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High laser damage threshold coatings and damage testing technology

MA Ping, HU Jian-ping, CHEN Song-lin, TANG Ming, WANG Zhen, LI Wei, XU Qiao

(Chengdu Fine Optical Engineering Research Center, Chengdu 610041, *China)*

Abstract: The laser-induced damage threshold (LIDT) of optical coating is a limited factor for development of a high peak power laser. The automatic damage testing facility was built to determine the LIDT of optics at 1 064 nm and 355 nm.. The cleanning and processing procedure of the substrate and coating technique were improved, and the damage resistance of high-reflective coating at 1 064 nm was increased.

Key words: laser coating; laser damage threshold; damage testing

1　Introduction

The laser-induced damage threshold (LIDT) of optical coatings is a limited factor for development of a high peak power laser. The output fluences that can be attained on the National Ignition Facility (NIF) which contains 192 beamlines built by the Unite States are ultimatly limited by optical coatings within the chain. These optical coatings need to satisfy the fluence request, 22 J/cm^2 for reflective mirrors and 11 J/cm^2 for polarizers (1 064 nm, 3-ns pulse length). Because the damage mechanism of the coatings under strong laser irradiation is very complicated, due to a lot of relevant factors, such as different manufacture progresses, layer combinations, deposition techniques, and laser parameters. Therefore, the researchers in optical coating field focused all their attention on finding a solution to increase the laser damage threshold of optical coating[1-4]. Our recent research on laser coatings has been reported in this paper.

2　Measurement of the laser damage threshold

We have set up a testing facility to measure laser damage threshold of optical coatings. The layout of the facility was showed in Fig. 1.

The measuring system consists of a Nd:YAG laser, a series of optics for frequency conversion, a beam splitter, a translated sample stage, an energy meter, a CCD camera, and a He-Ne laser collimation source, etc.. The damage wavelength can be convenient to change at 1 064 nm and 355 nm. The measure system is controlled by computer, so it is easy to operate and handle. The damage experiment can be conducted using 1-on-1, N-on-1, S-on-1, and R-on-1 laser modes. In the laser damage threshold measurement, the laser parameter should be measured such as pulse width of laser, laser space distribution, laser energy and effective area of laser light beam on the sample surface.

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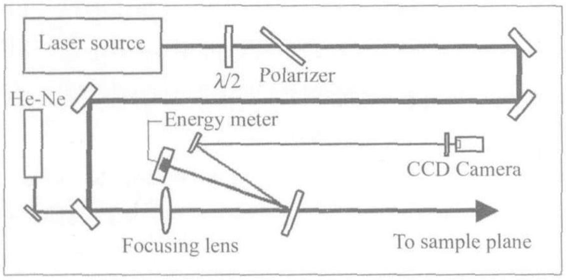

Fig. 1 Schematic diagram of laser damage threshold testing facility

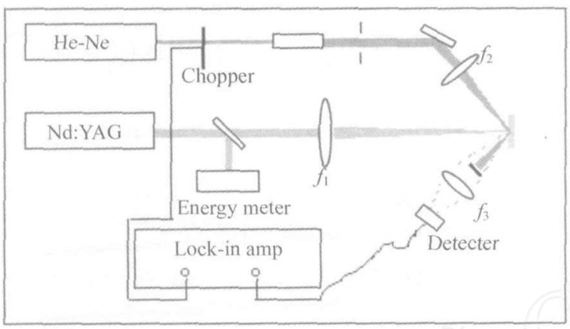

Fig. 2 Schematic diagram of scattering signal detector

To determine damage, we have added the He-Ne laser scattering detector in the system, the layout is shown in Fig. 2.

Passed through chopper the He-Ne laser light became modulation light, then incidenced with 45° angle on the sample surface, and accurately coincided with damage laser facula. Scattering light passed the collective lens focus on the photoelectric probe. The slight scattering signal was accepted by a phase locking amplifier. When laser induce damage take place, the laser scattering signal will be harder, and then we can judge the laser induced damage in real time.

In this paper, damage of optical coatings was using 1-on-1 mode, and pulse width was 10 ns. Damage sites were investigated by Normarski microscope at 100～200 ×. If any permanent change can be observed on sample surface, in other word, laser induced damage existed.

Laser damage threshold is defined with zero probability method. We graph damage probability at different energy density, and a linear extrapolation of damage probability data to zero damage probability yields the threshold.

3 Research of the thin films

3.1 Cleaning and treatment of the substrate

The optical component for the laser system need satisfy certain demands, such as surface roughness and figure. All substrates are obtained after shaping, grinding and polishing. The state of the substrate surface significantly influence on coating quality (adhesion, microstructure, distribution of the defect), optical loss, and damage resistance. Impurity and particle on substrate surface and in layer interface will absorb laser, result in damage. Thus, high-quality cleaning procedure before coating is an important process. We have used mechanical and chemical cleaning process and obtained satisfied result.

