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Laser-induced damage of the optical coatings due to organic contamination in vacuum

Xiulan Ling[a,*], Gao Wang[a], Yuanan Zhao[b], Xiaofeng Liu[b], Jianda Shao[b]

[a] Key Laboratory of Instrumentation Science & Dynamic Measurement, Ministry of Education and Key Laboratory of Science and Technology on Electronic Test & Measurement, North University of China, Taiyuan 030051, China

[b] Key Laboratory of Material Science and Technology for High Power Lasers, Shanghai Institute of Optics and Fine Mechanics, Shanghai 201800, China

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ABSTRACT

Monolayer ZrO_2 and multi-layer ZrO_2/SiO_2 films were contaminated deliberately with toluene in vacuum environments. Laser-induced damage tests were made on clean and contaminated ZrO_2/SiO_2 high reflective films. Surface adsorption layer model was presented to evaluate the impact of organic contaminations on the laser-induced damage. Based on this model, the distributions of electric field and temperature field in multi-layer ZrO_2/SiO_2 films were calculated. Results show that the mere organic contaminations cannot induce the thermal damage of optical films. The inter-coupling between defects and organic contaminations is probably attributed to the decrease of the laser-induced damage threshold in contaminated samples.

1. Introduction

Laser-induced damage of optical materials in the vacuum and space environments has aroused great interests during the last decade. Compared to the atmosphere, the optical films used in vacuum circumstance have a decreasing laser-induced damage thresholds and a short service life time [1–3]. Organic contaminants outgassing from materials present in closed or vacuum environments have been proven to be responsible for the degradation of optical performances [4,5]. Reflective and transmissive losses as well as laser-induced damage have been correlated to organic contamination level in many cases [6,7]. The studied wavelengths ranged from far ultraviolet to visible domains, and the incriminated molecules were aromatics, siloxane derivatives, and phthalates. Adsorption or deposition of organic contamination molecules on the surface of optical thin films is the first step-induced degradation of optical performances. The control of the adsorption of organic contamination molecules on the surface of optical thin films is possible of main practical and economical interest for future design. Various hypotheses are also proposed to explain the damage mechanism [8]. However, most of the studies have little attention to developing an understanding of the damage characteristic of dielectric optics exposed to organic contaminations.

The aromatic toluene was used as a representative of aromatic compounds as it is a common impurity in many paints and adhesives used for space and vacuum applications [9,10].

In the current work, monolayer ZrO_2 and multi-layer ZrO_2/SiO_2 films were contaminated deliberately with gaseous toluene in vacuum system. Laser-induced damage tests were made on clean and contaminated ZrO_2/SiO_2 high reflective films. Surface adsorption layer model was presented to evaluate the impact of organic contaminations on the laser-induced damage. Based on this model, the distributions of electric field and temperature field in multi-layer ZrO_2/SiO_2 films were calculated to analyze organic contamination effects on the laser-induced damage and understand the damage progress and mechanism.

2. Contamination experiments and laser-induced damage test

Monolayer ZrO_2 and multi-layer ZrO_2/SiO_2 films were evaporated at a substrate temperature of 120 °C by an electron beam with the base pressure of approximately 3.0×10^{-3} Pa. The oxygen partial pressure was set as 5.0×10^{-3} Pa and the deposition

* Corresponding author. Tel.: +86 3513559476.
E-mail address: nmlxlmiao@126.com (X. Ling).

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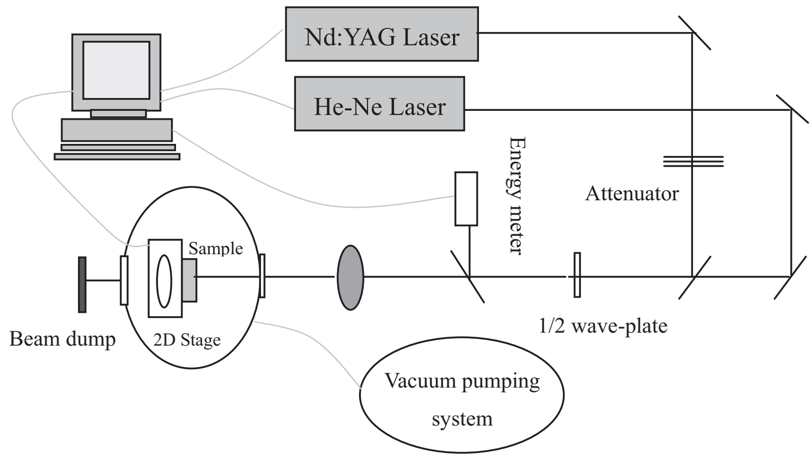

Fig. 1. Measurement setup of laser-induced damage in vacuum.

rate was about 0.3 nm/s, respectively. ZrO_2 single layer films with optical thickness of 5 QWOT (quarter wavelength optical thickness) were deposited at the reference wavelength of 530 nm. Reflection film design [air: 2H(2L2H)Î3LH: K_9] with a center wavelength of 1064 nm consisted of coating layers of ZrO_2 and SiO_2 on a K_9 substrate, where H stood for a quarter wavelength optical thickness (QWOT) of ZrO_2 and L stood for a QWOT of SiO_2. High quality K9 substrates were polished and cleaned ultrasonically in alcohol solution before deposition.

