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Study on the feasibility of double stack high reflector coating at 355 nm

Hua Yu [a,*], Longqi Wu [a], Caifeng Liu [a], Jianda Shao [b], Zhengxiu Fan [b]

[a] Hangzhou Dianzi University, Hangzhou 310018, China
[b] Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China

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ABSTRACT

The feasibility of the idea of double stack HR coating was discussed in this paper both in theory and experiment. The theoretical simulation was made by employing optical coating design software. The analysis results showed that the design of double stack HR coating was feasible, which made the HR coating have ascendancy not only at reflectance but also at laser damage resistance. Then, the LaF_3/MgF_2 HR coating, the HfO_2/SiO_2 HR coating and the double stack HR coating were prepared for comparison, respectively. Transmittance spectra, surface morphologies and damage morphologies of these coatings were measured. Measurement of laser-induced damage threshold (LIDT) of S polarized light of the samples was performed at 355 nm, 45° incidence. The measurement results showed that the LIDT value of the LaF_3/MgF_2 HR coating with 30 layers was very high, but the reflectance was low. When the layer number was increased up to 36, lots of cracks appeared on the surface of the LaF_3/MgF_2 HR coating, with the LIDT badly declining. It was thought that the residual stress resulted in the cracks and the decline of the LIDT. The spectra measurement showed the double stack HR coatings could provide higher reflectance and wider reflection band than LaF_3/MgF_2 HR coating with less layer pairs. Any crack was also not found on the surface of the double stack coatings. Meanwhile, the double stack HR coatings possessed greater laser damage resistances than the HfO_2/SiO_2 HR coating. The damage morphologies showed that the damage of the double stack coating was even milder than that of the HfO_2/SiO_2 coating. Therefore, the double stack design was effective to gain high reflectance and great UV laser radiation resistance simultaneously.

1. Introduction

One of the continuous challenges for high power UV laser system is the manufacture of optical coatings that can withstand high laser fluences [1,2]. Therefore, it is urgent to improve the laser-induced damage threshold (LIDT) of optical coatings used in the UV range [3]. A lot of methods were attempted to raise UV laser damage threshold of optical coatings [4–6]. On one hand, the attempt of employing fluoride materials with lager band gaps, among these methods, achieved better effect due to a fact that the fluoride high reflector (HR) coating has been proved to possess excellent UV laser damage resistance [7,8]. But, it has serious residual stress problem [9,10], which will result in the cracks when the layer number is increased, and as a result, greatly limit its reflectance and damage resistance. On the other hand, the oxide HR coating can reach high reflectance in a walk because of the large difference of the indexes in different materials. However, it also has a problem, i.e., it has the relatively low UV laser damage resistance. If the fluoride coating and the oxide coating are combined with the excellent integrative properties, the attempt of raising UV laser damage threshold of optical coatings may be achieved. To be specific, the fluoride coating is used as the top layer to provide great damage resistance and the oxide coating as the bottom layer to fulfill high reflectance. We can call this kind of HR coating as double stack HR coating.

LaF_3 and MgF_2 are much widely used as fluoride materials in the UV region due to their outstanding damage resistance [11]. HfO_2 and SiO_2 are also common oxide materials in this region. The four materials were chosen to prepare double stack HR coatings. In reference [12] double stack HR coatings of HfO_2/SiO_2/LaF_3/MgF_2 had been prepared as a method to reduce the stress of fluoride coating and higher reflectance was gained in the reference. But the laser damage resistance ability of the double stack HR coating were not studied in that reference. In this article, the properties of the double stack HR coatings will be discussed more roundly. Firstly, the feasibility of the idea of double stack HR coating was discussed in theory. Then, LaF_3/MgF_2 HR coatings, HfO_2/SiO_2 HR coatings and the double stack HR coatings were manufactured. Moreover, the properties of all the samples were investigated and compared. Because HR coatings of oblique incidence are used largely to change the beam path in laser system, the properties of all HR coatings in this article were tested at 45° incidence by employing S polarized light.

