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Influence of oxygen post-treatment on laser-induced damage of antireflection coatings prepared by electron-beam evaporation and ion beam assisted deposition

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ABSTRACT

Antireflection coatings at the center wavelength of 1053 nm were prepared on BK7 glasses by electron-beam evaporation deposition (EBD) and ion beam assisted deposition (IBAD). Parts of the two kinds of samples were post-treated with oxygen plasma at the environment temperature after deposition. Absorption at 1064 nm was characterized based on surface thermal lensing (STL) technique. The laser-induced damage threshold (LIDT) was measured by a 1064-nm Nd:YAG laser with a pulse width of 38 ps. Leica-DMRXE Microscope was applied to gain damage morphologies of samples. The results revealed that oxygen post-treatment could lower the absorption and increase the damage thresholds for both kinds of as-grown samples. However, the improving effects are not the same.

1. Introduction

Antireflection coatings were the principal objective of much of the early work in thin-film optics. Of all the possible applications, antireflection coatings have had the greatest impact on technical optics, and even today, in sheer volume of production, they still exceed all other coating. In some applications, antireflection coatings are simply required for the reduction of surface reflection or the increase of transmittance [1]. However, in high-power laser system, since damage of optical coatings often brings about declined performance and invalidation of the whole optical setup [2], antireflection coatings were required for not only good optical property but also high laser-induced damage threshold (LIDT).

The ion beam assisted deposition (IBAD) and oxygen ion post-treatment have been used for improving of the LIDT of optical coatings, respectively [3–6]. However, the different effects of ion post-treatment on coatings prepared by different methods were not fully discussed. So, in this work, antireflection coatings at the center wavelength of 1053 nm were prepared on BK7 glasses by electron-beam evaporation deposition (EBD) and IBAD technique. Parts of the two kinds of prepared samples are post-treated with oxygen plasma at the environment temperature after deposition. The absorption, the LIDT and the damage morphology of the samples were studied.

2. Experimental details

Antireflection coatings at the center wavelength of 1053 nm were prepared on BK7 glasses by EBD and IBAD in the same coating chamber ZZFX-1100. Then parts of samples post-treated with oxygen plasma at the environment temperature after deposition. The samples were divided into four groups, which are shown in Table 1. Group A1 were deposited by electron-beam evaporation without operating the ion source. The chamber was baked under 573 K for 3 h and pumped to a base pressure of 2.0×10^{-3} Pa. Ultrahigh purity O_2 was used to get a chamber pressure of 2.0×10^{-2} Pa to avoid off stoichiometric ratio of the sample. Film thickness was monitored by an optical monitor system. Group B1 were evaporated by an e-beam gun while with operating the Mark

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Table 1
The details of four-group samples

Group ID	Deposition method	Post-treated
A1	EBD	No
A2	EBD	Yes
B1	IBAD	No
B2	IBAD	Yes

II end-Hall ion source with oxygen gas flow as working gas. The anode voltage and current were 200 V and 2 A, respectively. Correspondingly, the ion energy and current density were about 120 eV and 280 mA/cm^2, respectively. Group A2 and B2 were post-treated for 10 min with the same ion source in the same chamber. However, the anode voltage and ion energy used were 120 V and 72 eV, respectively, which were different with the parameters used in the IBAD process.

Designs of four-group antireflection coatings stacks are the same and given by the following expressions:

$$G|H2.5L|Air \quad (1)$$

where G indicates BK7 glass substrate. L and H stand for low refractive index material (SiO_2) and high index oxide (HfO_2), respectively, with quarter wavelength optical thickness (QWOT). The reference wavelength was 520 nm.

Absorption test was performed with a practical high-sensitivity apparatus for the weak absorption analysis of optical coatings based on surface thermal lensing (STL) technique [7–9]. Ten points at different position on the sample were taken for absorption test. A continuous-wave 1064 nm Nd:YAG laser and a He–Ne laser were employed as pump source and probe source, respectively. The calibration coefficient was obtained by measuring the STL signal of a calibrated thin-film sample with known absorption, which is easy to be tested by PerkinElmer Lambda900 spectrometer. In order to get higher photothermal signal and higher sensitivity of weak absorption coating samples, the system configuration had been optimized by choosing appropriate parameters, including pump beam diameter (409 μm), pump beam power (2 W), probe beam diameter (857 μm), probe beam power (2 mW). Of course, there are other optimization parameters, such as pump chopper frequency, detection distance, and position of probe beam [8,9]. After optimization, the sensitivity should be much better than 1 ppm level, a very good sensitivity of 100 ppb was achieved and approved in our experimental, and the utmost sensitivity of the system was estimated to be 10 ppb level.

