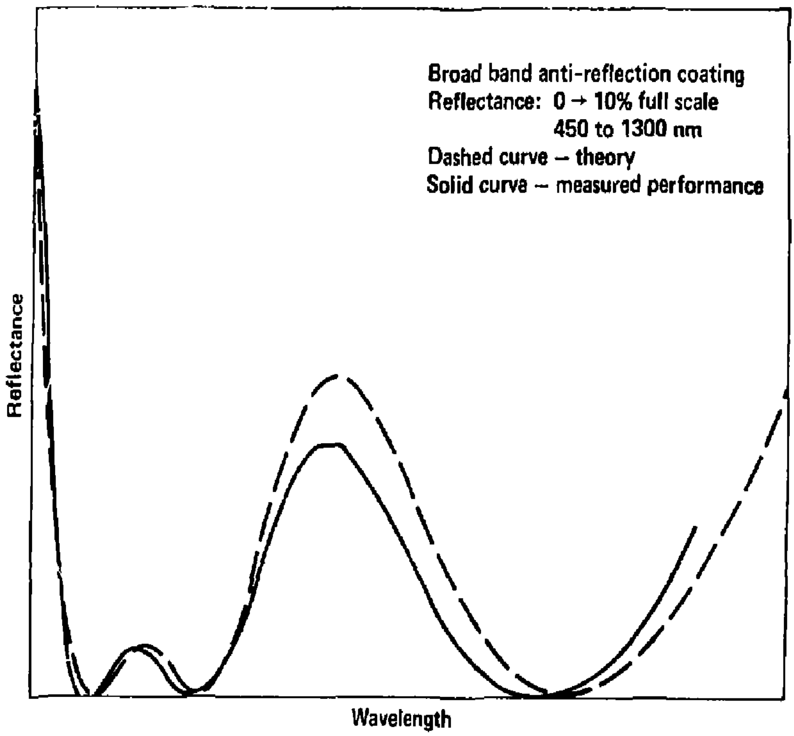
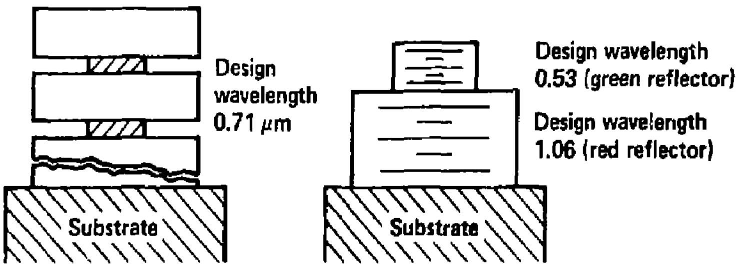

Broad band anti-reflection coating
Reflectance: 0 → 10% full scale
450 to 1300 nm
Dashed curve – theory
Solid curve – measured performance
Reflectance
Wavelength

Figure 2

REFLECTOR DESIGNS

2:1 Design

Ensemble



Single reflecting stack with half wave low index layers and quarterwave high index layers

