Thin-film polarizer for high power laser system in China

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ABSTRACT

Thin-film polarizers are essential components of large laser systems, switching the beam out of the primary laser cavity and/or protecting the system from back-reflected light. The requirements for a polarizer include specific spectral performance, high laser-induced damage resistance and low surface figure deformation. Generally speaking, a polarizer coating has a thicker thickness than a mirror coating, and a narrower bandwidth that fulfills the specific spectral specification, which makes the design and fabrication of polarizer coating challenging. Large aperture (up to ~900 mm in diameter) polarizer coating deposited on both BK7 and fused silica substrates with *p*-polarized transmittance higher than 98%, *s*-polarized reflectance higher than 99% at 1053 nm, and can tolerance a fluence higher than 17 J/cm^2 (9 ns) at 1053 nm has been achieved.

Keywords: Thin film polarizer; Spectral performance; Laser induced damage threshold; Stress control

1. INTRODUCTION

Thin-film Brewster's angle polarizer is a key component of large laser systems such as SG II-UP Facility (China), National Ignition Facility (USA) [1], OMEGA EP Laser System (USA) [2] and Laser Megajoule (France) [3]. When combined with an optical switch called Pockels cell, it allows light to pass through or reflect off, switching the beam out of the primary laser cavity and/or protecting the system from back-reflected light. Considerable efforts have been devoted to improve the performance of polarizer coating [1-5]. Thin-film Brewster's angle polarizer coating is mainly characterized by the following specifications: *p*-polarized transmittance (*T*p), *s*-polarized reflectance (*R*s), laser induced damage threshold (LIDT), as well as wavefront deformation. The preparation of polarizer coating is more challenging than the preparation of mirror coating, especially for the large aperture polarizer coating. The main difficulties lie in narrow spectral bandwidth and large thickness. The spectral requirements for a polarizer on high power laser system usually include a *T*p greater than 98% and a *R*s greater than 99% at 1053nm [1, 6]. A spectral bandwidth allowance must be made because of the random thickness error, the thickness uniformity over the aperture, as well as allowing for some tolerance of angular misalignment. A polarizer coating usually has a thickness up to 8 μm, which will consequently induce many problems, like more defects and larger stress. The defects in the coating will induce damage under laser irradiation, especially for the *p* polarized light, because it is highly transmitted, all the defects in the coating and substrate may induce laser damage. Larger stress may also aggregate laser damage, induce wavefront deformation, and may even cause the failure of coating [2, 3, 6].

In this paper, works on improving the spectral performance and laser damage threshold, as well as controlling the coating stress have been done. Large aperture (up to ~900 mm in diameter) polarizer components with *p*-polarized transmittance higher than 98%, *s*-polarized reflectance higher than 99% at 1053 nm, and can tolerance a fluence higher than 17 J/cm^2 (9ns) at 1053 nm have been achieved.

2. SPECTRAL PERFORMANCE

Spectral performance depends greatly on the coating design. Theoretical and experimental investigation results demonstrate that the spectral performance and relative preparation difficulty of polarizer coating can be predicted from the coating design and layer thickness error tolerance [5]. A design with higher layer thickness error tolerance will be easier to achieve the designed spectral performance. In addition, the LIDT of the polarizer can also be greatly influenced by the coating design. For both *p* polarized and *s* polarized light, the lower the electric field peak value and the farther the layer which has the strongest electric field away from air, the higher the LIDT of the polarizer coating.

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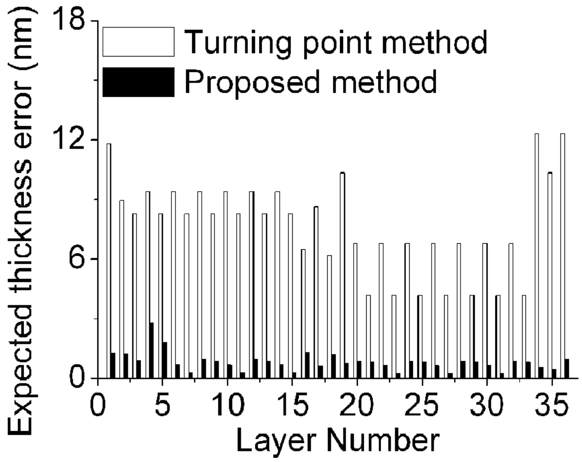

Figure 1. Expected thickness error monitored by turning point method and proposed method, respectively.

