(2)

FTD-ID(RS)T-1278-90

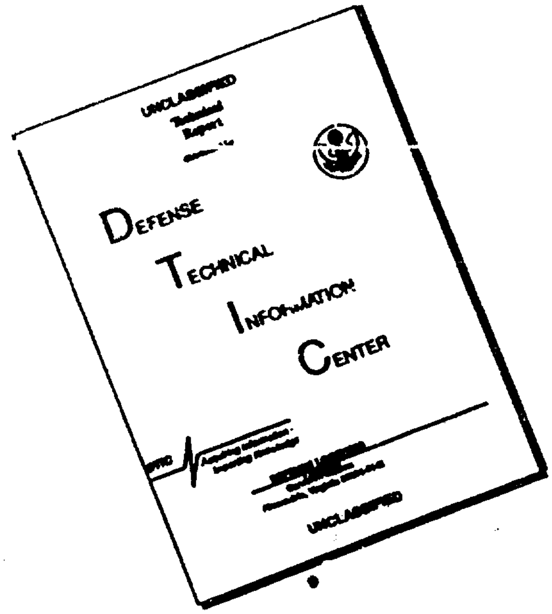
FOREIGN TECHNOLOGY DIVISION

DAMAGE THRESHOLD DEPENDENCE OF MULTILAYER LASER MIRRORS ON COATING DESIGN

by

Wu Zhouling, Fan Zhengxin

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

HUMAN TRANSLATION

FTD-ID(RS)T-1278-90 5 June 1991

MICROFICHE NR: FTD-91-C-000401

DAMAGE THRESHOLD DEPENDENCE OF MULTILAYER LASER MIRRORS ON COATING DESIGN

By: Wu Zhouling, Fan Zhengxin

English pages: 10

Source: Acta Optica Sinica, Vol. 9, Nr. 9, 1989, pp. 830-835

Country of origin: China
Translated by: Leo Kanner Associates
F33657-88-D-2188
Requester: FTD/TTTD/Jacobsen
Approved for public release; Distribution unlimited.

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION	PREPARED BY. TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WPAFB, OHIO

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this **translation were** extracted from the best quality copy available.

DAMAGE THRESHOLD DEPENDENCE OF MULTILAYER LASER MIRRORS ON COATING DESIGN

Wu Zhouling and Fan Zhengxin, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences

Abstract: The damage threshold of TiO_2/SiO_2 and ZrO_2/SiO_2 coatings with different structures--$A(HL)^mHG$, $A[(2p+1)HL]^m(2p+1)HG$ and $A[H(2q+1)\ L]^mHG$--were measured. The results showed a strong dependence of damage resistance on coating design. Generally, an increase in film thickness of the high refracting component (especially up to p=2) leads to a strong decrease in laser damage resistance, while all the systems had an increase in damage threshold with an increase in thickness of the low refracting component up to q=2. The damage threshold of the q=3 systems is commonly higher than that of q=0 systems. For the systems with q greater than 3, damage resistance decreases very rapidly, becoming much lower than that of the standard systems with q=0.

In this paper, the above results are preliminarily described and analyzed, with respect to the mechanism of laser damage of optical coatings, with the measurement of optical losses and a study of the effect of protective film thickness.

Key words; optical coating, laser damage, optical losses.

I. Introduction

Laser damage to thin coating films results from interaction between the laser and the thin film, relating to two aspects of the thin film and the laser. The correct realization of the experimental role of these aspects is helpful in elucidating the laser damage mechanism of optical thin films and to raise the damage threshold value of film coatings [1,2].

By citing an example of TiO_2/SiO_2 and ZrO_2/SiO_2 medium reflecting films, the article studies the effect on the laser damage threshold of different film system structures: $A(HL)^mHG$, $A[(2p+1)HL]^m(2p+1)HG$ and $A[H(2q+1)L]^mHG$. It was discovered that the laser damage threshold of the optical film system decreases simple-harmonically with an increase in the thickness of the high refractive index medium layer. However, with increasing thickness of low refractive index medium layer, first the laser damage threshold value improves to a greater extent, simple-harmonically; then, while $(2q+1)\geq 7$, the laser damage threshold of the related film system rapidly decreases, considerably lower than that of the standard film system $A(HL)^mHG$.

