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Effects of annealing on laser-induced damage threshold of TiO_2/SiO_2 high reflectors

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Abstract

The mechanism of improving 1064 nm, 12 ns laser-induced damage threshold (LIDT) of TiO_2/SiO_2 high reflectors (HR) prepared by electronic beam evaporation from 5.1 to 13.1 J/cm^2 by thermal annealing is discussed. Through optical properties, structure and chemical composition analysis, it is found that the reduced atomic non-stoichiometric defects are the main reason of absorption decrease and LIDT rise after annealing. A remarkable increase of LIDT is found at 300 °C annealing. The refractive index and film inhomogeneity rise, physical thickness decrease, and film stress changes from compress stress to tensile stress due to the structure change during annealing.

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1. Introduction

Laser-induced damage in optical coatings used in high power laser has been recognized as a key performance limiting factor, nearly since the invention of the laser [1]. The high reflector (HR) is one of the high fluence optics used in the injection laser systems. The nominal laser-induced damage threshold (LIDT) requirement is 10 J/cm^2 at 1053 nm, 3 ns laser pulse [2]. Reduction the absorption of HR is crucial to applications of high-energy laser [3]. TiO_2 is a hard, durable, and laser-damage-resistant material of high refractive index and is widely used to produce multilayer coatings in the visible spectral region [4]. Non-stoichiometric, [5] surface defects [6] and the damage initiation of high-power laser coatings [7] are the typical absorption center in TiO_2 coatings. The defects concentration is mainly determined by deposition process and other factors [8]. Annealing is a common practice to reduce absorption. LIDT related optical properties, structure, chemical composition and absorption can be changed after annealing [9].

In this paper, the effects of annealing on optical properties, structure, chemical composition, absorption and LIDT of titanium oxide films are investigated. The mechanism of improving LIDT of TiO_2/SiO_2 HR by annealing is discussed.

2. Experiments

TiO_2 and SiO_2 are used as high and low-refractive-index materials, respectively. High-quality BK7 substrates are super-polished and cleaned ultrasonically in alcohol solution before deposition. The physical thickness of single layer TiO_2 film is about 500 nm. The film's design of HR is $(HL)^{10}H$, where H stands for quarter wavelength optical thickness (QWOT) of TiO_2 and L stands for QWOT of SiO_2. All films are deposited by electronics beam evaporation in the following process parameters: the substrate temperature is kept at 300 °C during deposition. The base pressure is 2.0×10^{-3} Pa and oxygen partial pressure is 3.0×10^{-2} Pa during deposition. The deposition rates of TiO_2 and SiO_2 are 1.33 and 0.2 nm/s, respectively. Annealing on samples under the temperature from 200 to 400 °C by a step of 100 °C is performed in a furnace with air environment to the desired temperature for 4 h. They are then cooled to room temperature in air. All samples

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are carefully packed in a glass vessel for avoiding contamination.

The transmittance spectra of films are measured with a Lambda 900 spectrometer. The surface thermal lensing (STL) technique [10] is used to measure the absorption of HR. Refractive index, extinction coefficient and physical thickness of films are calculated from the transmittance spectrum by the envelope method [11].

The crystalline phase of films is investigated by a RGAKU/MAX-3C X-ray diffraction (XRD) meter. X-ray photoelectron spectroscopy (XPS) analysis is performed with an ESCALab MK2 spectrometer to investigate the binding energy of titanium oxide. The surface defects are detected by a Nomarski microscope. LIDT is tested using a 1064 nm, 12 ns laser pulse in the 1-on-1 mode with the ISO standard 11254-1[10].

3. Results and discussion

3.1. Optical properties

Fig. 1 shows the transmittance spectra films. The single layer films' spectrum shifts to short wavelength region and