With a good coating design, it is essential to precisely control the layer thickness to obtain the desired spectral performance. We propose an optical monitoring approach based on using two pieces of witness glass, which are brought into the measuring position in a specially chosen sequence. To reduce the thickness error, some thick layers are divided into two layers and monitored by different witness glasses. Comparing the expected thickness error monitored by the proposed method with that by turning point method, the proposed method can notably reduce the thickness error, as shown in Figure 1. With the proposed method, spectral performance close to theoretical design can be achieved, as illustrated in Figure 2.

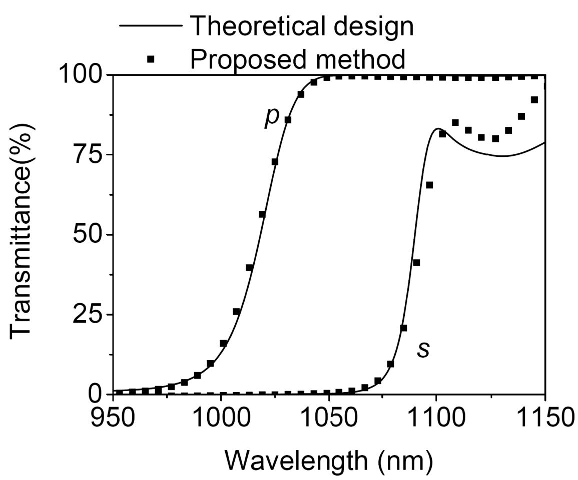

Figure 2. Theoretical and experimental spectra of a design monitored by proposed method.

3. LASER INDUCED DAMAGE THRESHOLD

Damage behavior of the polarizer coating is studied to understand the origin of laser damage. Defects are responsible for coating damage under laser irradiation. As indicated in Figure 3 (A), the typical damage morphology of polarizer coating induced by *p*-polarized laser irradiation is pit, plasma scald will be observed with the increase of laser fluence, as indicated in Figure 3 (B). As shown in Figure 3 (C), the typical damage morphology of the polarizer coating induced by *s*-polarized laser irradiation is smaller nodular ejection pit surrounded by plasma scald, similar to the damage morphology of mirror coating.

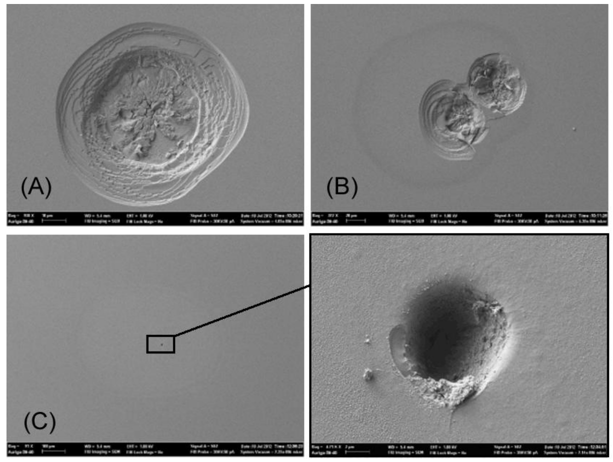

Figure 3. Typical damage morphology induced by laser irradiation with a fluence of (A) 39.2 J/cm^2 (p-polarized light), (B) 53.5 J/cm^2 (p-polarized light), and (C) 61.4 J/cm^2 (s-polarized light).

Due to the defect-induced damage mechanism, it's extremely important to decrease the defect density. Defect can be originated from the substrate, coating, as well as substrate-coating interface. Impurities and scratches are two major defects in substrate surface that influence the LIDT. Impurities in the subsurface play an important role in the damage of polarizer coating induced by *p* polarized light. Experimental results demonstrate that the HF based etching method is more efficient to remove the sub-surface impurities than ultrasonic cleaning [7], and therefore improve the LIDT of *p* polarized light, as illustrated in Figure 4. Besides, the plasma ion cleaning conducted right before the film deposition in the same process chamber is useful to remove the adsorbed contaminations on the substrate surface, as well as enhance the bonding between the coating and the substrate, and therefore improve the LIDT. The scratches may induce the mechanic structure degradation and E-field intensity enhancement [8], and should be carefully treated in the substrate polishing process.

