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Effects of oxygen flows on optical properties, micro-structure and residual stress of Ta_2O_5 films deposited by DIBS

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ABSTRACT

High precision optical components, such as ultra-high reflectors, severely suffer from absorption losses. In order to get optical films with low absorption losses, many techniques, such as annealing and laser conditioning, have been widely employed as a post-deposition treatment process to deal with as-deposited films. However, the success of these processes starts with the correct choice of the deposition parameters. In this paper, Ta_2O_5 films are deposited by dual ion beam sputtering (DIBS) method and the effects of target oxygen flows on optical properties, microstructure and residual stress are systematically investigated. The results show that target oxygen flows can significantly affect the absorption losses and residual stress of Ta_2O_5 film. The XRD patterns reveal that Ta_2O_5 films deposited at different parameters are all amorphous. Finally, based on the results of Ta_2O_5 films, broadband dielectric mirror with high reflection and low absorption losses in the range from 380 nm to 750 nm is successfully fabricated.

1. Introduction

Ta_2O_5, which is one of the most important optical film materials, has a relatively high refractive index, a high packing density, a relatively broadband gap, a low absorption, a high laser induced damage threshold (LIDT) and an excellent thermal stability [1–12]. It has been widely used for optical films in high power laser systems, such as National ignition facility (NIF), Laser Interferometer Gravitational-wave Observatory (LIGO), VIRGO and other inertial-confinement-fusion (ICF) class laser system [13–15]. However, the absorption of as-deposited Ta_2O_5 films is the major obstacle to the improvement of high-power laser systems [16–18]. Thus, it is very important to optimize deposition process parameters to further decrease the absorption of Ta_2O_5 films.

It is well known that the dual ion beam sputtering (DIBS) technology is a superior method [19–21], which can fabricate optical films with high LIDT, bulk-like packing density, low absorption and scattering loss [22]. Many studies on Ta_2O_5 films deposited by IBS have been reported. For example, Cheng Xu reported the effect of the initial temperature on the nanosecond laser-induced damage and the ion energy on optical properties of Ta_2O_5 films prepared by DIBS [23,24]. But till now there are no systematical studies on the effect of oxygen flow on the absorption properties of the Ta_2O_5 films, which is an important factor for the LIDT and high power environmental stability of the films.

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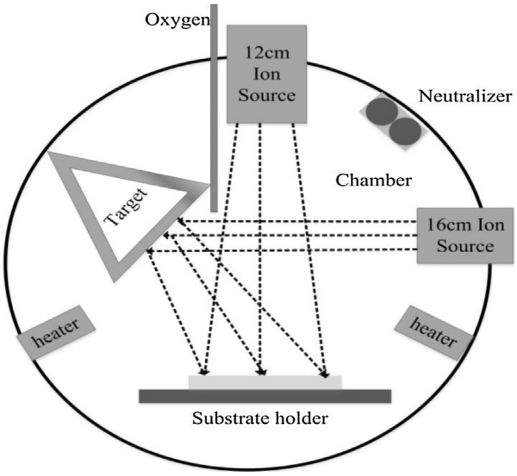

Fig. 1. Scheme of the dual ion beam sputtering system.

Table 1
Main basic deposition parameters including ion beam voltage, current, deposition temperature and base pressure.

16 cm Ion beam		12 cm Ion beam		Deposition temperature (K)	Base pressure (Torr)
Voltage (V)	Current (mA)	Voltage (V)	Current (mA)		
1350	1100	650	500	353	8×10^{-7}

In this paper, the effects of the oxygen flows on the absorption, micro-structure and stress of Ta_2O_5 films deposited by DIBS method were investigated systematically. In order to obtain optical films with low absorption losses, it is very important to select proper parameters for the fabrication of Ta_2O_5 films. The optical properties, microstructure and residual stress of Ta_2O_5 films were comparatively studied. Finally, based on the results of Ta_2O_5 films, broadband dielectric mirror with high reflection and low absorption losses was designed and fabricated.

2. Experiment

In this study, the Ta_2O_5 films and multilayer films were deposited by IBS method, as shown schematically in Fig. 1. The sputtering chamber was cryogenically pumped to a base pressure below 8×10^{-7} Torr. The target materials were Tantalum (99.99%) and Silica (99.99%). Fused silica as the substrate was heated up and maintained at 353 K during the whole deposition process. The film machine was equipped with a 16 cm main ion source and a 12 cm RF assist ion source. In this paper, ion beam voltage, ion beam current, deposition temperature and oxygen flows were set as the independent deposition parameters. The main basic deposition parameters were shown in Table 1.

A Zygo interferometer (Zygo, Fizeau, GPI-XP) was employed to measure the reflection surface figure of the substrate before and after deposition. Then the residual stress of films was calculated by the Stoney equation [25]. In general, negative and positive stress values represent tensile and compressive stress, respectively.

$$\sigma = \frac{E_s}{6(1-V_s)}\frac{t_s}{t_f}\left(\frac{1}{R_1}-\frac{1}{R_0}\right) \tag{1}$$

$$R = \frac{1}{4f\lambda}\left[D^2 + \left(f\lambda\right)^2\right] \tag{2}$$

where E_s and V_s are Young's modulus and Poisson's ratio of the substrate, R_0 and R_1 are the radii of curvature of the substrate prior to and after film, respectively. λ is the wavelength, f is fringes of power or wave front distortion, and D is the diameter of the clear aperture.

The transmittance and reflection spectra in the range between 250 nm and 900 nm were obtained by a Perkin Elmer Lambda 950 spectrophotometer. Based on the transmittance spectra, the optical constants and physical thickness were fitted using the commercial Optichar software. The accuracy in n (refractive index) determination is of the order of ± 0.005 [22].

A scanning atomic force microscope (AFM, di Digital Instruments, D3100, Veeco Metrology Group) was utilized to measure the roughness of these films. The scanning mode was configured as contact, with a scanning rate of 1 Hz and high resolution. A region with the size of $5\,\mu m \times 5\,\mu m$ was selected for the characterization of the specimen. The obtained images were processed to remove background signals, and to extract results such as surface roughness (RMS) and topographic profiles.