* Corresponding author. Tel.: +86 571 86878591.
E-mail address: yuhua5101@163.com (H. Yu).

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2. Theoretical analysis

Firstly, we analyzed the feasibility and merit of the design of double stack HR coating. The theoretical reflectance spectra and electric field distributions were simulated by employing optical coating design software [13]. Fig. 1 shows the theoretical reflectance spectra of S polarized light at 45° incidence for two different designs. The expression $(MA)^{15}$ represents the pure fluoride HR coating, where M is a quarterwave layer of MgF_2, A is a quarterwave layer of LaF_3. Similarly, H is a quarterwave layer of HfO_2, L is a quarterwave layer of SiO_2 in $(HL)^6H$ and $(HL)^6H(MA)^8$ expressions. It is obvious that the double stack HR coating has much higher reflectance and wider reflection band than the pure fluoride HR coating. That is to say, the double stack HR coating can easily obtain higher optical performance than the pure fluoride HR coating with less number of layers. The electric-field intensity distributions of the three kinds of HR coatings are exhibited in Fig. 2. From Fig. 2, we can see that the double stack HR coating has the similar peak intensity in LaF_3 layers with the pure fluoride HR coating. Whereas, the maximal intensity in HfO_2 layers of double stack coating (indicated by A) is much smaller than the pure oxide coating. That is to say the electrical field intensity in HfO_2 layers of double stack coating may be too small to damage the coating. Therefore, the double stack HR coating probably achieves the same LIDT value with the pure fluoride HR coating. The pure fluoride HR coating usually possessed higher LIDT than the pure oxide HR coating in the UV region [7,11], so the double stack coating may achieve greater laser damage threshold than the pure oxide coating. From the above analysis, we can see that the design of double stack has preponderance not only at reflectance but also at laser damage resistance.

3. Experiment

3.1. Sample preparation

The pure fluoride HR coating and the pure oxide HR coating were deposited by boat evaporation and electron-beam evaporation, respectively. The double stack HR coatings were deposited by electron-beam evaporation combining with boat evaporation. The coating designs were $S|(MA)^m|air$, $S|(HL)^4H|air$ and $S|(HL)^4H(MA)^n|air$ where H was a quarterwave layer of HfO_2, L was a quarterwave layer of SiO_2, M was a quarterwave layer of MgF_2, A was a quarterwave layer of LaF_3, S was the substrate of high quality K9 glass with the dimension of $\emptyset 30 \times 3\ mm^2$, *m* and *n* were the pair numbers. The substrate temperatures of all deposition samples were 280 °C. The WZK silicon controlled temperature control system was used to measure the substrate

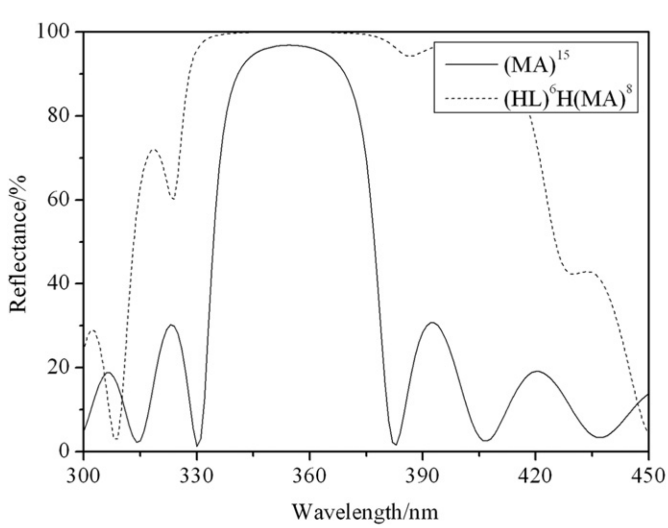

Fig. 1. Theoretical reflectance spectra of S polarized light at 45° incidence for two different designs.