According to preliminary experimental results of the thickness effect with optical loss measurements, a preliminary discussion is made on the laser damage mechanism of optical thin films.

II. Experimental Section

1. Preparation of specimens: all specimens are vapor-coated onto a substrate of K_9 glass. Table 1 shows the design of the film system, the technical conditions, and the refractive indexes of the film materials.

TABLE 1. Coating Design Deposition Parameters and Refractive Indexes of the Specimens Investigated (lambda=1.06micrometers)

No.	Material	design		deposition parameters	n
		(p, q)	$A[(2p+1)H(2q+1)L]^s(2p+1)HG$		
1	H:TiO_2 L:SiO_2	(0, 0)	$A(HL)^sHG$	EB evaporation	$n_H=2.40$ $n_L=1.46$
2		(1, 0)	$A(3HL)^s3HG$	$T_s=300°C$	
3		(2, 0)	$A(5HL)^s5HG$		
4		(0, 1)	$A(H3L)^sHG$	$T_{baking}=400°C$	
5		(0, 2)	$A(H5L)^sHG$		
6		(1, 3)	$A(H7L)^sHG$		
7	H:ZrO_2 L:SiO_2	(0, 0)	$A(HL)^sHG$		$n_H=1.90$ $n_L=1.46$
8		(1, 0)	$A(3HL)^s3HG$		
9		(2, 0)	$A(5HL)^s5HG$	EB	
10		(0, 1)	$A(H3L)^sHG$	evaporation	
11		(0, 2)	$A(H5L)^sHG$	$T_s=300°C$	
12		(0, 3)	$A(H7L)^sHG$	$T_{baking}=200°C$	

2. Experimental method: Fig. 1 shows the experimental setup for laser damage. Table 2 lists the experimental data. The damage experiment adopts the 1-*on*-1 approach; in other words, only a single laser exposure is made on the same position on the specimen surface, notwithstanding how much damage received by the position. The damage situation in the specimen is determined by the subsequent observation with a high power microscope. The damage threshold is defined by the traditional threshold in the following equation [3]:

$$F_{th}=\frac{[E_{max}(ND)+E_{min}(D)]/2}{A},$$

In the equation, $E_{max}(ND)$ is the highest energy quantity causing no damage to the specimen; $E_{min}(D)$ is the lowest energy quantity causing specimen damage. A is the area of the radiation light spot on the specimen surface.

By adopting the thermal diffraction technique of pulsed light, the absorption of the experimental film system is measured [4,5]. The experimental setup is a collinear layout; in other words, the pumping light (Nd:YAG, lambda=1.06micrometers) is parallel to the measurement light in a near-collinear relation [6], as shown in Fig. 2. This method is used to measure the light absorption of a multilayer medium film with sensitivity approximately at 10^{-5}, and the repeated precision better than 10%. The measurement of the total integrated scattering by the film system was carried out at a laser thin film scattering measurement instrument developed by the Shanghai Institute of Optics and Fine Mechanics. The instrument employs a He-Ne laser as the measurement light source, and adopts the technique of optical modulation, weak signal synchronous phase locking with sensitivity of 10^{-5} and a relative measurement error in excess of 15% [7,8].

