Investigation on the properties of high reflective mirror prepared by ion-beam sputtering

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The single-sided and dual-sided high reflective mirrors were deposited with ion-beam sputtering (IBS). When the incident light entered with 45°, the reflectance of p-polarized light at 1064 nm exceeded 99.5%. Spectrum was gained by spectrometer and weak absorption of coatings was measured by surface thermal lensing (STL) technique. Laser-induced damage threshold (LIDT) was determined and the damage morphology was observed with Lecia-DMRXE microscope simultaneously. The profile of coatings was measured with Mark III-GPI digital interferometer. It was found that the reflectivity of mirror exceeded 99.9% and its absorption was as low as 14 ppm. The reflective bandwidth of the dual-sided sample was about 43 nm wider than that of single-sided sample, and its LIDT was as high as 28 J/cm^2, which was 5 J/cm^2 higher than that of single-sided sample. Moreover, the profile of dual-sided sample was better than that of substrate without coatings.

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Due to vaporing particle having rather low energy by electron beam evaporation (0.01—0.1 eV)[1], optical coatings exhibit columnar structure with a great deal of pinholes, which pose inferior density and poor optical stability of thin films, so it is prone to absorb vapor in the air, and its resistance to laser-induced damage usually is rather poor.

In the process of deposition by ion-beam sputtering (IBS), due to high energy of the sputtering particle (as high as 500—1000 eV), these coatings have rather high stacking density and fine microstructure[2], and at the same time, its refractive index is close to that of bulk material, so this kind of coatings have properties of good optical stability and low scattering. High-energy sputtering particle can remove absorptive impurity from substrate or deposited layer as a result that the impurity content decreases and adhesion of coatings increases, however, oxide films deposited by IBS exhibit rather great stresses[3,4]. Moreover, the technique of IBS can adequately improve the stoichiometric proportion of the deposited layer to minimize the absorption of coatings[5], all of which can account for the fact that coatings deposited by IBS have rather strong resistance to laser damage[6]. It is obvious that IBS technique is a very important method of manufacturing optical thin film with high quality[7].

The designed stack formula of PICK-OFF mirror is (hl)ˆ11 h4l, where h and l denote high refractive index Ta_2O_5 and low refractive index SiO_2, respectively, and 4l serves as protective layer to improve the resistance to laser damage, its reference wavelength is 1160 nm and incident angle is 45°.

Before the coatings were deposited, the substrates were immersed to de-ionized water for ten minutes to get rid of oil contamination on substrate surface and then scrubbed with acetone. The samples were prepared in an ion beam sputtering system that has a 16-cm ion source for sputtering and a 12-cm ion source for assistance. Before deposition run, the chamber was pumped to a base pressure of 5×10^{-7} torr (1 torr = 133 Pa) by cryogenical pump and the substrates were baked up to 136 °C. The samples 1# and 2# were deposited on single surface and samples 5#, 6#, 7#, 8#, 9#, and 10# were deposited on two surfaces. The substrates of samples 1#, 2#, 9#, and 10# are fused silica, and the others are BK7.

The optical transmittance of the samples was measured by spectrometer LAMBDA900. The measurement light, 45° incident, is p-polarized. The experimental setup for measurement of weak absorption is based on the surface thermal lensing (STL) technique. Every sample was scanned in line at the central part, and point interval was 100 μm. We obtained 20 data with this method. The profile measurement of coating surface was performed using Mark III-GPI digital interferometer made by ZYGO whose precision is $\lambda/50$ (λ = 632.8 nm).

Damage testing was performed in the "1-on-1" regime, using 1064-nm Q-switched pulsed laser with the pulse duration of 12 ns. The laser was focused to provide a far-field circular Gaussian beam with a diameter of 0.46 mm at e^{-2} of the maximum intensity. The laser energy that was used to damage the sample can be obtained by adjustment of the attenuator, and the pulse energy was measured by an energy meter from a split-off portion of the beam. The laser-induced damage threshold (LIDT) was defined as energy density of the incident pulse when the damage occurs at 0% damage possibility (joule per square centimeter). Lecia-DMRXE microscope was used to observe the damage morphology of the samples, and its magnification is 100.

Figure 1 shows the transmission spectra of samples 1# and 9#. From the measurement result, it was found that the reflectance of sample 1# was as high as 99.94% and that of 9# reached 99.98%, moreover, the reflective bandwidth of the sample 9# was about 43 nm wider

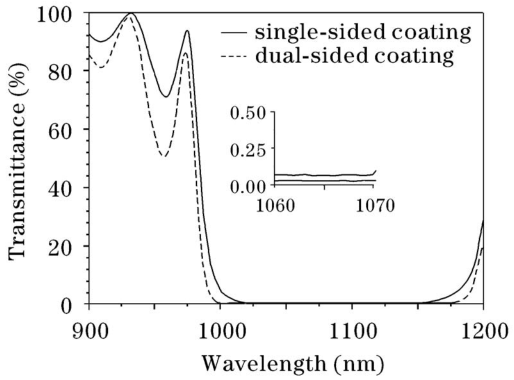

Fig. 1. Optical transmittance of p-polarized light at 45°.

