Enhanced laser induced damage threshold of dielectric antireflection coatings by the introduction of one interfacial layer

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A new method for increasing laser induced damage threshold (LIDT) of dielectric antireflection (AR) coating is proposed. Compared with AR film stack of H2.5L (H:HfO_2, L:SiO_2) on BK7 substrate, SiO_2 interfacial layer with four quarter wavelength optical thickness (QWOT) is deposited on the substrate before the preparation of H2.5L film. It is found that the introduction of SiO_2 interfacial layer with a certain thickness is effective and flexible to increase the LIDT of dielectric AR coatings. The measured LIDT is enhanced by about 50%, while remaining the low reflectivity with less than 0.09% at the center wavelength of 1064 nm. Detailed mechanisms of the LIDT enhancement are discussed.

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Antireflection (AR) coatings have been widely studied and used in numerous optical applications for increasing transmission or reducing reflection[1−3]. Dielectric AR coatings play an important role in reducing spurious reflection and energy losses, especially in the high power laser system. Besides, the low reflectivity, high laser induced damage threshold (LIDT), and durability are important in practice. To achieve the goal, many efforts have been taken to reduce the introduction of defects, impurities, and contamination, such as substrate cleaning[4,5], film deposited methods[6,7], and different post-processing[8−10]. But the study on this is far from completing.

In this letter, we try to increase the LIDT of AR coatings by improving film design. An interfacial layer is introduced between the coating and the substrate, and its effects on optical properties, absorption, microdefect, electric field distribution, and LIDT are studied.

The films were prepared according to two different film designs, including the usual film design H2.5L (AR1) and the improving film design 4LH2.5L (AR2). All the samples were deposited on BK7 substrates by e-beam evaporation. Each substrate was cleaned ultrasonically in petroleum ether. The base pressure was 2×10^{-3} Pa and oxygen filled the vacuum chamber with a pressure of 2×10^{-2} Pa during deposition. The deposition temperature was approximately 300 °C and the rate was 3.5 and 4.0 nm/s, respectively.

Transmittance spectra of the films were measured using a Lambda 900 spectrophotometer. Surface thermal lensing method has been used to measure the absorption of samples. Defect density was measured under a Leica-DMRXE dark-field Microscope. Damage testing was performed in the "1-on-1" regime, using a 1064-nm Q-switch pulsed laser at a pulse length of 12 ns[11] and the damage morphology was measured by Wygo analyses (Wyko NT 1100 optical profiling system).

Reflectance spectra of AR1 (a) and AR2 (b) performed on UV-visible spectrometer are shown in Fig. 1, in which the measured spectra have a good agreement with the theoretical design. Low reflectivities with 0.04% and 0.09% at 1064 nm are gained, which are nearly one third of that in the previous report, 0.24% at 1064 nm[12]. But in AR2 film, one interfacial layer of silica with four quarter wavelength optical thickness (QWOT) has been deposited before deposition of AR1 films. As a result,

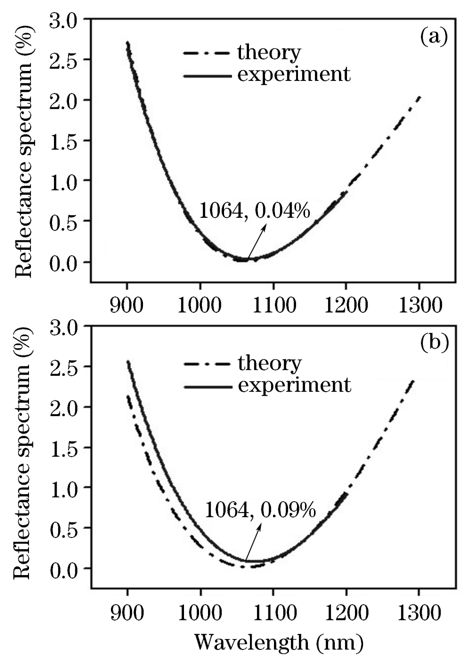

Fig. 1. Reflectance spectra of (a) AR1 and (b) AR2, the solid lines are the measured data and the dashed lines show the theoretical data by TFCal software.

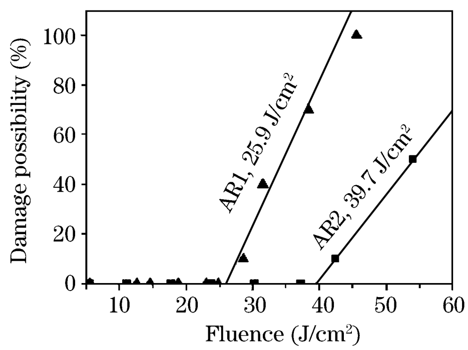

Fig. 2. LIDT of the samples AR1 and AR2.