TABLE 2. Experimental Parameters of Damage Testing

wavelength	1.06 μm
mode	TEM_{00}
pulse width (FWHM)	10 ns
spotsize $1/e^2$	44 μm

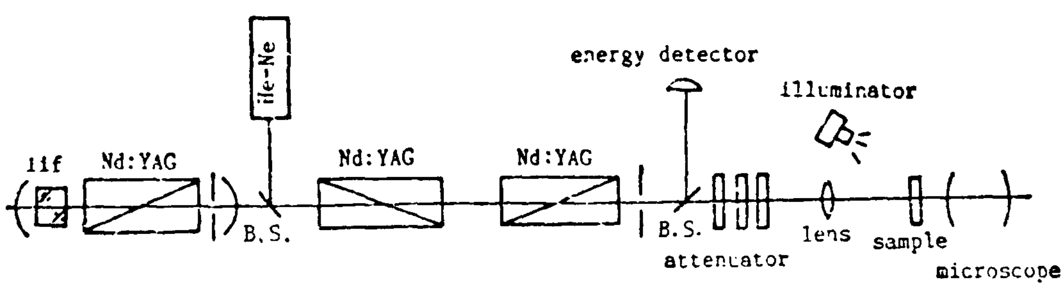


Fig. 1. Experimental setup for damage testing

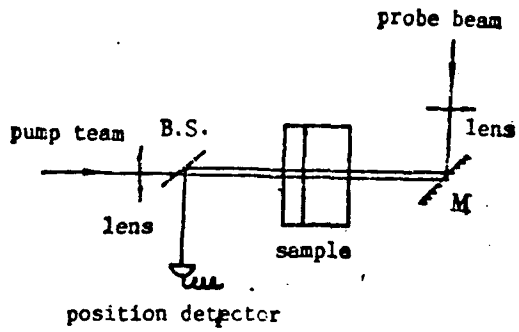


Fig. 2. Schematic diagram of pulsed collinear photothermal deflection technique

III. Results and Discussion

Table 3 shows the measurement and test results of the laser damage threshold values and the optical losses of the thin film specimens that were measured. If these results are expressed in curves, refer to Fig. 3. From Table 3 and Fig. 3, we can see the following:

1. The laser damage threshold apparently relies on the film system structure. As a general rule, with increase in the thickness of the high refractive index medium layer, the laser damage threshold decreases simple-harmonically. However, with increasing thickness of the low refractive index medium layer, first the laser damage threshold improves relatively speaking, in greater amplitude simple-harmonically than when $(2q+1) \geq 7$ or the laser damage threshold of the film system rapidly decreases, becoming considerably lower than the damage threshold of the standard film system $A(HL)^3HG$.

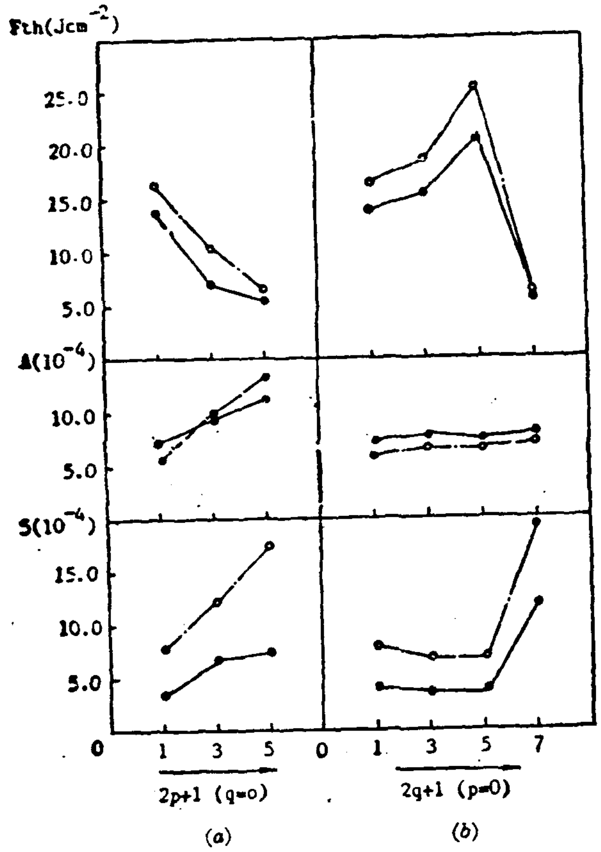


Fig. 3. Representation of the experimental results in Table 3 O—TiO_2/SiO_2; ●—ZrO_2/SiO_2