The experimental setup used in this study is shown schematically in Fig. 1. Nd:YAG laser delivered a single longitudinal mode, Gaussian-shaped laser beam of high spatial quality at a wavelength of 1064 nm with a pulse width of 12 ns. A stabilized He–Ne laser was made collinear with the main Nd:YAG beam and both beams were directed onto the sample surface under investigation with an convex lens. The spot size of the beam incident on the sample was about 400 μm diameters at $1/e^2$ of the maximum intensity. The sample was fixed in a sample holder within the vacuum chamber which could be moved and positioned laterally relative to the beam with an x/y translation stage controlled by a PC computer. Based on the standard ISO11254-1 [11], the test method of laser-induced damage thresholds (LIDT) was the 1-on-1 mode, which the LIDT (J/cm^2) was defined as the incident pulse's energy density with 0% probability of damage, as obtained by linear extrapolation of the damage probability data. Pulse energy fluctuations of the laser is within the scope of 3%, spot size variations measured by Beam ViewTW beam diagnostics and peak energy density fluctuations are less than 2.6% and 5.8%, respectively. Laser damage tests were carried out in vacuum with the measurement pressure set between 1.2×10^{-2} Pa and 4×10^{-3} Pa. The damage was detected with a Normarski interferential contrast microscope off-site.

Our experiments were performed as following procedures. At first step, we deliberately contaminated some single-layer ZrO_2 and multilayer ZrO_2/SiO_2 samples. In this step, toluene in gaseous phase was introduced in the vacuum chamber, and samples were kept in vacuum chamber for several days. Then, the transmittance spectra of clean and contaminated single-layer ZrO_2 and multilayer ZrO_2/SiO_2 films were measured with a Lambda 900 spectrometer, as is shown in Figs. 2 and 3. The measurement error of the spectrometer was within 0.08%. From Figs. 2 and 3, we can see that the transmittance of monolayer ZrO2 coating gradually decreased with the time in vacuum in the presence of gaseous toluene and the transmittance spectra of both single-layer ZrO_2 and multilayer ZrO_2/SiO_2 films have a shift to long wavelength region. The

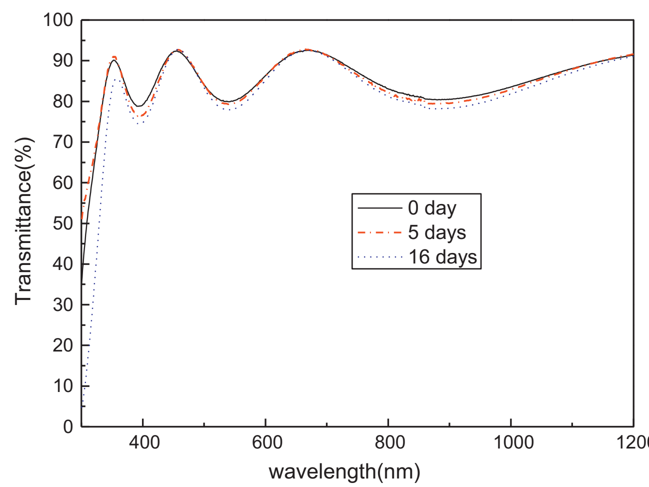

Fig. 2. Transmittance spectra of ZrO_2 coatings placed in vacuum with gaseous toluene after several days.

refractive index and extinction coefficient of single-layer ZrO_2 films presented in Fig. 4 were determined from the transmission spectra based on envelope method [12,13] to analyze the impact of organic contamination adsorption. From Fig. 4, we can see that the

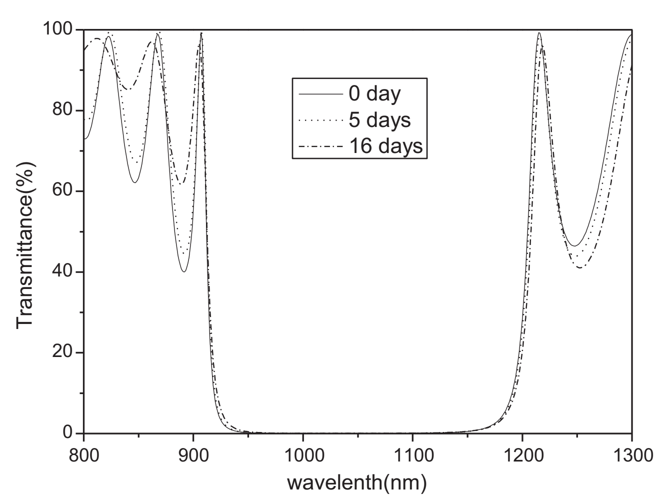

Fig. 3. Transmittance spectra of ZrO_2/SiO_2 coatings placed in vacuum with gaseous toluene after several days.