研 究 速 報
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RELATIONSHIP BETWEEN OPTICAL DAMAGE THRESHOLD AND RESIDUAL ABSORPTION IN EXCIMER LASER COMPONENTS

エキシマレーザー用光学素子の光損傷しきい値と残存吸収の関係

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Introduction

Optics of excimer laser system must have a small aberration under high energy flux. In most of such system, ray passes through more than ten surfaces such as windows, lenses or mirrors, so that anti-reflection or high-reflection coatings must be needed. The coatings is so thin that the absorption coefficients is large even if its total absorption is small. Optical damage of the coatings limits the peak and/or total energy of high power optics.[1,2] It becomes necessary to measure the absolute value of the damage threshold with high reproducibility and also to study the cause of the damage so as to make new coatings with higher damage threshold.

Damage Threshold Measurements

In measuring the damage threshold, it is important to monitor the fluence on the sample, and to determine whether the damage occurs or not. To calculate the fluence we measure the total energy which reaches to the sample surface, the spot size on sample and the spatial distribution of the beam. Measurement system is shown in Fig. 1. We control the total energy on the sample by moving lens L_1 along the optical axis. The image of aperture Ap falls on sample surface through lenses L_2 and L_3, so that spot size does not change with moving lens L_1. The optical system is designed as quasi infinite condition. Beam pattern is measured by fluorescence of scintillation film which is the magnified image of aperture. Power monitoring error is about 0.7% rms. Measurement system is controlled by micro-computer (DEC, LSI-11/73).

We monitor the damage in three ways. One is realtime observation on sample surface from back side by optical microscope with low magnification of 100. Second, scattered light of co-axial He-Ne laser is observed with human eyes. Though above two techniques are advantageous in that realtime observation, sensitivity is not high in all morphology of the damage. So the final determination of damage we use Nomarsky optical microscope with magnification of 1000, where we observed the damage sites with diameter equal or less than 1 μm. The threshold is the mean value between maximum fluence without damage and minimum fluence with damage.

Results of the damage threshold measurements of anti-reflection and high-reflection coatings is shown in table 1 and 2. A combination of the high and the low index materials that we got the highest damage threshold is Sc_2O_3/SiO_2 for anti-reflection coatings and Al_2O_3/SiO_2 for high-reflection coatings. We also measure damage threshold of optical coatings for 193 nm ArF excimer laser light, after correcting the chromatic aberration of the measurement system.

Absorption Measurements

Optical absorption is one of the most probable cause of damage in Excimer laser coatings at $\lambda = 248$ nm. We measured the absorption of the coatings by the interferometric laser calorimetry. The temperature rise caused by the absorption of the laser beam is determined by the measurement of the change in optical path length, which is measured by the Twyman-Green type inrferometer. Measurement sys-

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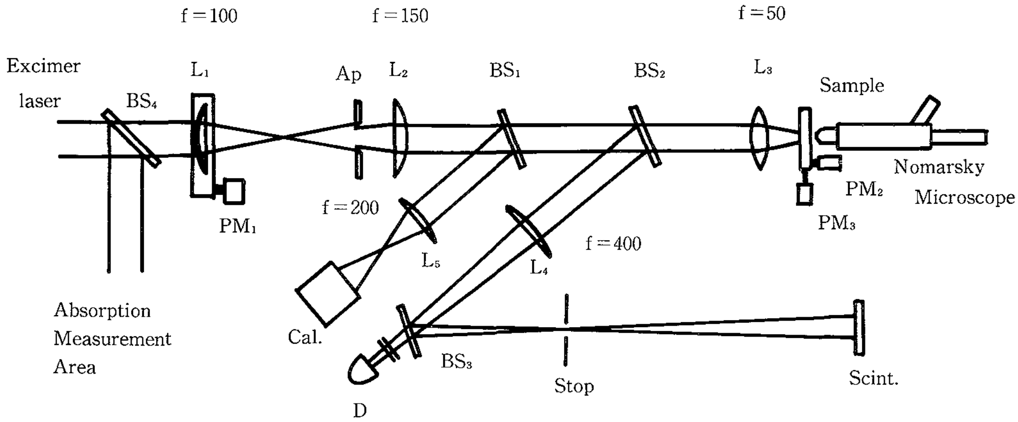


Fig. 1 Laser damage threshold measurement system

Table 1 Damage threshold of anti-reflection coatings.

