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Investigation of laser induced damage threshold measurement with single-shot on thin films

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ABSTRACT

A method for rapid determination of laser induced damage threshold (LIDT) of optical coatings is proposed and investigated in this paper. By use of this method, the LIDT of thin film can be rapidly obtained by only one shot. The modulation of laser beam profile, which is considered as a negative factor in conventional LIDT test, is utilized in this method. Basing on image processing technique, the damage information could be extracted from the comparison between the damage pattern and beam intensity distribution in the test region. The applicability and repeatability of this testing method has been verified on three type reflectors, HfO_2/SiO_2, HfO_2/Al_2O_3 and Ta_2O_5/SiO_2. In addition, the experimental results showed that appropriate beam size, laser energy and image compression ratio are the key factors to ensure a high accuracy of LIDT.

1. Introduction

The laser induced damage threshold (LIDT) is an important parameter of laser materials applied for nanosecond regime. It is necessary to obtain an accurate LIDT for both scientific research and engineering application. Usually the traditional offline LIDT test in laboratory is performed by a commercial laser. The beam needs be focused to 1 mm or smaller diameter to form a high fluence spot on sample [1–9]. The test should contain a sufficient range of laser fluence to get the damage threshold. Due to the fact that the beam size is usually too small comparing with the test area, it is a time consuming process to test amount of sites to get high confidential result. In order to reduce the time cost, researchers have developed several methods to measure LIDT by single-shot. In early years, by accurately comparing the damage pattern and beam intensity distribution, the LIDT is considered equal to the local laser fluence on the boundary of damage region [10]. Another way to realize single-shot LIDT test is using binary mark, hole-grating or Talbot array illuminator to divide a beam spot into dozens of smaller sub-spots [11–14]. The light intensity of these sub-spots can be calculated by Fresnel diffraction function. The test sites are simultaneously irradiated by sub-spots and thus the LIDT could be revealed by single-shot. This method reduces the time cost of LIDT test. It requests high quality of laser source because the fluence of sub-spot is calculated theoretically. And the number of sub-spots is also limited by the size of grating, usually less than one hundred. To solve this problem, a larger beam (more than one centimeter in diameter) with higher power (usually above 10 J) is applied and the image comparison method is developed. By accurately obtaining the damage pattern of surface or bulk material under large laser beam, it is considered that the relationship between damage density and fluence could be extracted by accurately comparing the damage pattern and beam intensity distribution. This method is successfully used in damage density test for fused silica [16] and KDP crystal [15,17].

In this work, we established a method of accurately measuring the LIDT of optical coatings with only one large laser beam shot. Usually the thermal effect of amplified pump module in solid-state laser device is a critical problem which will worsen the transverse mode and then cause intensity modulation, and this problem will become more significant along with laser energy output increasing. Therefore, we considered that the intensity modulation of large laser beam at near filed is quite prominent. One shot covers a sufficient range of fluence which can be utilized for LIDT measurement. On this purpose, we firstly built the coordinates systems of damage/beam intensity distribution and completed the coordinate transformation. Secondly, image compression process was performed on damage pattern to extract the test information. Finally, the LIDT is obtained by an improved calculation procedure. The repeatability of this testing method has been verified on three type reflectors, HfO_2/SiO_2, HfO_2/Al_2O_3 and Ta_2O_5/SiO_2. The comparison between single-shot and 1/1 test was carried out as well to

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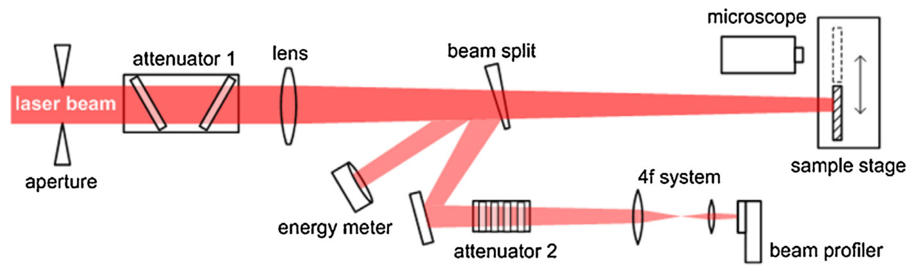

Fig. 1. The structure of single-shot LIDT test bench.

identify the applicability of single-shot method. In addition, three main factors were discussed to improve the measurement accuracy in the last section.