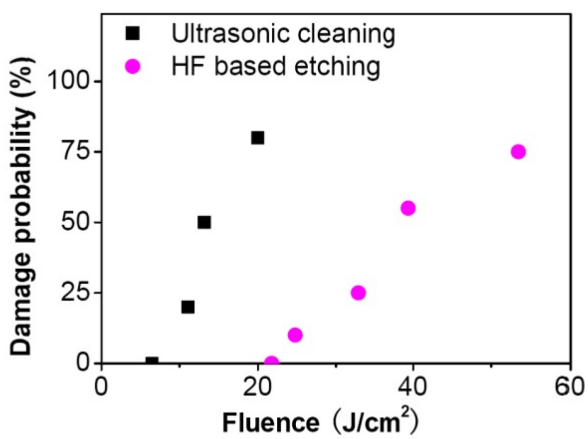

Figure 4. Damage probability of polarizer coating deposited on substrate cleaned by different cleaning methods.

Ejection of the coating material is an important source of nodular defect introduced during the deposition process. The experimental results demonstrated that optimizing the sweep pattern of E-beam used for evaporating metallic hafnium is efficient to suppress the material ejection, and consequently increase the damage threshold of the coating, as shown in Figure 5. To improve the laser damage resistance of the defect, a relatively higher oxygen flow and lower deposition rate is used to benefit the coating oxidization. Recently, co-evaporated interface is proposed to improve the interface property of multilayer coating [9].

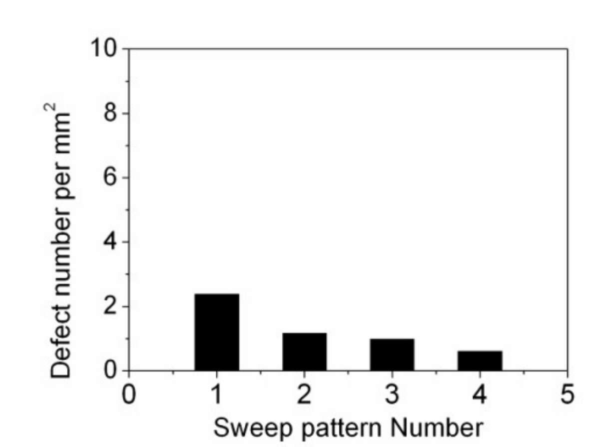

Figure 5. Influence of sweep pattern on defect density of multilayer coatings.

Post treatment, including off-line laser conditioning and post plasma treatment [10], has also been researched. Comparing the damage performance with and without laser conditioning, it is clear that laser conditioning could effectively reduce the number and size of the plasma scalds, and consequently increase the functional LIDT of the coating. Today's large aperture polarizer coatings are off-line laser conditioned by a 2-step process. The final fluence is 17 J/cm^2 with a 9 ns pulse length using 1064 nm Q-switched lasers.

Figure 6. The picture of the platform for off-line laser conditioning

4. FILM STRESS

Stress in optical coating, both compressive and tensile, may cause deformation of the substrate on which it is coated, and therefore influence the optical performance of the system. Too high stress may even cause failure of the coating. Although many works have been done to investigate the coating stress prepared by different deposition parameters, polarizer coating, especially the large aperture polarizer coating may suffer from the stress-induced cracking problem. To control the film stress, it is important to understand the evolution of the film stress. An in-situ stress measurement system, based on wafer curvature measured by optical deflection of two laser beams, has been built [11]. With this in situ measurement system, the stress evolution during the film deposition, stopping deposition, cooling, venting, and atmospherically exposure have been investigated. Based on the investigation results, the stress in polarizer coating is well controlled and the stress-induced film cracking problem is avoided.

5. CONCLUSION

The design and fabrication of polarizer coating has been systematically studied. Large aperture polarizer component (up to ~900 mm in diameter) with *p*-polarized transmittance higher than 98%, *s*-polarized reflectance higher than 99% at

1053 nm, and can tolerance a fluence higher than 17 J/cm^2 (9ns) at 1053 nm has been prepared and been well operated in the SG II-UP laser facility.

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