A novel remote plasma sputtering technique for depositing high-performance optical thin films

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ABSTRACT

This paper describes a novel remote plasma sputtering technique for depositing optical thin films. This technology is based on generating intensive plasma remotely from the target and then magnetically steering the plasma to the target to realize the sputter deposition. It overcomes several of inherent limitations in conventional sputtering techniques and realizes the fully uniform erosion over the surface of the target and less target poison. This allows a uniform reaction in the plasma phase when performing reactive sputtering, leading to the formation and deposition of material with a uniform stoichiometry and gives pseudo-independence of target current and voltage. This pseudo-independence offers a great deal of flexibility with regard to the control of growth conditions and film properties, the benefits include control of stress, very low deposition rates for ultra thin films. By remote reactive sputtering, dense metal-oxide optical thin films (SiO_2, Ta_2O_5, Nb_2O_5) with a high deposition rate, excellent optical properties are achieved. High process stability shows an excellent time terminating accuracy for multilayer coating thickness control. Typically, thin film thickness control to $<\pm1\%$ is accomplished simply using time. The multilayer coating, including anti-reflection, dichroic mirror and 2μm laser mirrors are presented.

Keywords: Plasma source, sputtering deposition, reactive sputtering, optical thin films, laser mirror

1. INTRODUCTION

Multilayer optical thin films are important in a number of applications including precision optics, fiber optical telecommunications and solid state laser. Traditionally, physical vapor deposition techniques are utilized including electron beam deposition and evaporation. Sputter deposition is emerging as a preferred alternative for deposition of optical coatings. Magnetron sputtering has a number of advantages over conventional physical vapor deposition techniques such as electron beam and thermal evaporation. For example, the kinetic energy of the sputtered atoms is typically 10 times higher than that of evaporated species, and these results in much harder and much more adherent coatings. The energy of the process also removes the need for substrate heating during deposition which is of specific benefit when coating plastic substrates or other temperature sensitive substrate materials.

The metal-oxide materials used in multilayer optical coatings are good electrical insulators. It is possible to sputter insulators using radio-frequency power, but the deposition rates are too low to be economical. Generally, a metal target is used in metal-oxide deposition for achieving a high deposition rate by DC reactive magnetron sputtering. Conventional reactive sputtering deposition normally has very low deposition and high compressive stress. Especially in magnetron sputtering, because of racetrack formation over the surface of target, this has a strong effect on the process instabilities and rate drifts, even results in local target poisoning. To overcome this problem, following early work[1-2], techniques have been developed in which a few monolayers of metal are deposited using dc sputtering in one zone of a vacuum chamber and the metal is then oxidized in another zone as the substrates rotate.

The remote high density plasma source was developed in 2001 by Prof. Mike[3]. This technique overcomes several inherent limitations of conventional sputtering and has been used successfully in the fields of flexible display and ferromagnetic materials[4-5]. In this paper, the process was developed as a method of depositing high refractive index, low loss metal-oxide optical thin films for laser application.

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2. THE REMOTE PLASMA SPUTTERING PROCESS

A schematic drawing of the system is shown in Fig.1. Unlike conventional magnetron sputtering, the technique relies on the generation of plasma remotely from the targets, and the internal magnetic elements behind the target are eliminated. An RF coil antenna surrounding a quartz tube is attached to the vacuum chamber as a side arm. The plasma is initiated and amplified by a DC launch electromagnet towards the plasma source exit. By altering the current applied to the electromagnet and in particular to the steering electromagnet, the position of the plasma beam can be adjusted to ensure good beam impingement on the target surface. In order to sputter material, a negative DC bias (0-800V) needs to be applied to the target. Pure Argon gas was introduced to the chamber by placing a diffusion ring close to the target, and the oxygen was fed into the chamber though another diffusion ring placed as close as possible to the substrate. This was done to maintain the target in a metal mode. Because of the special conformation for plasma system, fully uniform erosion over the whole target surface is realized because of eliminating the internal magnetic elements behind the target. This is obvious difference from the conventional magnetron sputtering. This allows for a uniform reaction in the plasma phase when performing reactive sputtering, leading to the formation of material with a uniform stoichiometry. Fig. 2(a) shows the photo of the remote plasma when the system is operating. Fig. 2(b) shows the niobium target which has been uniformly eroded.

