Plasma Assisted Pulsed DC Magnetron Sputtering System for Optical Thin Film Coatings

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Abstract: Using plasma assisted pulsed DC magnetron sputtering technology, low loss, high performance optical coatings have been achieved. Multi-layer coating examples using Ta_2O_5 and SiO_2 materials are demonstrated. This technology is suitable for volume production.
OCIS codes: (310.0310) Thin Film; (310.0360) Deposition and Fabrication

1. Introduction

DC magnetron sputtering has been widely used for producing numerous types of high quality thin films. Its stable, repeatable process and ability to handle large area deposition makes it very attractive to the optical coating industry. However, to make high quality, low loss optical thin films, one issue often encountered in the process control of reactive sputtering is arcing [1, 2] induced coating defects that cause scattering and absorbing films. This is particularly the case with SiO_2, an important low index material widely used in the optical coating industry, which is typically sputtered from a Si target.

The arcing is a result of the breakdown of the thin dielectric film caused by electrical charge build up on the target. It is obvious that eliminating or minimizing arcing can be achieved by a) avoid insulating films to be formed on the target by minimizing reactive gas in the target area; b) remove the charges that are accumulated on the insulating films before its breakdown voltage is reached.

To resolve the arcing issue, we adopted a two-step approach in the layout of the optical sputtering system: 1) by strategically placing a plasma source at a location that directs most of the reactive gas towards the coating surface while minimizing the reactive gas migrating to the target area to ensure that targets are maintained at the metallic mode, 2) using pulsed DC magnetron sputtering technology to periodically remove (neutralize) the charges that may build up on the target surface. By adopting those, arcing has effectively been eliminated during the reactive sputtering process and the thin film deposition rate as high as 0.6nm/s has been achieved.

2. Optical Sputtering System and Sample Coating Results

Shown in Figure 1 is an overview of the pulsed DC magnetron sputtering system. It is based on a 54-inch chamber and consists of a plasma source, a quartz crystal monitor and three round magnetrons. Through pumping and other mechanical arrangements, the three magnetrons are installed in the reactive gas (oxygen, in this case) poor area, while the plasma source creates an oxygen rich area above its discharge surface. During the sputtering process, metallic or semi-metallic films are first being deposited, and then the substrates rotate to the oxygen rich area that is created by the plasma source. In the oxygen rich plasma zone the metallic layers react with oxygen ions and form stoichiometric oxide films.

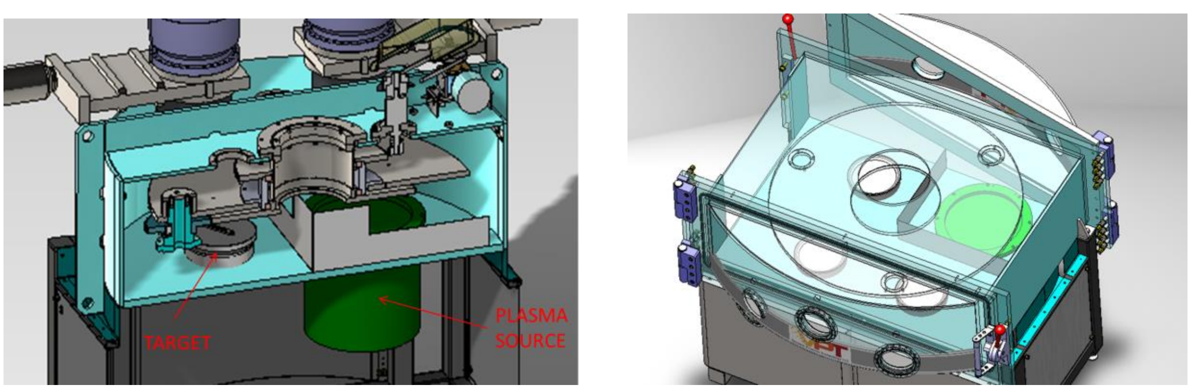

Fig. 1. Schematics of the pulsed DC magnetron sputtering system that consists of three magnetrons and a plasma source.

In the experiments discussed in this paper, Ta and Si targets were installed and sputtered at 20 kHz pulsing frequency. With the assist of a plasma source, high quality Ta_2O_5 and SiO_2 films were produced.

The sputtered Ta_2O_5 and SiO_2 films are characterized and their refractive indices are shown in Figure 2. Their values are slightly higher than the films produced by ion assisted e-beam evaporation (IAD).

