Impact of organic contamination in vacuum on laser-induced damage threshold of TiO_2/SiO_2 dielectric mirrors

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The influence of organic contamination in vacuum on the laser-induced damage threshold (LIDT) of coatings is studied. TiO_2/SiO_2 dielectric mirrors with high reflection at 1064 nm are deposited by the electronbeam evaporation method and their LIDTs are measured in vacuum and atmosphere, respectively. It is found that the contamination in vacuum is easily attracted to optical surfaces because of the low pressure and becomes the source of damage, O_2 molecules in vacuum with contamination can accelerate the laser-induced damage by observing LIDT and damage morphologies. LIDTs of mirrors have a little change in vacuum compared with in atmosphere when the organic contamination is wiped off. The results indicate that organic contamination is a significant reason to decrease the LIDT in vacuum.

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Laser induced damage of optics is a common problem for all high power lasers and becomes even more important for spaceflight lasers[1]. Because the surroundings in space are different from that in atmosphere, the materials in vacuum may give out diversified gases or become volatile themselves. They make contamination for optical mirrors, and affect their laser-induced damage thresholds (LIDTs), so the simulation measurement in high vacuum is important and effective for evaluating the LIDT of optical component used in space.

There are many countries involved in the study of space damage of optics. At the German Aerospace Center in Stuttgart[2,3] a vacuum laser damage test bench was developed for the test of space laser optics. The damage data was evaluated according to ISO 11254, parallel testing of reference samples showed a distinct degradation under vacuum compared with atmospheric or pressurized environment. Christopher Scurlock of American Genesis engineering solutions[4] found that the presence of trace levels of contamination to an otherwise evacuated system led to rapid onset of damage to optical elements in the presence of 1064-nm laser radiation. These results prove that optical components are affected by contamination in vacuum, but there lacks damage mechanisms understanding of dielectric optics exposed to vacuum. Little is known about the effect of O_2 or N_2 molecules on the LIDT in vacuum.

In this letter, we measure the LIDT of high-reflectance (HR) coatings at 1064 nm in vacuum, and investigate the effect of organic contamination, O_2 and N_2 molecules on the LIDT. These findings may be useful for improving LIDT in vacuum and practicable for the application of optics in space or similar environments.

The experimental setup is shown schematically in Fig. 1. The parameters of measure are listed in Table 1. Nd:YAG laser delivers a single longitudinal mode, Gaussian-shaped laser beam of high spatial quality at a wavelength of 1064 nm. The spatial distribution of laser measured by Beam ViewTW beam diagnostics is shown in Fig. 2. The test method of LIDT is 1-on-1, according to Refs. [5] and [6].

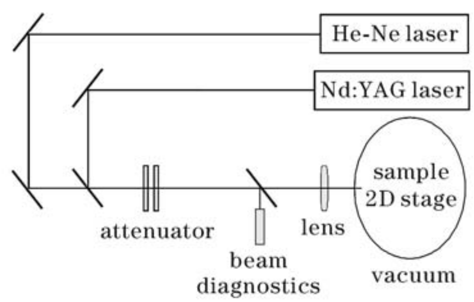

Fig. 1. Measurement setup of laser-induced damage.

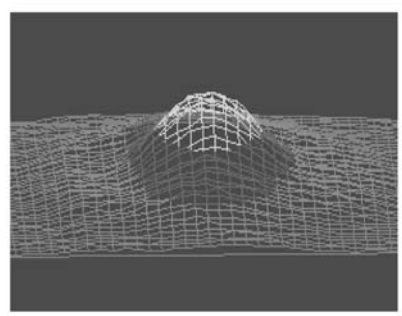

Fig. 2. Spatial distribution of laser.