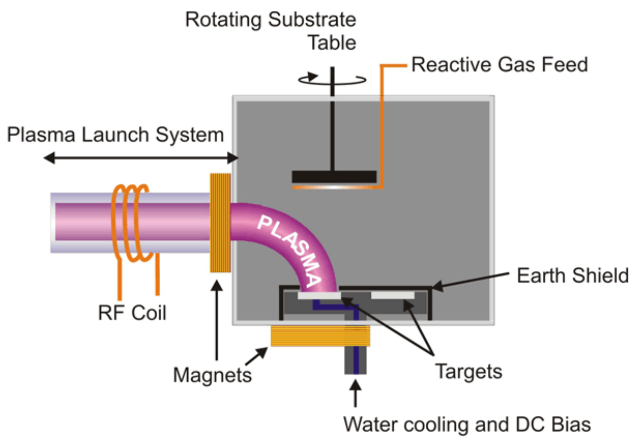


Figure 1. The remote plasma sputtering deposition schematic drawing

(a) The remote plasma beam (b) The niobium target

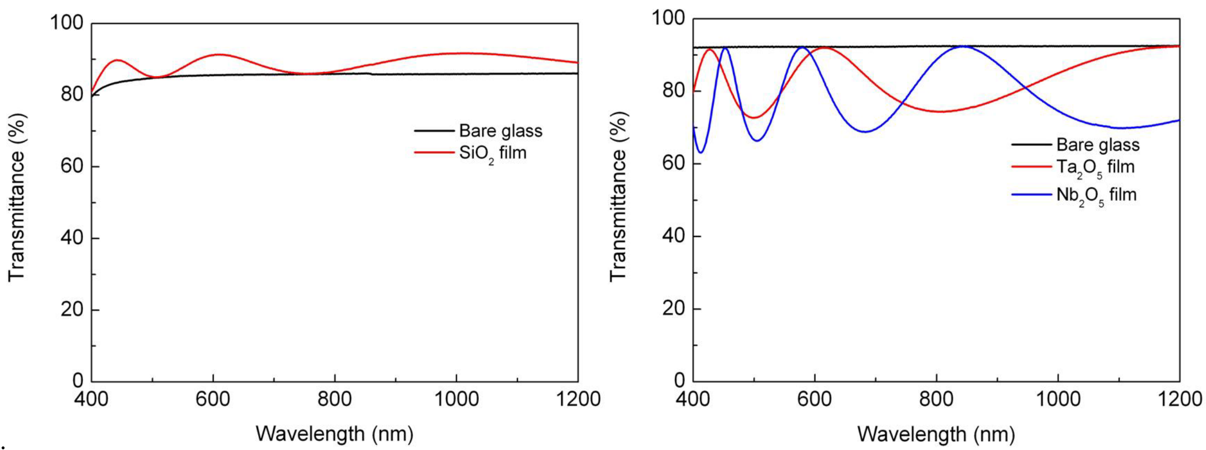
Figure. 2. Photos of (a) the remote plasma beam when the system is operating and (b) the niobium target which has been uniformly eroded.

During the deposition process, the system was pumped using cryo-pump with a base pressure of 6×10^{-6} Torr; The oxygen flow was regulated from 0-30sccm, the argon flow was fixed at 85sccm, and the background pressure is approximately 5×10^{-3} Torr level. To achieve a high deposition rate in reactive process, the RF power was adjusted from 1-2.2 kW and the target negative bias voltage was set from 300V- 700V respectively. The BK7 and ZF7 glass with 30mm diameter, 3mm thick, and high surface quality 20-10 scratch dig was used to deposit the films. Transmission measurements were performed using Perkin-Elmer Lambda 750 spectrometer. The optical constants, n and k, were calculated from the transmission spectra by the envelope method , which is based on the analysis of the transmission spectra of weakly absorbing film that deposited on an free-absorption substrate. Meanwhile the deposition rate was measured and monitored by the Telemark 880 quartz crystal thickness control. Main work focused on determining the optimal reactive process transparency window for low loss dielectric films.

3. RESULTS AND DISCUSSION

3.1 PROPERTIES OF SINGLE FILMS

When the remote plasma process is used with pulsed dc power supplies it produces metal oxides such as SiO_2, Nb_2O_5 and Ta_2O_5 with outstanding optical properties. For high rate and low loss oxide films, the oxygen flow is very key parameter. Optical properties of the single layer SiO_2, Nb_2O_5 and Ta_2O_5 were studied in order to deposit multilayer optical coatings with performance that matches design. The optical transmittances of samples with uncoated substrate are showed in Fig. 3. The transmittance at half-wave point reaches the highest value, and this means that at this condition the deposited film has the lowest absorption. The refractive index of these oxides is close to that of the bulk material, due to the high energy of the process. The films are spectrally stable due to the absence of porosity. Figure 3 demonstrates the exceptional optical quality in relation to low absorption characteristic and film homogeneity over the visible spectrum, particularly over the low wavelength region. Such film properties are necessary to coating high performance multilayer optical coatings.