Two reflecting stacks of quarter wave design

Figure 3

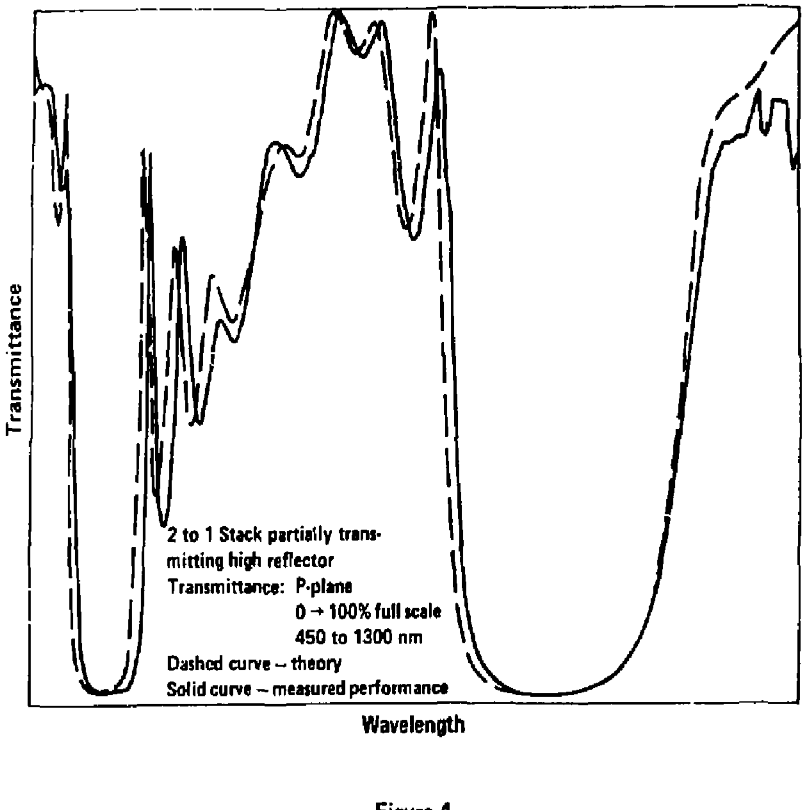

Transmittance
2 to 1 Stack partially trans-
mitting high reflector
Transmittance: P-plane
0 → 100% full scale
450 to 1300 nm
Dashed curve – theory
Solid curve – measured performance
Wavelength

Figure 4

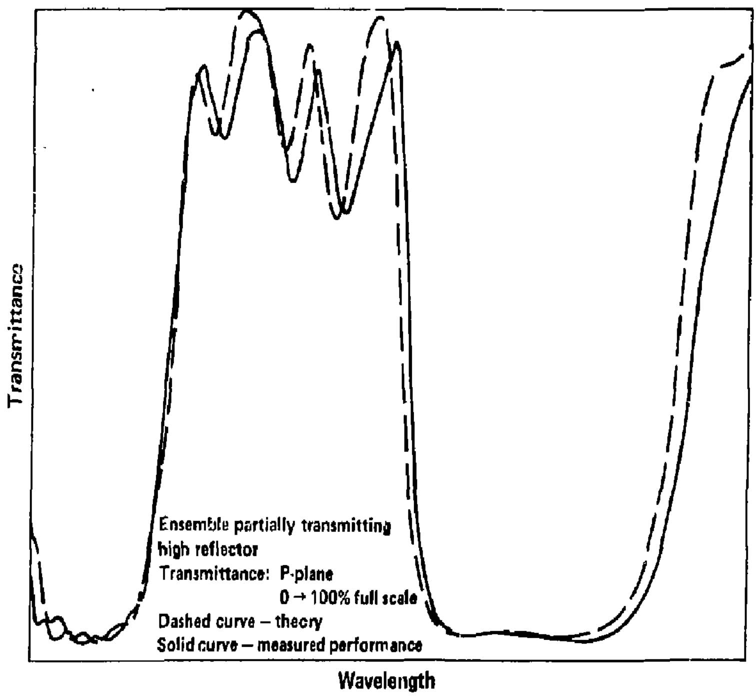

Transmittance
Ensemble partially transmitting
high reflector
Transmittance: P-plane
0 → 100% full scale
Dashed curve – theory
Solid curve – measured performance
Wavelength