We used ultrasonic technology to clean the substrate, and studied the relationship between the damage threshold of single layers and the different cleaning procedures. Then the highest damage threshold with best procedure was found.

Recent research indicated that the damage threshold had been influenced not only by the existence of surface defects, but also subsurface defects, especially for transmission components.

The subsurface defects were produced during fabrication, including impurity, scratch and little crackle under surface that extent on the order of several to hundreds microns into the bulk. Existence of subsurface defects would cause laser absorption and increase electric field distribution, thus rise the damage probability in the bulk or on the back surface.

We have studied on the subsurface defects with the different etching processes. As shown in Fig. 3, the substrate in (b) has appeared to subsurface defect. These two substrates come from different vendors were measured by WYKO roughness instrument after chemical etching for one micrometer.

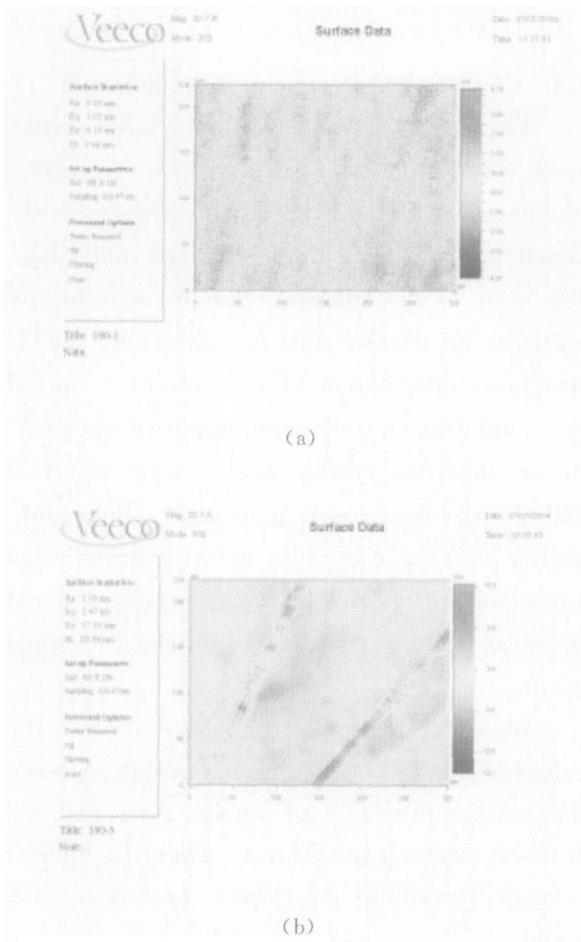

Fig. 3 Measuring results of different substrates after chemical etching

As a brief summarization, we need remove not only the contamination on substrate surface ,but also the subsurface defects, and we must consider suitable process for the different subsurface defects caused by different fabrication technologies. The treatment process is complicated and needed to be studied further.

3.2 Deposition parameters

Oxygen partial pressure and substrate temperature are two key parameters to electron beam evaporation technology.

Zirconia is a very good coating material for high laser damage threshold coatings. We prepare two group ZrO_2 samples at different substrate temperatures and Oxygen pressures. Microstructure and damage characteristic of ZrO_2 thin films has been studied[5].

XRD diffraction pattern at different oxygen pressures was shown in Fig. 4. It was obvious that with the increase of O_2 pressure, the morphology of thin film transition occured from polycrystalline to amorphism.

Fig. 5 showed XRD diffraction pattern at different substrate temperatures of ZrO_2 thin films, we can see that the microstructure of ZrO_2 thin films was changed from amorphism to polycrystalline with the rising temperature.

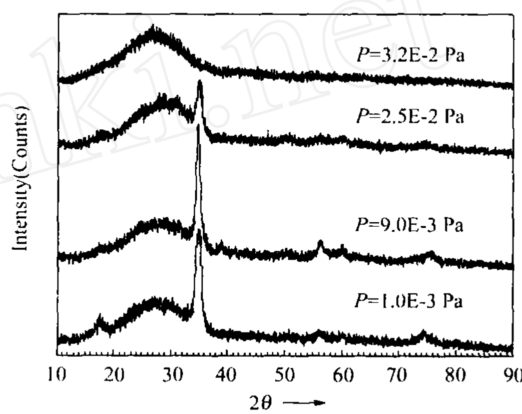

Fig. 4 XRD diffraction pattern at different Oxygen pressures of ZrO_2 thin films

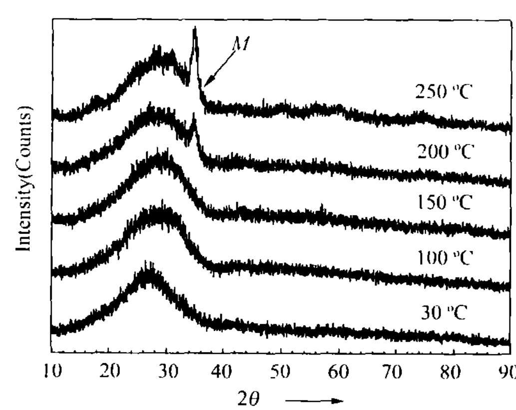

Fig. 5 XRD diffraction pattern at different substrate temperatures of ZrO_2 thin films