LIDT test was performed in the S-on-1 (S = 10) mode according to ISO standard 11254-2 [10]. The experimental setup is shown in Fig. 1. The samples were irradiated with Nd:YAG laser system (PY61-10, Continuum), which produced linear polarization laser pulses of 38 ps full width half maximum (FWHM) for the 1064 nm wavelength at a repetition rate of 10 Hz. The shutter was used to make sure that each location on the sample was irradiated by only 10-laser pulse. The filters served as attenuator to change the pulse energy. A CCD camera-microscope detector was used to monitor the occurrence of damage in situ. The picosecond laser has been focused on the front surface of the sample by a lens of 26 cm focal length. The $1/e^2$ spot radius w_{1/e^2} at the focus was measured to be 150 ± 10 μm. The pulse energy E_{pulse} was monitored with an energy meter. Then the laser energy fluence was calculated by $F_0 = 2E_{pulse}/\pi(w_{1/e^2})^2$ [11]. The incident angle was 0°. Damage threshold data was obtained by the damage probability. Only one site of the sample was exposed at the same fluence, and this procedure was repeated for other fluences until the range of fluence was sufficiently broad to make sure the highest energy density with no damage $F_{max}(ND)$ was larger than the lowest energy density with damage $F_{min}(D)$ and the space between two laser fluence was enough narrow based on the test condition. Meanwhile, the area irradiated with laser beam locates in the center of the whole sample and was broad enough to reflect the actual situation of the sample. Therefore, the damage threshold F_{th} is interpreted as some kind of 50% damage probability threshold [12], which is defined as the mean-value of the highest energy density with no damage $F_{max}(ND)$ and the lowest energy density with damage $F_{min}(D)$. That is,

$$F_{th} = \frac{[F_{max}(ND) + F_{min}(D)]}{2} \quad (2)$$

A spread is defined by

$$\Delta = \frac{[F_{max}(ND) - F_{min}(D)]}{F_{th}} \quad (3)$$

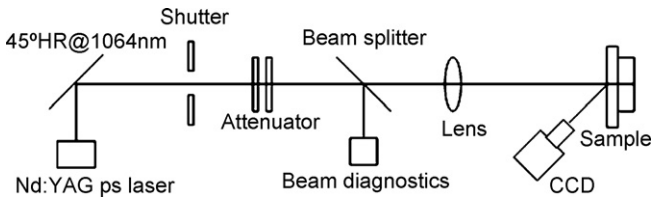

Fig. 1. Experimental setup used for laser damage test.

3. Results and discussion

Thermal absorption is one of the main factors which cause damage to optical coatings under the radiation of high-power lasers. Fig. 2 shows the absorption of the samples measured with the STL technique. Then the average absorptions and the uniformities of measurements were calculated from Fig. 2 and are shown in Table 2. It can be found that the average absorption and the uniformity of group A2 post-treated are significantly lower than those of group A1 as-deposited by EBD. Meanwhile, the average absorption and the uniformity group of B2 post-treated are little lower than those of group B1 as-grown by IBAD. The reasons may be that the sites with high absorption are the sites where a thermal defect is located. Usually, samples deposited by EBD have the porous and void-rich structure resulting in absorbing water evaporation more easily, which would make the samples contain enough defects and impurities leading to the high absorptance. Moreover, the samples would show a substoichiometric ratio of

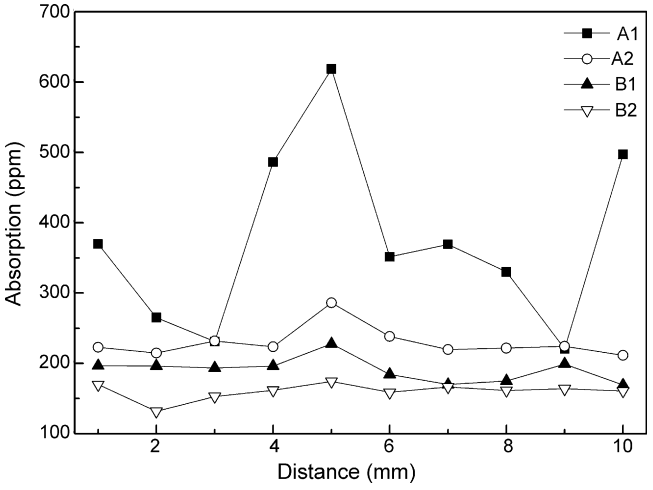

Fig. 2. The absorptions of four-group samples.