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PREPRINT UCRL- 78249

CONF-760724--4

Lawrence Livermore Laboratory

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S. S. Glaros

P. Baker

D. Milam

July 27, 1976

This paper was prepared for submission to
Proceedings of 1976 Symposium on Optical Matl's for High Power Lasers
Boulder, CO, July 15-17, 1976

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DIELECTRIC COATINGS ON METAL SUBSTRATES*

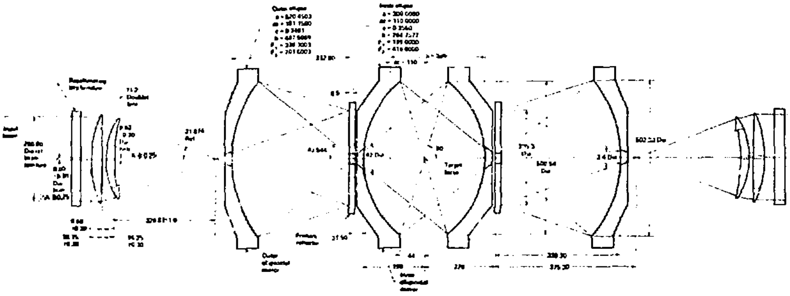
S. S. Glaros, P. Baker and D. Milam
Lawrence Livermore Laboratory
Livermore, California 94550

Large aperture, beryllium substrate based mirrors have been used to focus high intensity pulsed laser beams. Finished surfaces have high reflectivity, low wavefront distortion and high laser damage thresholds. This paper describes the development of a series of metallic coatings, surface finishing techniques and dielectric overcoatings to meet specified performance requirements. Beryllium substrates were coated with copper, diamond machined to within 5 micro-inches to final contour, nickel plated and abrasively figured to final contour. Bond strengths for several bonding processes will be presented. Dielectric overcoatings were deposited on finished multimetalic substrates to increase both reflectivity and the damage thresholds. Coatings were deposited using both high and low temperature processes which induce varying stresses in the finished coating substrate system. Data will be presented to show the evolution of wavefront distortion, reflectivity, and damage thresholds throughout the many steps involved in fabrication.

1. Introduction

The reflectors described in this paper were designed for use with the ARGUS laser. The system shown in figure 1 consists of a pair of nested ellipsoidal reflectors [1], coupled with an aspheric doublet refracting element, which provides uniform illumination of the specified laser beam profile. There are three distinct but interrelated sections of this reflector design; the substrate choice, multi-metallic coating adhesion, and dielectric overcoating choice.

Figure 1: Argus Optics Parameters



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*Work performed under the auspices of the U.S. Energy Research and Development Administration under contract No. W-7405-Eng-48.

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2. Substrate Choice

The mirror substrate material choices were KB-7, Cervit and beryllium. There are four primary properties which determine the final choice since each of the four effect the substrate design [2] at different times during processing and final use.

The first property affecting substrate choice is strength and micro-yield strength. Macroscopic strength affects the shape of the substrate. Micro-yield strength describes local substrate strength. Here beryllium substrates are seven times stronger than those of BK-7 or Cervit thus giving superior rigidity for the same geometric dimensions as seen in table 1. The second property of interest is the modulus of elasticity which is the magnitude of stiffness. Again from table 2, beryllium is four times stiffer than BK-7 and three times stiffer than Cervit.

Due to the required high aspect ratio required in the geometry of the reflecting portion, both strength and stiffness necessitate thicker peripheral sections for BK-7 and Cervit than for beryllium substrates.

The third property affecting substrate choice is thermal diffusivity (K/ρC). A certain amount of the laser pulse energy is absorbed in the coating and transmitted to the substrate. An excellent diffusivity such as that of beryllium, allows for rapid thermal equilibrium.

The fourth design property is thermal distortion which would be experienced in the final step of mirror processing, the dielectric overcoating. This overcoating subjects the substrate to temperatures of 200-300°C. BK-7 experiences nearly six times the distortion of Cervit while beryllium has only twice the distortion. The amount of distortion seen by beryllium substrates can be further reduced by coating both sides and by substrates stabilization where the substrate has been previously subjected to numerous cycles at these temperatures such that all creep has been accelerated prior to final lapping.

The logical choice based on the forementioned properties is beryllium [3], [4], [5] but even this material is subject to further choices. The desired high strength and low creep with relatively low cost and delivery time was met using ultra pure beryllium particles further shattered by impact with a beryllium target in an inert gas atmosphere. This material is subjected to a number of proprietary elevated temperature pressing and sintering operations to give the highest density with a maximum isotropy. The amount of beryllium oxide in the chosen material directly determines the strength and indirectly the amount of long term creep hence long term dimensional stability. A number of different vendors processes will meet the forementioned criteria but hot isostatic pressed beryllium was the least expensive and was available in shorter delivery times than some of the more exotic but slightly superior processes.