TABLE 3. Measured Damage Thresholds and Optical Losses of the Samples Investigated

date \ sample	S_1	S_2	S_3	S_4	S_5	S_6
F_{th}(J cm^{-2})	13.8±1.8	7.0±1.6	5.1±1.2	15.2±1.8	20.3±2.0	6.0±3.2
$A(10^{-4})$	7.1±0.5	9.5±0.8	11.2±1.0	7.6±0.7	7.4±0.5	7.8±0.7
$S(10^{-4})$	3.28±0.37	6.58±0.72	7.3±0.81	3.15±0.22	3.01±0.21	10.4±4.3
date \ sample	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
F_{th}(J cm^{-2})	16.3±1.9	10.3±3.1	6.4±2.8	18.4±1.6	25.1±1.8	5.8±3.3
$A(10^{-4})$	5.6±0.6	9.8±1.2	13.2±1.8	6.2±0.6	6.4±0.8	6.9±0.7
$S(10^{-4})$	7.83±0.25	12.1±0.31	17.3±2.8	6.05±0.19	6.70±0.20	19.2±3.4

2. Absorption and scattering losses also exhibit a higher dependence on the film system structure. The general rule is as follows: with increase in the medium layer thickness of the higher refractive index, specimen absorption and scattering increase simple-harmonically; however, with an increase in medium layer thickness of the low refractive index, on the one hand, specimen absorption does not basically change; on the other hand, first specimen scattering slightly decreases, then rapidly increases. This phenomenon is just in contrast to the foregoing for rapid decrease in damage threshold.

By analyzing the above-mentioned experimental results, some preliminary conclusions can be drawn.

1. Absorption of the high refractive index medium layer and the volumetric scattering contribute importantly to the overall absorption and overall scattering of the film system.

2. The laser damage threshold of an optical film system drops simple-harmonically with an increase in the high refractive index medium layer; the reason can be explained as follows: an increase in the thickness of the high refractive index medium layer leads to higher absorption; generally, the profile structure of the high refractive index medium film grows in columnar shape, with an increase in the thickness of the film layer, the columnar-shaped structure is gradually coarser and coarser, together with an increasing number of defects [9].

3. The laser damage threshold of the optical film system improves to a great extent with an increase in thickness of the low refractive index medium layer; this phenomenon can be explained by the growth of the microparticle state with fine and uniform structure, in contrast to the SiO_2 film used for low refractive index material from the profile structure of most thin films [9]. Then, in the multilayer film system, SiO_2 has an improvement function on the boundary surface structure of the film layers. This improvement function increases with increase in film thickness at the optimal state when 2q+1=5. At that time, if a further increase is made in the low refractive index medium layer, due to the stress function, many microcracks form in the multilayer medium film to greatly lower the damage threshold because of a significant increase in film thickness scattering.

In addition, the article studies the thickness effect of the protective film of high refractive film; Fig. 4 shows the related experimental results. By comparing Fig. 4 and Fig. 3 (b), it is easy to observe that there are very similar regularities between the two figures. As explained by this phenomenon, the high refractive film has a protective function as a protective film with the similar mechanism of raising the damage threshold of the film system in the low refractive index film system in a multilayer medium film. The low refractive index SiO_2 film improves the microscopic structure adjacent to the high refractive index medium layer.