Table 1. Parameters of Laser-Induced Damage Experiment

Laser Wavelength (nm)	1064
Mode of Operation	TEM_{00}
Incident Angle (deg.)	0
Pulse Duration (ns)	12
Testing Method	1-on-1
Gaussian Diameter (μm)	500

Samples are deposited by electron beam evaporation one run in the same chamber. They are divided into four groups, each group has two samples. Each sample is measured three times in different areas, the first time in atmosphere without contamination, secondly in vacuum, and thirdly after the air vented. The gaseous composition in vacuum can be adjusted conveniently, we can add the organic contamination to the vacuum by vent. Group A is measured with O_2 pressure and group B with N_2 pressure in vacuum with organic contamination, group C with O_2 pressure and group D with N_2 pressure in vacuum after eliminating organic contamination. The base pressure is 8×10^{-3} Pa, and O_2 pressure or N_2 pressure is 6.0×10^{-2} Pa. Organic contamination is inspected using KTKY Series Quadrupole Mass Spectromerers, as shown in Fig. 3. Figure 3(a) is the relative gaseous composition in vacuum with organic contamination, Fig. 3(b) is the one after eliminating organic contamination, the pressure inspected is 3×10^{-3} Pa.

Figure 4 shows that the LIDTs fall when there are organic contamination in vacuum, which still affects the LIDT after the air is just vented over. When the contamination presents in vacuum, O_2 molecules accelerate the laser damage and decrease the LIDT greatly, while N_2 molecules have a little effect on the LIDT. Figure 5 shows that the LIDT in atmosphere is similar to the one in vacuum after eliminating contamination, O_2 molecules and N_2 molecules have little influence on the LIDT.

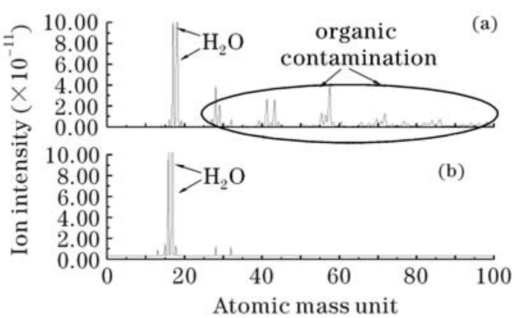

Fig. 3. Ion intensity of vacuum gaseous composition.

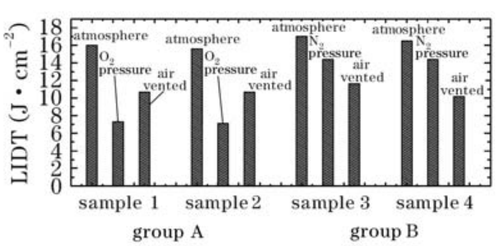

Fig. 4. LIDTs of group A measured with O_2 pressure and group B with N_2 pressure in vacuum with organic contamination.

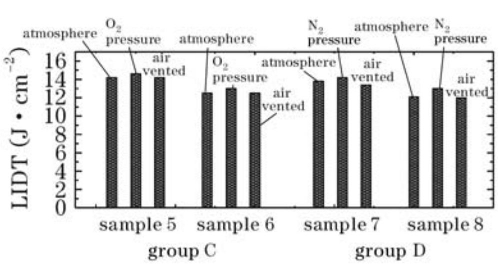

Fig. 5. LIDTs of group C measured with O_2 pressure and group D with N_2 pressure in vacuum after eliminating organic contamination.

Figure 6 shows the display of the surface with organic contamination using WYTO NT1100 optical profiling system and sketch map of laser irradiation. It is obvious that there are many droplets on the surface and the distance between droplets is far less than the beam diameter (500 μm), that means each laser beam can cover many droplets. When the organic contamination is present in vacuum, low pressure makes them against any optical surface and form droplets easily. Figure 7 shows the three-dimensional (3D) interactive display after wiping off contamination, there have no droplets on surface. It also indicates that the droplets are made of contamination, and organic contamination is a significant factor to affect LIDT in vacuum.

