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Interface characteristics of peeling-off damages of laser coatings

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ABSTRACT

Coating stacks of HfO_2/SiO_2 and Ta_2O_5/SiO_2 were separately prepared by electron beam evaporation and dual ion beam sputtering. Damage characteristics at the interlayer interfaces were analyzed after irradiation of the coatings by a 1064 nm laser. The cross-sectional morphologies of damage spots indicated that peeling-off damages always occurred at the interface where the low refractive index material (SiO_2) was deposited on the high refractive index material (HfO_2 or Ta_2O_5). The effects of interface microstructure and components on peeling-off damages were also discussed. The microstructure of the interface was not a major factor that influenced peeling-off damages. Incomplete oxides (SiO_x) and Na, K, Li ions accumulated near the interface and caused the formation of micro-defects layers with nano-sized thicknesses. Micro-defects layers maybe reduced adhesion of different interfaces and formed plasmas by absorbing laser energy. Finally stripping damages happened from micro-defects layers during irradiation by a 1064 nm laser.

1. Introduction

To improve the laser-induced damage threshold (LIDT) of coatings under the irradiation by a 1064 nm laser, researchers have determined the sources of coating damage [1–5]. Two damage geometries have been uncovered: layer peeling-off and deep craters. While deep craters are known to be caused by nodule defects in coatings [6], the sources of peeling-off damages [7] remain not clear. Some researches [8–10] suggest that if a pure film absorbs laser energy, the rise in temperature in the coating is inadequate to induce peeling-off damage during irradiation with a 1064 nm laser. Thus, the regularity and sources of peeling-off damages require further study.

In this work, thin films were prepared by electron beam evaporation (EBE) and dual ion beam sputtering (DIBS). The characteristics of peeling-off damages were analyzed after irradiation of the coatings by a 1064 nm laser. Changes in interface microstructures and components were also investigated.

2. Coating preparation and analytical methods

Multilayer films were evaporated on a BK7 substrate. EBE was performed on a Leybold Syrus C 1110 system using HfO_2 and SiO_2. DIBS was performed using a SPECTOR dual ion beam deposition system with Ta and SiO_2. In this article, the layer closest to substrate was considered the first layer.

The interface of the HfO_2 layer deposited on the SiO_2 layer was considered $\text{Interface}_{SiO_2 \rightarrow HfO_2}$, and the interface of the SiO_2 layer deposited on the HfO_2 layer was considered $\text{Interface}_{HfO_2 \rightarrow SiO_2}$. The interface of the Ta_2O_5 layer deposited on the SiO_2 layer was considered $\text{Interface}_{SiO_2 \rightarrow Ta_2O_5}$, and the interface of the SiO_2 layer deposited on the Ta_2O_5 layer was considered $\text{Interface}_{Ta_2O_5 \rightarrow SiO_2}$.

A Nd:YAG laser delivered a single, longitudinal mode, Gaussian-shaped laser beam of high spatial quality at a wavelength of 1064 nm and a pulse width of 10 ns. The spot size of the incident beam on the sample was about 500 μm at $1/e^2$ of the maximum intensity. The test method of LIDT was 1-on-1 according to the standard ISO11254-1 [11] and NASA Reference Publication 1395 [12].

Several characterization techniques, including focused ion beam-field emission scanning electron microscopy (FIB-FESEM; Zeiss), atomic force microscopy (AFM; Bruker Nano Inc.), X-ray photoelectron spectroscopy (XPS; Thermo Scientific), and time-of-flight secondary ion mass spectroscopy (TOF-SIMS; ION-TOF), were used to study the damage morphologies and interface characteristics of the coatings. XPS measurement and analysis were performed according to ASTM Guide 1523 [13] and ISO19318 [14].

3. Damage results and analyses

Three groups of coating stacks were used in the laser damage test: one group was prepared by EBE and the two other groups were prepared by DIBS. The parameters of the coatings and laser test are listed in Table 1.

Peeling-off damages in the coatings were observed by FESEM, and results are shown in Figs. 1 and 2. Brighter areas in

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Table 1
Sample and laser test parameters

No.	Deposit method	Total layer	Sub	Coating materials	Laser wavelength	Incident angle	Polarization
EBE-1	EBE	24	BK7	HfO_2 SiO_2	1064 nm	37.5°	S
DIBS-1	IBS	17		Ta_2O_5		45°	S
DIBS-2		42		SiO_2		56°	P

the secondary electron images indicate HfO_2 or Ta_2O_5 material whereas darker areas indicate the SiO_2 material.

To further analyze peeling-off positions, cross-sectional morphologies were obtained by FIB and photographed by FESEM, as shown in Figs. 3 and 4. Peeling-off positions occurred in $\text{Interface}_{HfO_2 \rightarrow SiO_2}$, such as in the interfaces between the 17th and 18th layers, the 19th and 20th layers, and the 21st and 22nd layers in sample EBE-1. In sample DIBS-1, peeling-off positions were observed in $\text{Interface}_{Ta_2O_5 \rightarrow SiO_2}$, such as in the interface between the 16th and 17th layers. Finally, in DIBS-2, peeling-off positions occurred between the 33rd and 34th layers as well as between the 41st and 42nd layers. Peeling-off damages occurred at the interfaces where the low refractive index material was deposited on the high refractive index material.