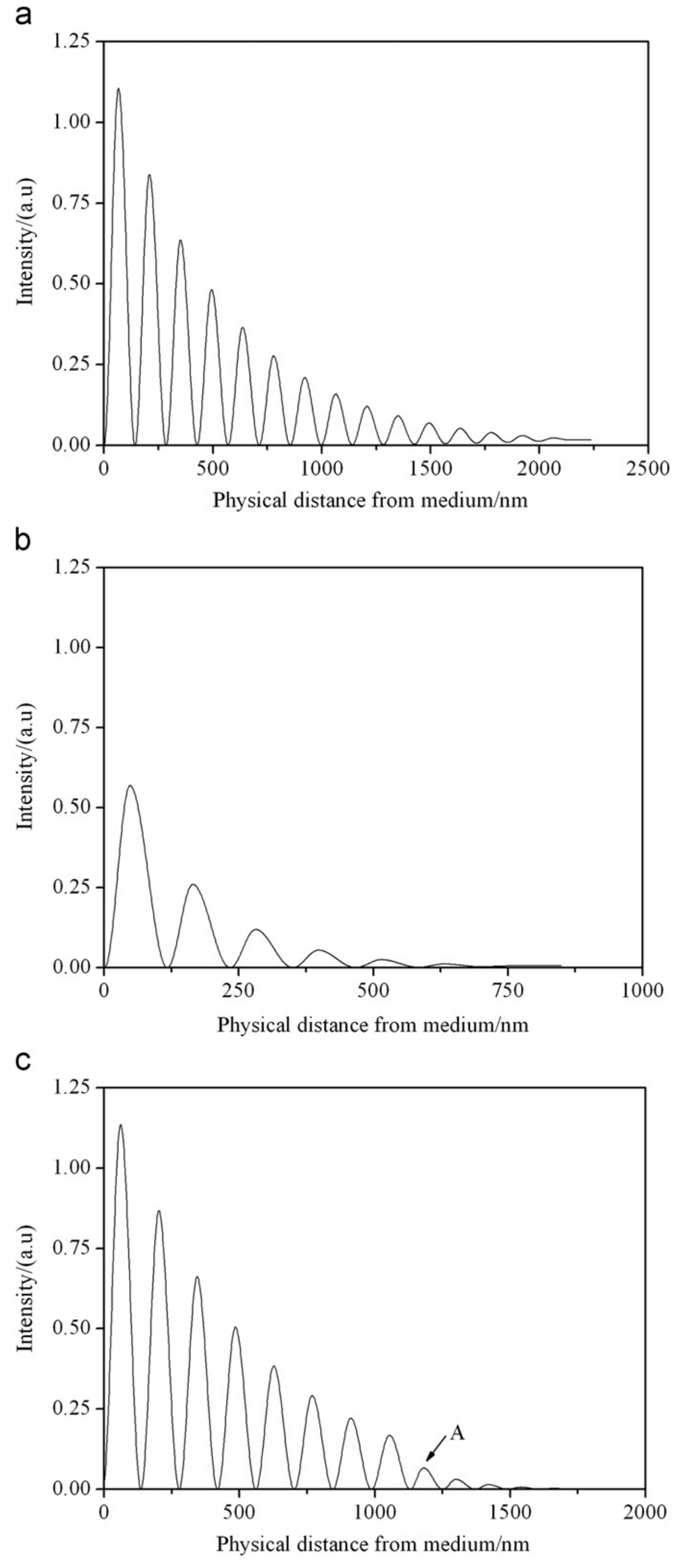

Fig. 2. The electric-field intensity distributions of S polarized light at 45° incidence for the three kinds of HR coatings: (a) $(MA)^{15}$, (b) $(HL)^6H$ and (c) $(HL)^6H(MA)^8$.