Figure 8 shows the damage morphologies of samples (a)—(d), sample (a) is produced in atmosphere, (b) in vacuum with O_2 molecules and organic contamination, (c) in vacuum with N_2 molecules and organic contamination, and (d) in vacuum with O_2 molecules after wiping off organic contamination. Damage morphology of sample (b) shows clear and serious black trace and (c) shows slight black trace on the surface of coating, while (d) is similar to (a), has not the black trace. These damage morphologies indicate that droplets are the source of serious damage in vacuum. When the O_2 is present in vacuum, chemical reaction may be happened between O_2 molecules and organic contamination on the surface of coatings during the fluence processing, this accelerates the damage and decreases the LIDT greatly.

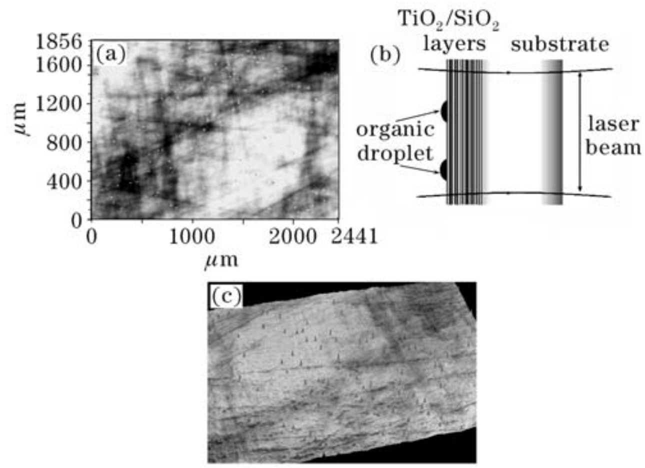

Fig. 6. Surface display and sketch map of laser irradiation with contamination. (a) Two-dimensional display with contamination, (b) sketch map of laser irradiation, and (c) 3D interactive display with contamination.

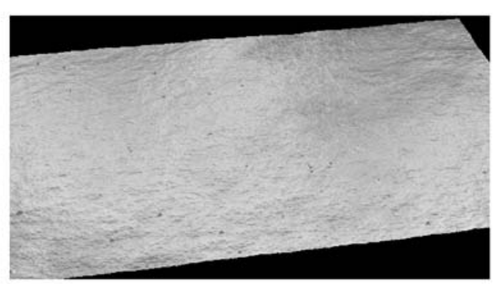

Fig. 7. 3D interactive display after wiping off contamination.

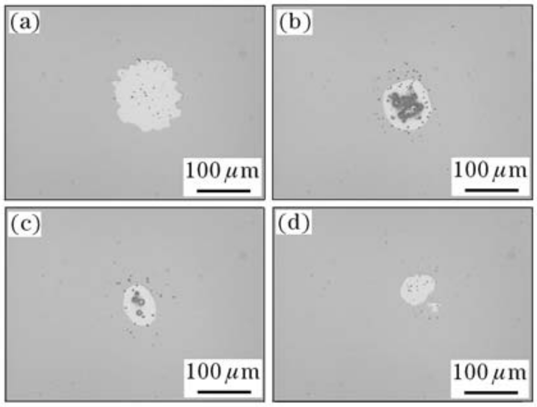

Fig. 8. Damage morphologies of the samples with the fluence of 20 J/cm^2 measured (a) in atmosphere, (b) with O_2 pressure and organic contamination in vacuum, (c) with N_2 pressure and organic contamination in vacuum, and (d) with O_2 pressure without organic contamination in vacuum.

In conclusion, we have studied the effects of organic contamination on LIDT of TiO_2/SiO_2 mutilayers. It is found that organic contamination is a significant factor to reduce the LIDT. When O_2 molecules and contamination are present at the same time, the damage becomes more serious because the chemical reaction is likely to happen between them on the coating surface. In this field, further and meticulous investigation are needed for better understanding the laser-induced damage in vacuum or similar environments.

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