Materials (high/low index)	Specification	Damage threshold (J/cm²)
Al_2O_3/SiO_2	NQW, UC : MgF_2	1.41
Al_2O_3/MgF_2		1.03
Al_2O_3/SiO_2	NQW	0.92
Sc_2O_3/SiO_2	CaF_2 substrate	1.65
Sc_2O_3/SiO_2	NQW, 4L, 250°C	1.64
Sc_2O_3/SiO_2	NQW, 4L, 200°C	1.17
Sc_2O_3/SiO_2	NQW, 4L, 250°C	0.99
HfO_2/MgF_2	NQW, UC : MgF_2	1.05
Y_2O_3/MgF_2	NQW, UC : MgF_2	1.10

NQW : non-quater-wave design,
UC : under-coated,
4 L : four-layer design, and
Centigrades (°C) : substrate temperature.

Table 2 Damage threshold of high-reflection coatings.

Materials (high/low index)	Specification	Damage threshold (J/cm²)
Al_2O_3/SiO_2	OC: MgF_2	6.50
Al_2O_3/SiO_2	OC: SiO_2	2.29
Al_2O_3/SiO_2	OC: SiO_2, NQW I	1.66
Al_2O_3/SiO_2		1.56
Sc_2O_3/SiO_2, MgF_2	OC: SiO_2	1.65
Sc_2O_3/SiO_2, MgF_2	OC: SiO_2, NQW I	1.37
Sc_2O_3/SiO_2, MgF_2	OC: SiO_2, NQW II	1.35
ZrO_2/SiO_2		<0.6
HfO_2/SiO_2		0.8
HfO_2/MgF_2	OC: MgF_2	2.31
Y_2O_3/MgF_2	OC: MgF_2	2.35

NQW I : non-quater-wave design for one pair
NQW II : non-quater-wave design for two pairs
OC : over-coated.

tem is shown in Fig. 2. Increasing sensitivity, we modulate an optical path of the reference arm by moving the mirror M_1 with the piezo-electric transducer PZT_1. We can lock the fringe by moving the mirror M_1. We can obtain the change in optical path length of the sample by the feedback voltage to the PZT_2.

In previous paper[3] we discussed about absorption measurements of the rectangular parallelepiped sample. We use the similar technique that we get the temperature distribution in the disk-like sample. The optical path length is proportional to the integration of the temperature along observation axis. We can obtain the film absorption by linear fitting of the change of optical path length to the solution of the thermal equation.

Results

Optical damage may result from dielectric breakdown, evaporation by absorption and fracture by thermal stresses. We will make qualitative analysis about the morphological study, damage localization, and the influence of film design. Some photographs of damage sites is shown in Fig. 3.

In high-reflection coatings, film melts irrespective of coating materials. If micro damage occurs, it degrade the film quality, so that absorption increase.