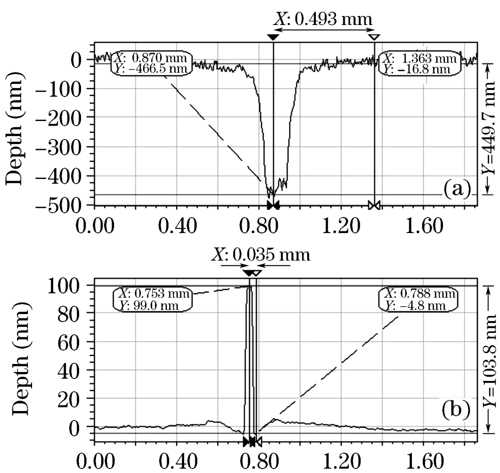

Fig. 3. Depth profiles of the damage point on (a) AR1 under laser fluence of 37.5 J/cm^2 and (b) AR2 under laser fluence of 42.7 J/cm^2.

LIDT of AR2 has been increased to 39.7 J/cm^2, about 50% higher than that of AR1, which is 25.9 J/cm^2, as shown in Fig. 2. Then it can be concluded that the SiO_2interfacial layer plays an important role in increasing LIDT.

Figure 3(a) gives the depth profile of one damage point (damaged under the laser fluence of 37.5 J/cm^2) on AR1 by Wygo analyses. The depth shows concave and gets to 449.7 nm, about 300 nm deeper than the film thickness. It can be investigated that the substrate may take a bad effect on the LIDT of AR coatings, such as absorption of subsurface defects on the substrate[13]. But in Fig. 3(b), the depth of one damage point (damaged under 42.7 J/cm^2 fluence) is 103.8 nm and shows protruding. It can be deduced that the interfacial layer limits the bad effect taken by subsurface defects in a certain level.

At the same time, electric field intensity distributions in AR1 and AR2 are almost the same, as shown in Fig. 4 and this cannot result in the large different LIDT between AR1 and AR2. The interfacial layer SiO_2 not only reduces the absorption resulting from subsurface of the substrate but also limits more defects, which can be proved by the defects statistics of the Normaski observation. We choose 30 random sites on each surface and make a statistics about possibility versus defect density, as shown in Fig. 5. The whole defect density of AR2 decreases a lot compared with that of AR1. It can be deduced that the defect density of the AR samples can be decreased after introduction of interfacial layer with a reasonable thickness, which also can be proved by the absorption comparison of AR1 and AR2. It can be seen from Fig. 6 that defects absorption of AR1 has stronger and more irregular dots than that of AR2. On the other

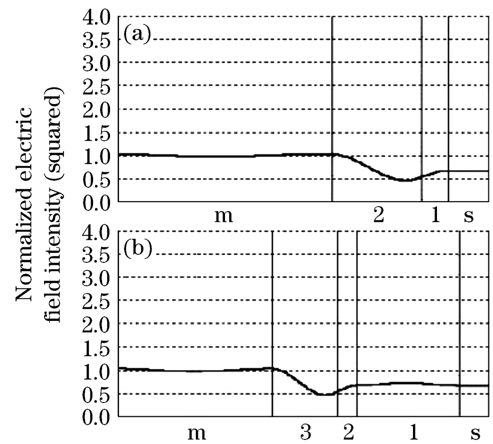

Fig. 4. Electric field distribution in (a) AR1 and (b) AR2 calculated by TFCal software (characters “m” and “s” represent air and substrate respectively, and numbers 1, 2, 3 represent the deposition layer order).

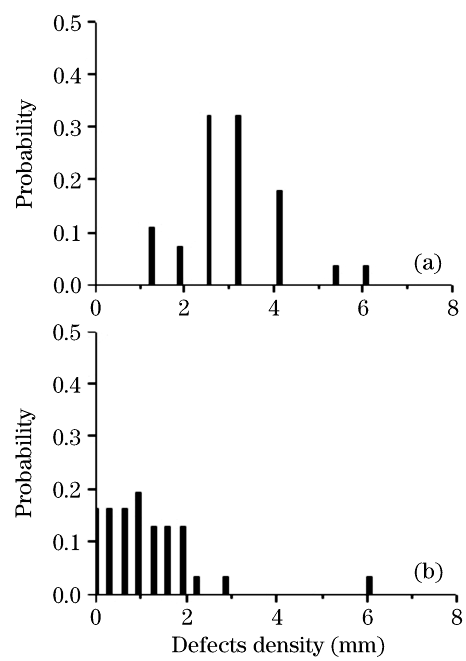

Fig. 5. Defects density statistics of (a) AR1 and (b) AR2.

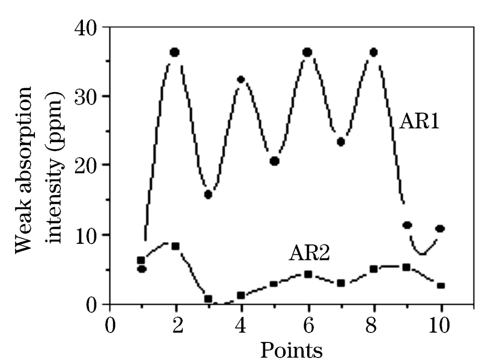

Fig. 6. Absorption of AR1 and AR2 at 1064-nm wavelength.

hand, we speculate that the interfacial layer can enhance the adhesion between substrate and HfO_2 layer. However, the concrete interaction progress is still unknown and we will continue to work on this.

In conclusion, the introduction of interfacial layer between the HfO_2 layer and substrate is a simple and effective method to improve the LIDT of dielectric AR coatings, while remaining the low reflectivity, which can be used in the other dielectric AR film design.

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