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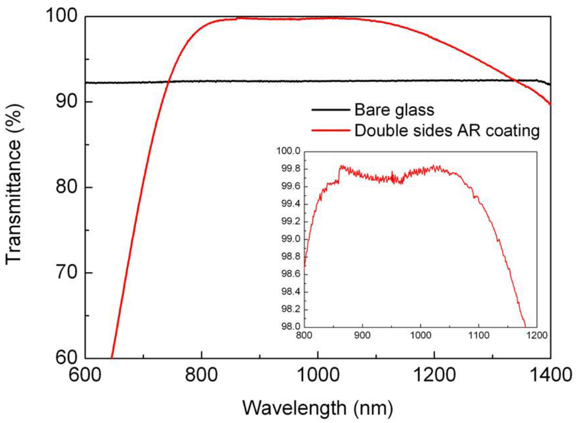
(a) SiO_2 single layer transmittance spectra (b) Nb_2O_5 and Ta_2O_5 single layer transmittance spectra

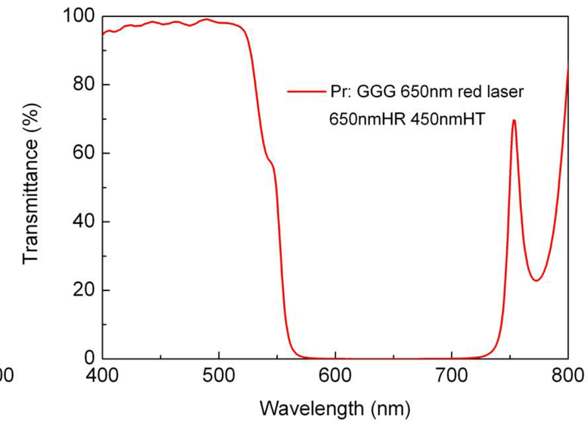
Figure. 3. Transmittance spectra of single films of (a) SiO_2, (b) Nb_2O_5 and Ta_2O_5

3.2 PROPERTIES OF MULTILAYERS

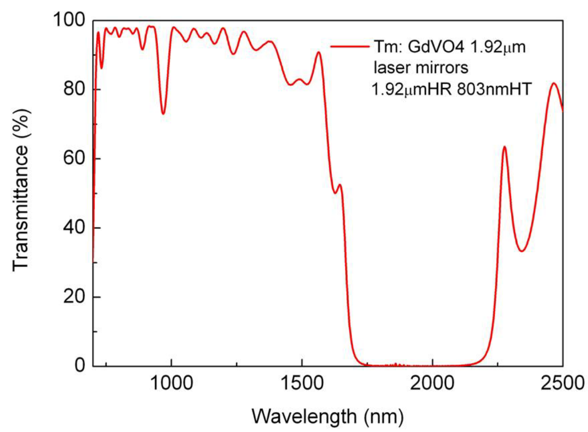
A number of multilayer experiments were performed to check the deposition stability and repeatability. The condition of single layer experiments could be a good starting point, and deposition parameters were further optimized for long time multilayer trials. Good multilayer coatings were finally prepared, parts of them were showed in Fig.4. Fig. 4(a) shows the transmittance spectra of a double-sides anti-reflection coating operating on 850-1100nm. The peak value of transmittance is more than 99.8%. Fig. 4(b) and (c) show the transmittance of coatings for diode pumped solid state laser. The coatings were deposited on one surface of the substrate, and the reflection of the other surface was removed by data processing. For Fig. 4(b), the pumping light (450nm) is highly transmitted (>95%), while the reflection of lasing wavelength (650nm) is near 100% to minimize the cavity loss. The coating showed in fig. 4(c) is similar to that in fig. 4(b), and the pumping light (806nm) is highly transmitted and lasing light (1.92μm) is highly reflected, too. The difference is that the thickness of coating (c) is times more than that of coating (b), which sets higher requirements of deposition stability and repeatability. The laser experiment is undergoing in the laboratory.



(a) Double sides anti-reflection coating for Near-IR



(b) Coating of input mirror for red laser



(c) Coating of input mirror for IR laser

Figure. 4. Optical performance of multilayers prepared by remote plasma sputtering

4. CONCLUSIONS

This work presents a new process which can be used to prepare high performance optical coatings, using high density plasma. The new construction makes a full target surface uniformly erosion and flexibility to deposition control. Single films of SiO_2, Nb_2O_5 and Ta_2O_5, and multi-layers of AR and laser input mirror coatings are prepared. The transmittance measurements show that this process has technological potential in high performance optical thin film deposition.

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