Another factor which enters into the substrate choice is economics. Figuring a cervit or BK-7 substrate is projected to be more expensive than diamond turning with final light lapping of the nickel coated beryllium substrate system.

Table 1: Mirror Substrate Design Parameters

MATERIAL ρ (gm/cm³)	E MODULES OF ELASTICITIES (10^6N/cm²)	MYS MICRO YIELD STRENGTH (psi)	UTS ULTIMATE TENSILE STRENGTH (psi)	K THERM CONDUCT (Cal/cm-sec C)	C SPECIFIC HEAT (Cal/gm C)	α COEF OF THERM EXPANSE (10^{-6}/C)	D THERMAL DIFFUSIVITY K/ρC	THERMAL DISTORTION α/D (x 10^6)	T TRANS (C)
BK-7 2.200	7.00	1,500	-	0.0033	0.188	0.55	0.008	69.0	1,500
CERVIT 2.500	9.23	1,500	-	0.0040	0.217	0.10	0.008	14.0	800
BERYLLIUM (KBI HP-20) 1.852	28.00	3,000-10,000	55,200	0.3800	0.450	12.40	0.450	27.0	1,300

Figure 2: Non-Contract Interometer Results on HP-20 Be 2" Disks

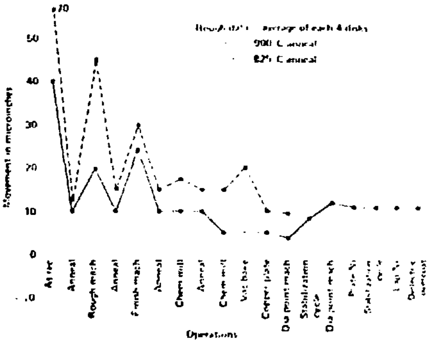
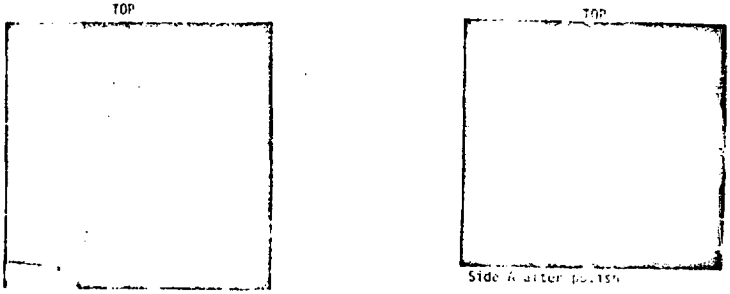
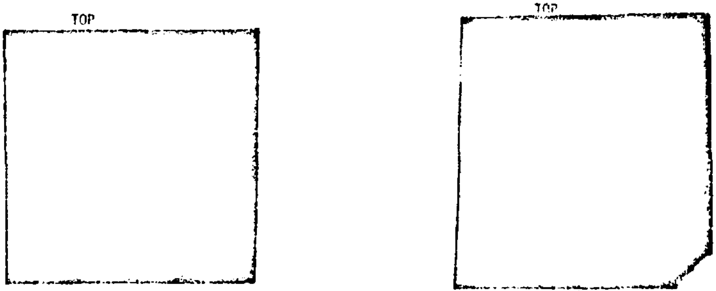


Figure 3: Interferograms During Processing of a Sample



Side A after coating

Side A after polish



Side B after coating

Side B after polishing

Table 3: Plating Bond Strengths

PLATING BOND STRENGTHS

SAMPLE NO. LOC	SINGLE ZINCATE Cu STRIKE Cu	DOUBLE ZINCATE Cu STRIKE Cu	DOUBLE ZINCATE Cu STRIKE Cu STABILIZED AT 150°	DOUBLE ZINCATE Cu STRIKE Cu STABILIZED AT 325 C
1 *RF	23,400 psi	8,8?0 psi	2?,700 psi	35,500 psi
2 *RF	12,700	4,600	15,300	22,600
3 *RF	17,600	2,000	15,500	
4 *RF	16,400	1,700		
5 *RF	15,200	1,300		
6 *RF	16,400			
7 *RF	11,500			
8 *RF	11,300			
9 *RF	22,400			

	DOUBLE ZINCATE Cu STRIKE Cu	DOUBLE ZINCATE Ni STRIKE Cu (Ni 2%)	DOUBLE ZINCATE Cu STRIKE Cu	DOUBLE ZINCATE Cu STRIKE Ni DIP Cu
1 LLL		7,389 psi	18,875 psi	11,031 psi
2 LLL		1,562	22,[illegible]	12,971
3 LLL		1,826	22,530	11,361
4 LLL		2,038	22,557	17,654
		(Ni 7% + ACID)		
5 LLL		1,853		
6 LLL		6,026		
7 LLL		4,035		
8 LLL		19,395		
		(Ni 5%)		
9 LLL		8,564		
10 LLL		4,370		
11 LLL		6,532		
12 LLL		3,341		