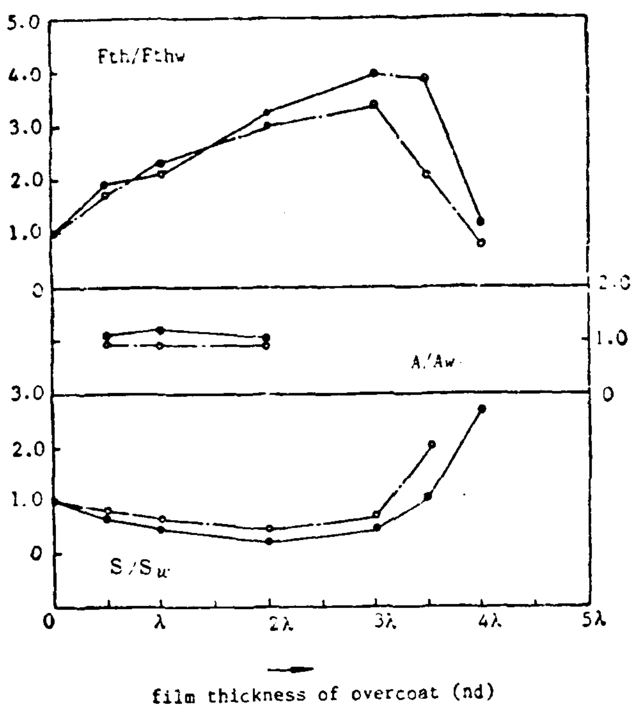


Fig. 4. Film thickness effect of SiO_2 overcoats: O - TiO_2/SiO_2 HR; ● - ZrO_2/SiO_2 HR. (Index w indicates measured results of the specimens without overcoat)

IV. Conclusions

The article studies the effect of film system structure on optical losses of a multilayer medium refractive film and the laser damage threshold. In addition, by combining with the experimental results or the effect of protective film thickness of the high refractive layer, a preliminary discussion of the related mechanisms is made, obtaining some preliminary conclusions. These conclusions have definite instructive bearing on the design and manufacture of heavy-duty laser thin films. The measurement and test results of the damage threshold of the film system can also be used by the appropriate personnel.

The authors are grateful to comrades Fan Ruiying, Lu Yuemai, Gao Yang, Huang Qiang, Chen Yisheng, Shi Boxuan, and Li Zhongya, for their assistance and comments on specimen preparation, measurement and testing.

The article was received on 5 December 1988. The revised article was received on 24 February 1989.

REFERENCES

1. Carniglai, C. K., SPIE 692, 202 (1986).
2. Guenther, K. H., SPIE 801, 200 (1987).
3. Guenther, K. H. et al., Appl. Opt. 23/21(Nov), 3743 (1984).
4. Dalageas, D. L., J. Appl. Phys. 59/2(Feb), 348 (1986).
5. Jackson, W. B. et al., Appl. Opt. 20/8(Apr), 1333 (1981).
6. Wu Zhouling, Zhonggo Jiguang [Lasers in China] 16/8(Aug), 468 (1989).
7. Chen Yisheng et al, Zhonggo Jiguang [Lasers in China] 12/3(Mar), 183 (1985).
8. Chen, Y.S. et al., ICO-13 Conference Digest (Sappora, 1984), 546.
9. Fan Zhengxiu, Jiguang Zashi [Laser Journal] 9/9(Sep), 582 (1982).

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

ORGANIZATION	MICROFICHE
B085 DIA/RTS-2FI	1
C509 BALLOC509 BALLISTIC RES LAB	1
C510 R&T LABS/AVEADCOM	1
C513 ARRADCOM	1
C535 AVRADCOM/TSARCOM	1
C539 TRASANA	1
Q592 FSTC	4
Q619 MSIC REDSTONE	1
Q008 NTIC	1
Q043 AFMIC-IS	1
E051 HQ USAF/INET	1
E404 AEDC/DOF	1
E408 AFWL	1
E410 ASDTC/IN	1
E411 ASD/FTD/TTIA	1
E429 SD/IND	1
P005 DOE/ISA/DDI	1
P050 CIA/OCR/ADD/SD	2
[redacted]	1
1051 AFIT/LDE	1
CCV	1
P090 NSA/CDB	1
2206 FSL	1