2. Method description

The principle of single-shot LIDT test can be described as follow: for a large energy laser, it usually holds some intensity modulation in the near field. The spatial spatial beam contrast (peak to average) offers us an opportunity to obtain an irradiated region that covers a wide range of fluence. If the total exposed energy is properly chosen, the irradiated region of sample will present a distribution of damage. For a uniform surface, the region exposed by higher fluence tends to be damaged. Otherwise, the left region is more likely to survive. The map of laser spot intensity and corresponding damage distribution will be recorded and gridded into amounts of cells. Each cell contains the status of local region, such as damaged/survived, local fluence, coordinates, etc. By accurately comparing these cell statuses, the damage data could be extracted in pairs. Finally, the LIDT can be evaluated from those data by use of the method described in ISO 21254 [18]. The single-shot LIDT test utilizes the features of near field distribution of large energy laser, spatial spatial beam contrast and irradiation area. Due to the spatial spatial beam contrast, a sufficient range of fluence covers those test cells. In the meanwhile, centimeter level irradiation area offers amount of test cells comparable with traditional small laser beam LIDT test.

3. Experiment

The test bench (see Fig. 1) is built to achieve single-shot LIDT measurement. A high energy Nd: YAG Q-switched laser (up to 10 J) is applied. The laser wavelength is 1064 nm and FHWH pulse duration is 10 ns. An adjustable aperture in the main beam path is applied to change the beam feature. The spatial spatial beam contrast ranges from 2.1 to 3.2, and the beam size ranges from 0.5 cm^2 to 1.5 cm^2. The laser energy is adjusted by a variable attenuator, composed of 1/2 wave plate and polarizer. The laser beam is focused by a 2 m lens, and then separated into two paths, damage testing path and diagnosis path, by a beam split. In the damage testing path, the laser beam is directly delivered to the sample plane. The damage pattern is obtained by an in-situ 100 × Nomarski microscopy. In the diagnosis path, the laser intensity is automatically reduced by a motorized attenuator to protect the CCD sensor of beam profiler. And then a 4f system is employed to zoom out the beam to adapt the CCD sensor size. Finally, the laser intensity distribution is recorded by the beam profiler. The optical length of these two paths is accurately adjusted to be equal, and thus the intensity distribution measured by beam profiler is similar to the beam spot on the sample surface.

In order to identify the applicability and repeatability of single-shot LIDT test method, several damage experiments were performed on three common type dielectric thin films, which are HfO_2/SiO_2, HfO_2/Al_2O_3 and Ta_2O_5/SiO_2 coatings. These coatings all consisted of a standard quarter-wave stack to realize a high reflectivity (at less 99.5%) at 1064 nm. Among them, HfO_2/SiO_2 and HfO_2/Al_2O_3 were manufactured by electric beam evaporation, and Ta_2O_5/SiO_2 was manufactured by ion beam sputtering (IBS).

4. Results

4.1. Image coordinates transformation

In experiment, the beam intensity distribution at the sample position is equivalently recorded by the beam profiler in the diagnosis path. Due to the deviation among imaging planes, zoom lens of beam profiler and microscope, the beam intensity distribution and damage pattern cannot be compared directly. Therefore, position relationship revision, which is defined as image coordinates transformation process, is needed before LIDT test. The flowchart of this process is shown in Fig. 2. Firstly, a high sensitive photo paper is placed at the sample position to get a scald pattern by one shot. Here the laser fluence should be adjusted carefully to avoid saturation on the photo paper. Secondly, the scald pattern image and beam intensity distribution image are respectively recorded by the in-situ microscope in the damage test path and CCD beam profiler in the diagnosis path. Thirdly, the coordinate system for each image is built and those points with common features are extracted by

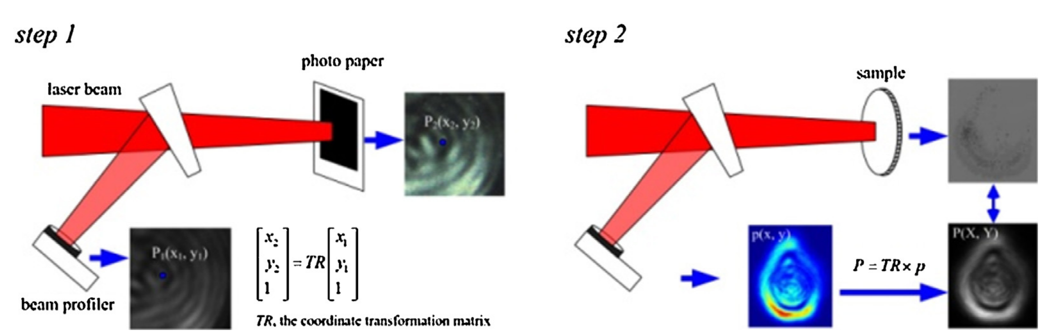

Fig. 2. The flowchart of position pre-adjustment for damage test path and diagnosing path.