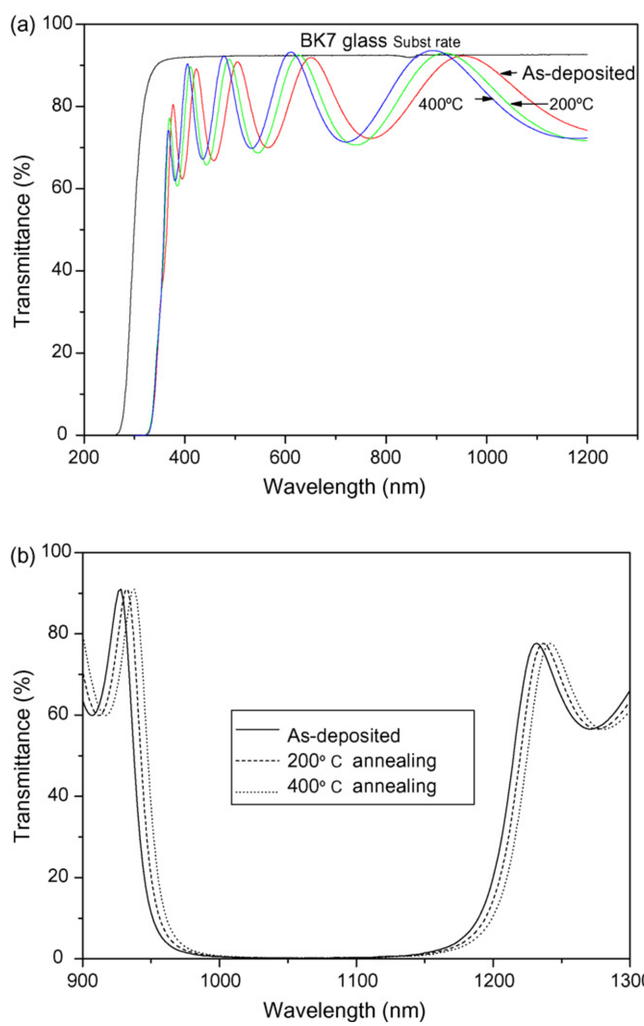

Fig. 1. Selected transmittance spectra of (a) single layer TiO_2 films and (b) TiO_2/SiO_2 HR at different annealing temperature.

Table 1
Absorption of HR at different annealing temperature

Annealing temperature (°C)	As-deposited	200	300	400
Absorption (ppm)	83.6	78.4	27.4	21.5

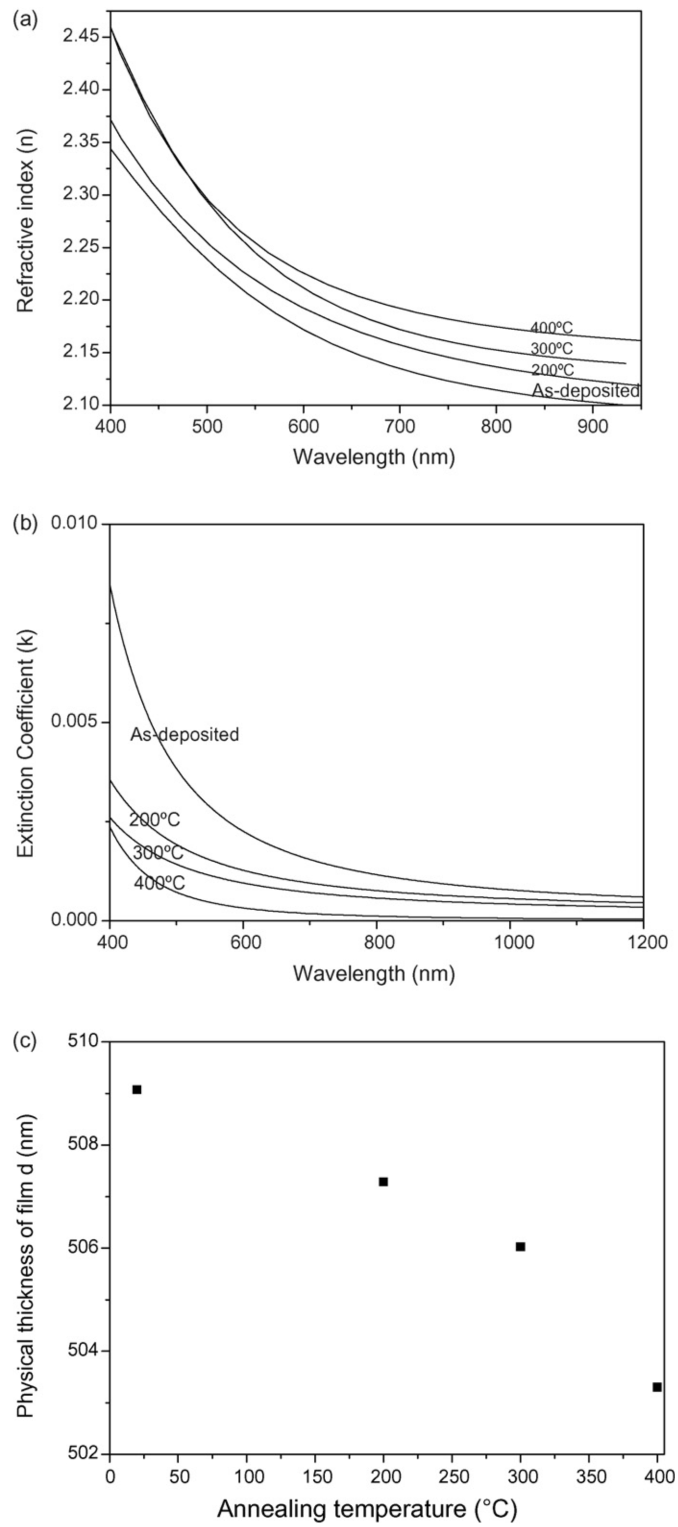

Fig. 2. (a) Refractive index, (b) extinction coefficient and (c) physical thickness of single layer TiO_2 films at different annealing temperature.