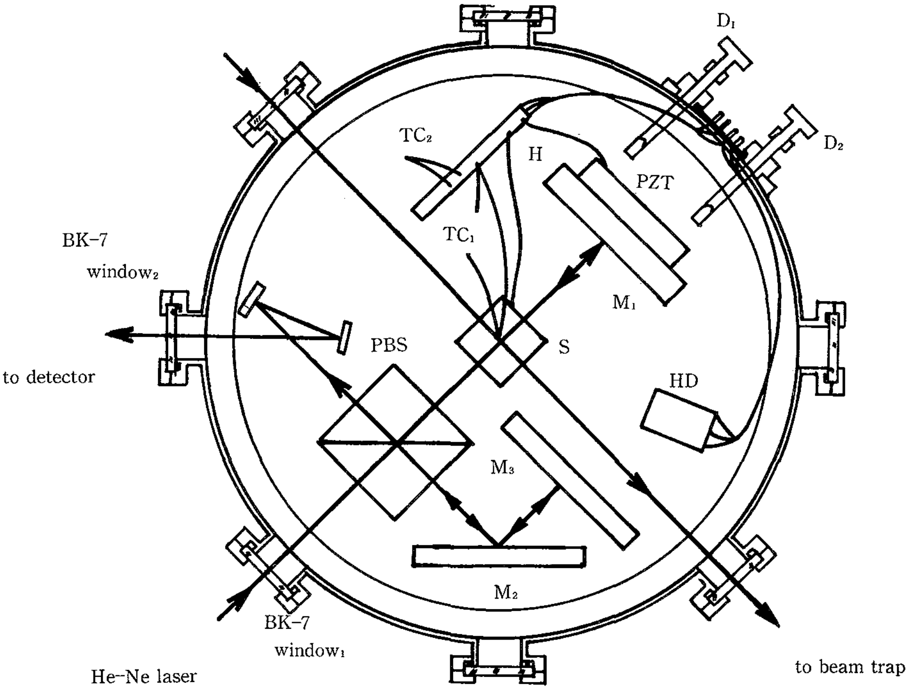
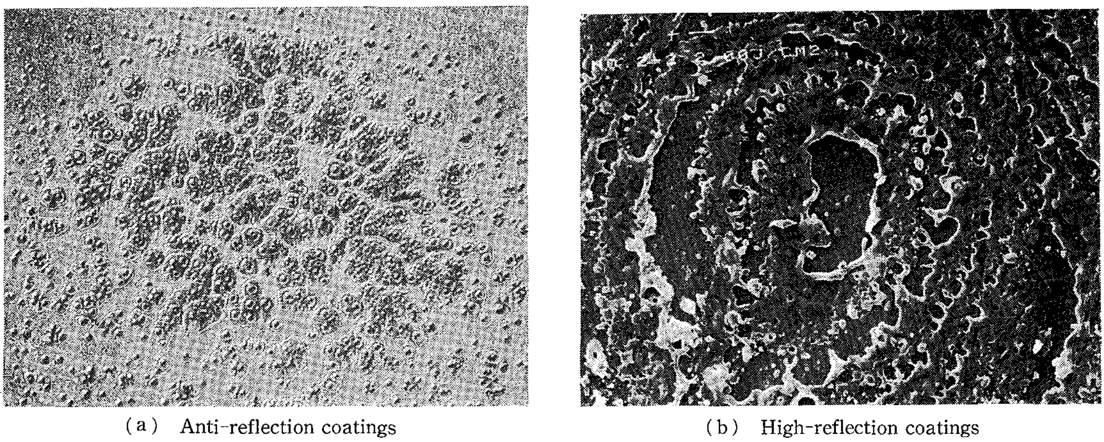


Fig. 2 Optical system of the interferometric laser calorimeter



(a) Anti-reflection coatings　　(b) High-reflection coatings

Fig. 3 Photograph of damage sites

With increasing the laser fluence, greater damage occurs.

In anti-reflection coatings we cannot observe the change of surface damage. By optical microscope, circle damage which diameter is $1\sim10\mu m$ is observed. The damage is non-absorbing because damage sites do not grow even number of site increase with increasing laser fluence.

In our experiments, non-quarter-wave stack made no difference in its damage threshold. It shows that damage depends on the total energy instead of the electric field. On the contrary, damage threshold increase with the half-wave overcoat in high-reflection coatings. The reason might be that the overcoat surpresses the evaporation of the top layer of quarter-wave stack.

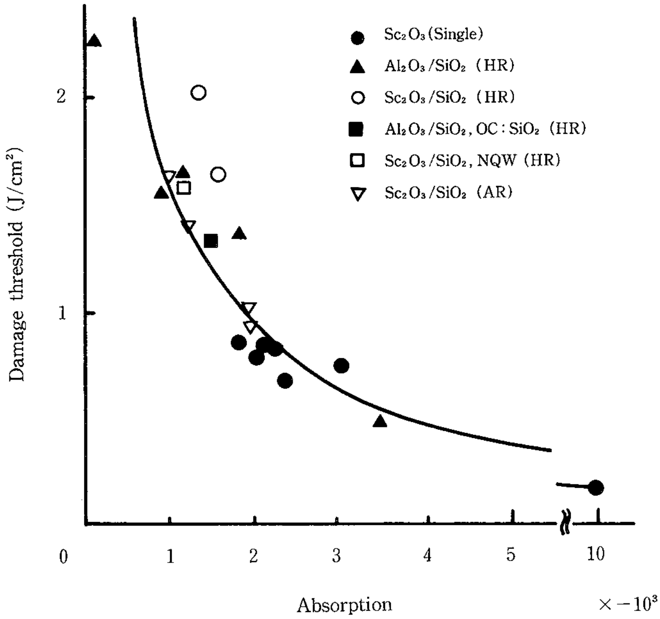


Fig. 4 Relation of damage threshold and residual absorption in optical coatings for $\lambda = 248$nm (experiments)

From the above arguments, it follows that the main cause of the damage of the optical coatings for $\lambda = 248$nm is the residual absorption of the films. Figure 4 shows the relation of the damage threshold and the residual absorption of the high and anti-relection conatings for $\lambda = 248$nm excimer laser components. The higher absorption gives the lower damage threshold. The solid line in the graph shows the constant energy in the film at the threshold.

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