Fig. 6 and Fig. 7 presented damage threshold of ZrO_2 thin films as a function of temperature and Oxygen pressure respectively. It was obvious that the damage threshold of ZrO_2 thin films has the tendency to decrease gradually as the temperature rising, simultaneously, with the rising of Oxygen pressure, the microstructure of thin films will be changed from polycrystalline to amorphism, but the damage threshold didn't increase gradually. This phenomenon indicated that the relationship between microstructure and damage resistance is complicated, so it is necessary to choose suitable parameters for the acquisition of high threshold coatings.

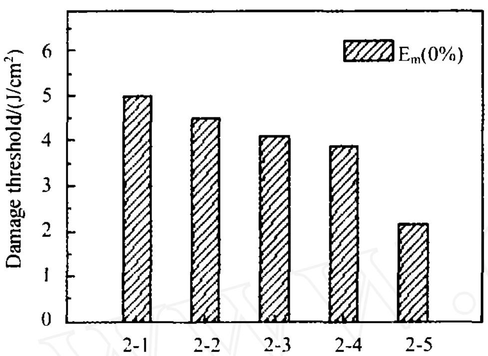

Fig. 6 Damage threshold of ZrO_2 thin films at different temperatures

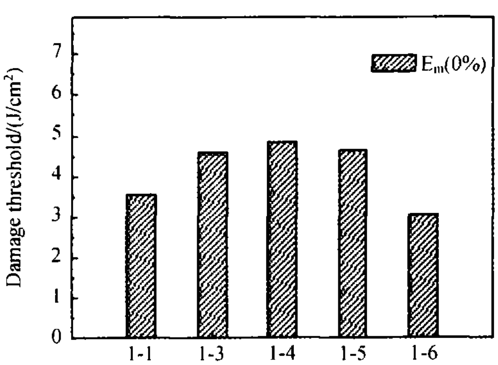

Fig. 7 Damage threshold of ZrO_2 thin films at different oxygen pressures

3.3 Surface defects

Impurity and nodular defect are mainly causes for the coating failure[6]. Under the laser irradiation, nodular defect is broken at first. Nodular defects come from the manufacturing, transport of substrate, coating process, etc. The emphasis of the development effort of us was to improving the fabrication process. After optimizing the coating parameters, making coating process stabilization, we restricted the forming of defect.

3.4 1 064 nm reflective coating

We prepared the reflector by APS1504 coating machine. The layer design was 45° of incidence, stack G| $(HL)^{18}$ H2L| Air (H: HfO_2, L: SiO_2) with $\lambda/2$ SiO_2 overcoat for improving the damage resistance[7]. Substrate was fusion quartz, mean square root surface roughness (Rq) was 0.6 nm, and the diameter was 85 mm.

Measuring result indicated that damage threshold (1 064 nm, 10 ns) of zero probability was 46 J/cm^2, converted to 3 ns reached 30 J/cm^2 (1 064 nm, 3 ns). Fig. 8 shown the damage morphology. From this figure we found that, there were less nodular defect on the coated surface and the density of defects was obviously small. This result demonstrated that damage threshold tightly correlated to the number of impurity and nodular defect.

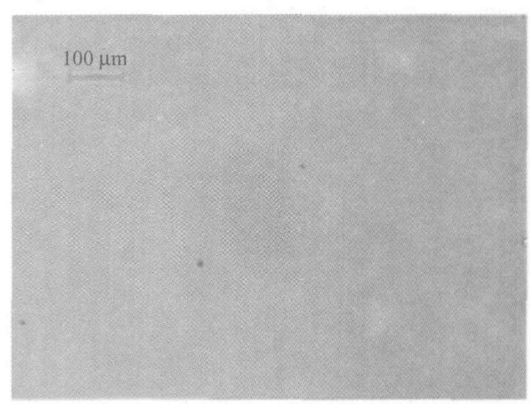

Fig. 8 Photograph of damaged reflector at 1 064 nm

4 Conclusion

We have set up an automatic laser induced damage threshold testing facility, this facility can determine the damage threshold at 1 064 nm and 355 nm. By improvimg the substrate treatment process and the coating technology, we have made some progress on high laser damage threshold coatings research, and the damage threshold of the 1 064 nm reflective coatings reached 30 J/ cm^2 (1 064 nm ,3 ns) .

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Brief professional biography of the author :

MA Ping ,vice director of Fine Optical Engineering Research Center (FOERC) ,was born in 1974. He received his B. S degree in 1994 and M. S degree in 1997 from Sichuan University. Now ,he is active in the fields of optical thin film ,laser coating and laser damage testing.