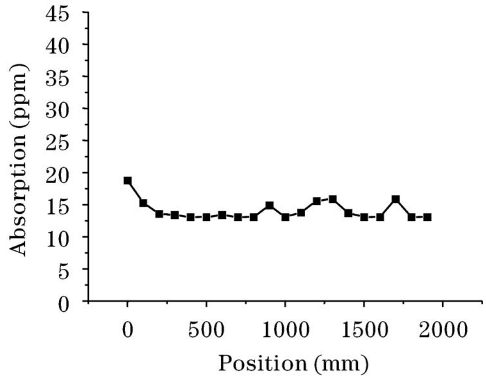

Fig. 2. Measurement result of weak absorption.

than that of sample 1#.

Sample 1# was selected to measure its weak absorption. From the measurement curve (Fig. 2), we can see that the mean absorption coefficient was 14 ppm, and its fluctuation was very small in all the measurement scope, which indicated that the uniformity of coatings was rather good, the defects in layer were very few and the absorption of coatings mainly resulted from intrinsic absorption.

Table 1 gives the power values of surface profile before and after deposition, and the minus and positive sign denote concave and convex profile, respectively. Power value is a measure of the curvature of the surface or wavefront without distinguishing between the X and Y dimensions. It is equivalent to the height difference between the center point and the point farthest from the center.

Table 1. Surface Profiles of Substrate before and after Deposition

Surface Profile	Serial Number			
	5#	6#	7#	8#
Substrate	0.316	−0.368	0.488	−0.481
Coatings Deposited on Only Front Surface	−1.544	−1.961	−1.469	−2.331
Coatings Deposited on Both Front and Back Surfaces	0.164	−0.350	0.285	−0.006

From the table, the results indicate that the profiles of all samples transform into concave after the front surface is deposited, and when the same layers are deposited on the back surface, all the profiles of sample are resumed and even better than substrate.

As shown in Fig. 3, the measured results indicate that the LIDT of the dual-sided sample was as high as 28 J/cm^2, and the LIDT of single-sided sample was 23 J/cm^2. The LIDT of dual-sided sample was 5 J/cm^2 higher than that of dual-sided sample. Coatings prepared by IBS usually exhibit rather great compression stresses, so the same layers were deposited on two surfaces of substrate to greatly decrease the stresses. Thermal-force couple is the essential factor in the laser damage of optical coatings, so small stresses in the coatings can help to improve the LIDT of coatings.

The surface damage morphology under laser energy density of 61.46 J/cm^2, obtained with Lecia-DMRXE microscope, is illustrated in Fig. 4. The photo indicated that color rather than depth of the coatings surface changed before and after damage. The transmittance of the damaged coatings was as same as that of the whole sample.

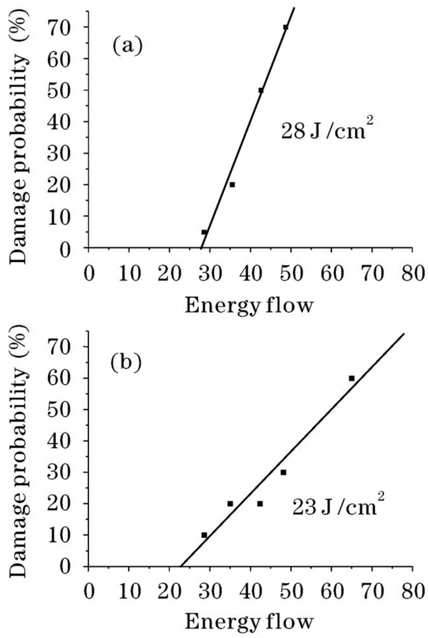

Fig. 3. LIDT measurement results of (a) dual-sided sample and (b) single-sided sample.

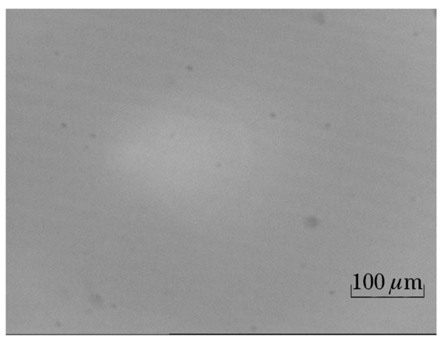

Fig. 4. Surface damage morphology.

From the above analysis, we can find that coatings deposited by IBS have few defects and the uniformity of coatings is very good, so the mean absorption is only 14 ppm. Even though the coatings are damaged by high-energy laser, the surface damage photo only exhibits color change, which is different from hole damage morphology of coatings deposited by electron beam evaporation.

From profile data, it is found that when coatings are deposited on single surface, the substrate exhibits concave as a result of compressive stresses in coatings. When back surface is deposited with the same layers, the stresses transform from compressive stresses to very small tensile stresses. At the same time, due to the laser damage of coatings resulting from thermal-force coupling, the less stresses are, the higher LIDT of coatings is.

In conclusion, we deposited the reflective mirror of single-sided and dual-sided sample by IBS. When the p-polarized incident light entered with 45°, the reflectance at 1064 nm exceeded 99.9%. The absorption of the coatings was as low as 14 ppm and its absorption fluctuation was very small in all the measurement scope. The LIDT of the single-sided sample was 23 J/cm^2, and the LIDT of dual-sided sample was as high as 28 J/cm^2, and the color rather than depth of the coatings surface changed before and after damage. The reflective bandwidth of the dual-sided sample was about 43 nm wider than that of single-sided sample. The profile of dual-sided coatings was better than that of substrate without coatings, and stresses of dual-sided sample were much less than that of single-sided sample.

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