Several investigations show that damages to optical coatings are closely related to the intensity of the electric field in the coating layers. The electric field distribution throughout the layers may thus be taken as an indicator of susceptibility to damage [15]. Electric field distributions among the three coating stacks at 1064 nm were calculated using the TFCalc software package, and results are shown in Figs. 5–7. Elliptic ring labeling positions indicate peeling-off positions in the figures. The electric field intensity of peeling-off positions was not strong. Thus, the initial laser damage that attributed to heating of the coatings caused by intrinsic absorption should not occur in these positions.

Interface characteristics of peeling-off damages were studied next by analyzing the microstructure and components of the interfaces.

4. Results of microstructure and components

4.1. Interface microstructure

The surface morphology and roughness of monolayer were determined by AFM. The AFM instrument had a measurement error

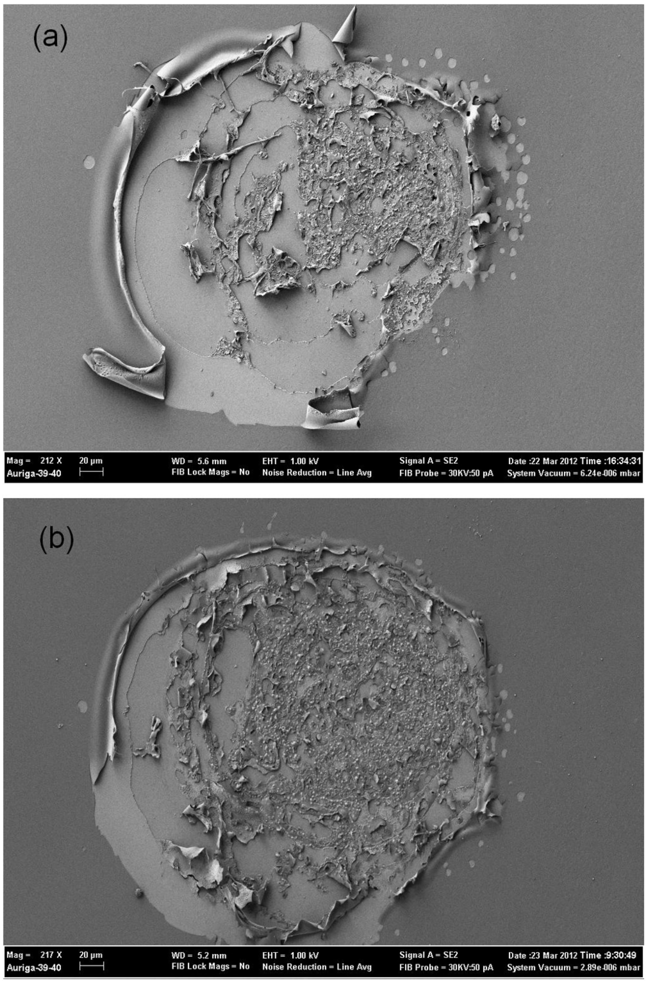

Fig. 1. SEM photographs of peeling-off damage in EBE-1: (a) one area and (b) the other area.

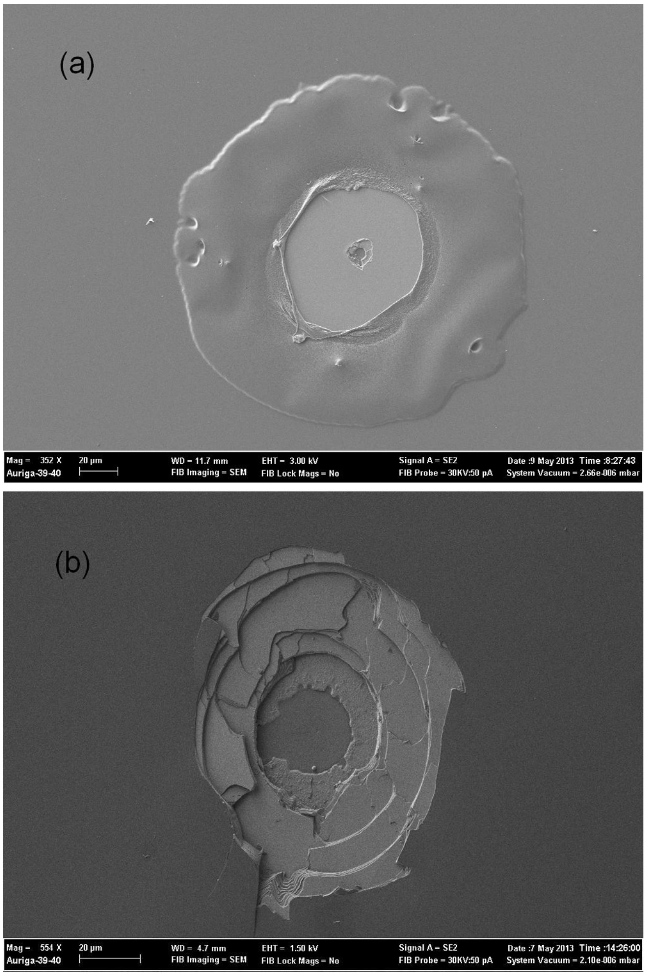

Fig. 2. SEM photographs of peel-off damage in (a) DIBS-1 and (b) DIBS-2.