*ROCKY FLATS PLANT OF NORTH AMERICAN ROCKWELL

4. Dielectric Overcoating

A number of different dielectric coatings were deposited on the successful substrate system candidate. Additional coating runs were made at a number of temperatures since potential stress introductions was suspected at the elevated temperatures. Since the samples consisted of many coatings of dielectrics, metals and beryllium, there was good reason to expect the coefficients of thermal expansion to vary such as to induce stress hence change the final figure. Interferograms were taken after coating to determine whether stress induced figure changes had occurred. Table 4 shows the relationship of the number of coatings on each sample, type of coating, application temperature, induced wavefront distortion, reflectivity, surface quality, and damage threshold.

Table 4: Dielectric Coating Parameters

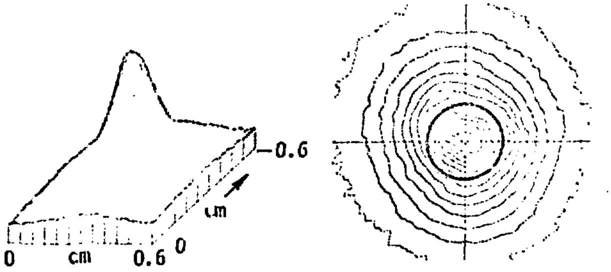
SAMPLES	REFLECTIVITY (%) AT 1.06 μm	SURFACE QUALITY SCRATCH/DIG	LAYERS	COATING	COATING APPLICATION TEMP (°C)	WAVEFRONT DISTORTION λ AT 1.06 μm	DAMAGE THRESHOLD (J/cm² FOR) 125 ps
1	99.5		[illegible]	ThF$_4$*	350	0.10	7.0 ± 1.5
2	[illegible]		[illegible]	ThF$_4$*	200	0.05	6.5 ± 1.5
3	>99.5		20	ZrO$_2$ + SiO$_2$	275 ± 25	0.75	4.1 ± 0.5
4	>99.0		20	ZrO$_2$ + SiO$_2$	275 ± 25	0.05	3.6 ± 0.5
5	>99.0		12	TiO$_2$ + SiO$_2$**	275 ± 25	0	6.5 ± 1.5
6	>99.0		12	TiO$_2$ + SiO$_2$	275 ± 25	0	5.0 ± 1.0
7	>99.0		12	TiO$_2$ + SiO$_2$	175 ± 25	0	1.4 ± 0.4
8	99.6	80-50		ZrO$_2$ + SiO$_2$**	300	0	3.6 ± 0.5
9	99.7	80-50		ZrO$_2$ + SiO$_2$**	200	0.05	3.1 ± 0.5
10	99.9	80-50		TiO$_2$ + SiO$_2$**	300	0	3.3 ± 0.5
11	99.7	80-50		ZrO$_2$ + SiO$_2$**	200	0	2.3 ± 0.5
12	99.6	80-50		TiO$_2$ + SiO$_2$**	200	0	1.75 ± 0.5

* AUGER ANALYSIS OF TOP COATING
** AUGER ANALYSIS OF TOP TWO COATINGS

5. Dielectric Coating Damage Testing

Damage thresholds were measured using linearly polarized 1064 nm pulses 125 ± 25 psec in duration at nearly normal incidence. Peak energy density for each pulse was determined by reconstructing the spatial profile of the beam from a photograph, and normalizing the profile to agree with the energy contained in the pulse. A typical beam profile is shown in figure 4, with the associated isointensity contour plot. The circle scribed on the contour plot indicates the portion of the profile used in the normalization. On-axis integrated energy density can be determined to within ± 5-7%.

Figure 4: Laser Pulse Utilized in Damage Testing



Energy density (J/cm^2)

Isointensity contour plot

6. Summary

From the data collected in table 4, it becomes apparent that the higher coating temperatures induces distortion into the coated substrate. The coating with neglible distortion and next to highest damage threshold was found in sampe #5. This sample was a 12 layer stack alternating TiO_2 and SiO_2 at 275°C temperatures resulting in no induced distortion and a damage threshold of 6.5 J/cm^2.

7. Conclusion

The beryllium substrate system with all of its complicated processing did prove to be about 50% less expensive than the comparable Cerevit or BK-7 substrate system after coating.

The multi-metallic coatings applied to the substrate did provide bond strengths nearly equivalent to the beryllium substrate strength itself.

The dielectric overcoating developed for this substrate does provide a distortion free coating with as high a laser damage threshold as any glass substrate coated system.

8. Acknowledgments

The authors wish to acknowledge the extensive support of J. L. Emmett and H. G. Ahlstrom. The multi-metallic coating work was done by W. Kelly and E. Childs. The dielectric coatings were developed in conjunction with Coherent Radiation, OCLI and Spectra Physics.

9. References

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