Figure 5

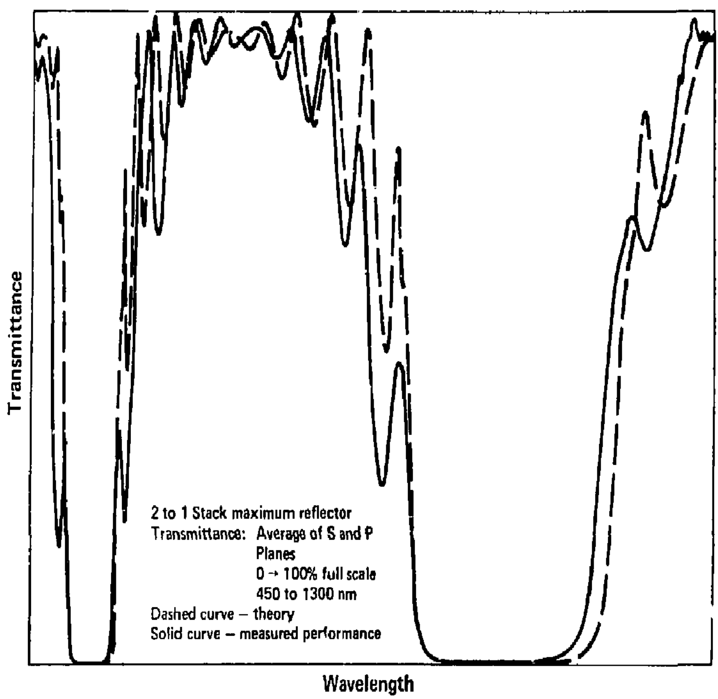

Transmittance
2 to 1 Stack maximum reflector
Transmittance: Average of S and P Planes
0 → 100% full scale
450 to 1300 nm
Dashed curve – theory
Solid curve – measured performance
Wavelength

Figure 6

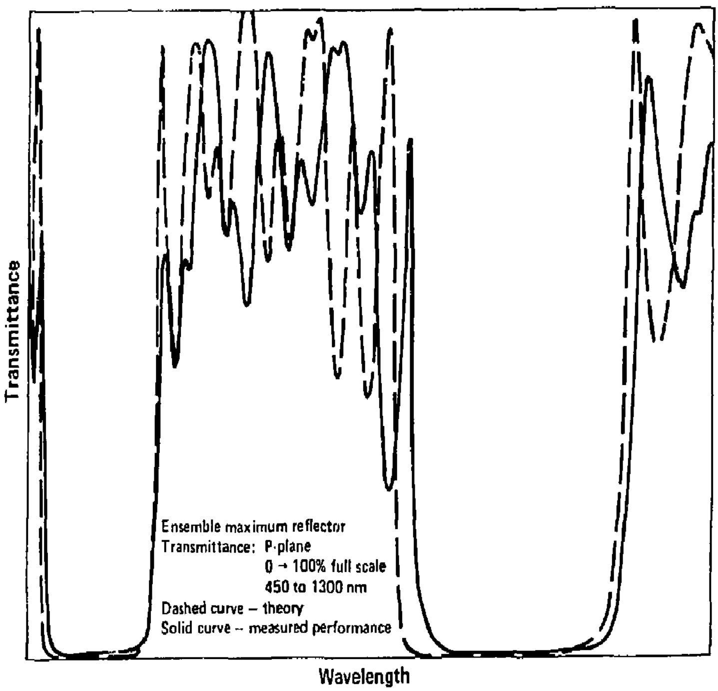

Transmittance
Ensemble maximum reflector
Transmittance: P-plane
0 → 100% full scale
450 to 1300 nm
Dashed curve – theory
Solid curve – measured performance
Wavelength

Figure 7

TABLE I

Coating Type	Damage Threshold, Range (mean), J/cm^2 0.53 μm	1.06 μm
Anti-reflection		
Narrow band	2.4 - 3.5 (2.5)	4.0 - 6.5 (5.5)
Broad band	2.4 - 3.5 (2.5)	4.0 - 6.5 (5.5)
Partially transmitting high reflection		
2:1	2.5 - 5.0 (3.5)	6.5 - 9.0 (7.5)
Ensemble	~ 2.5 (2.5)	7.0 - 11.0 (8.5)
Maximum reflection		
2:1	2.0 - 5.0 (3.0)	7.0 -13.0 (11.0)
Ensemble	3.5 - 7.0 (5.0)	6.5 - 9.0 (7.0)

Table II

Previous measurements on broad band AR design samples
6.2 ± 0.7
3.0 ± 0.5
5.4 ± 0.6
4.8 ± 1.0