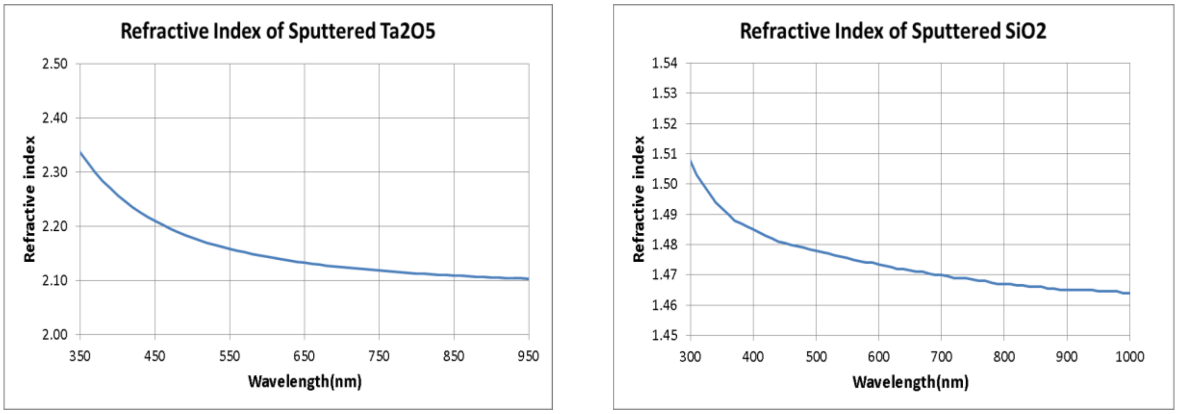

Fig. 2. Refractive indices of sputtered Ta_2O_5 and SiO_2 films

In order to test the process capabilities of the sputtering system and the film quality regarding its absorption and scattering losses, two thin film filters were designed and deposited: a) a 72-layer steep-slope short-pass filter; and b) an 80-layer low-ripple wideband pass filter. The film thicknesses of the sputtered filters were controlled by a quartz crystal monitor. Figure 3 shows the results. As can be seen, both filters exhibit very low losses in their pass band and their measured spectrums match very well with the theoretical designs.

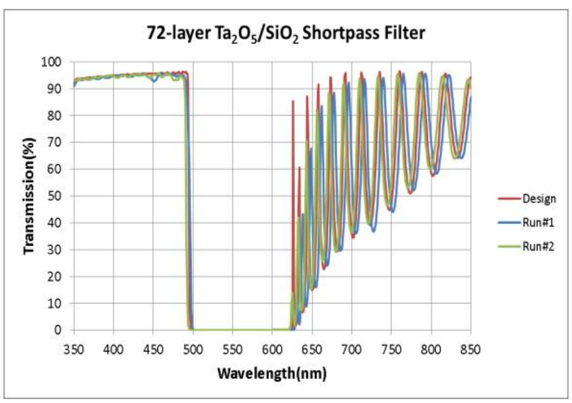

Fig. 3a. 72-layer short-pass filter performance. Filter thicknesses are controlled by quartz crystal and total thickness is 5.8µm. The back side of the substrate is not coated.

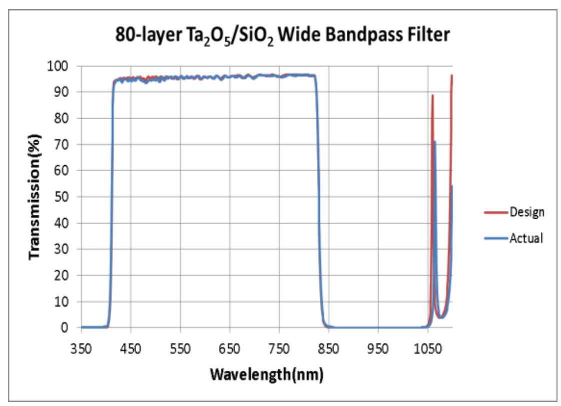

Fig. 3b. 80-layer wide-band filter performance. Filter thicknesses are controlled by quartz crystal and total thickness is 7.2µm. The back side of the substrate is not coated.

Selection of process parameters are critical to the final filter performance, and in some instances even substrate rotation speed plays an important role on the stoichiometry of the film. Figure 4 shows the significant difference of the passband loss of a short-pass filter at two different rotation speeds of the substrate while the filter design and all other process parameters maintained the same. This result shows that at certain process parameters, there is a thickness limit to fully oxidize metallic Ta or Si coatings, above that thickness stoichiometric Ta_2O_5 or SiO_2 films cannot be formed.

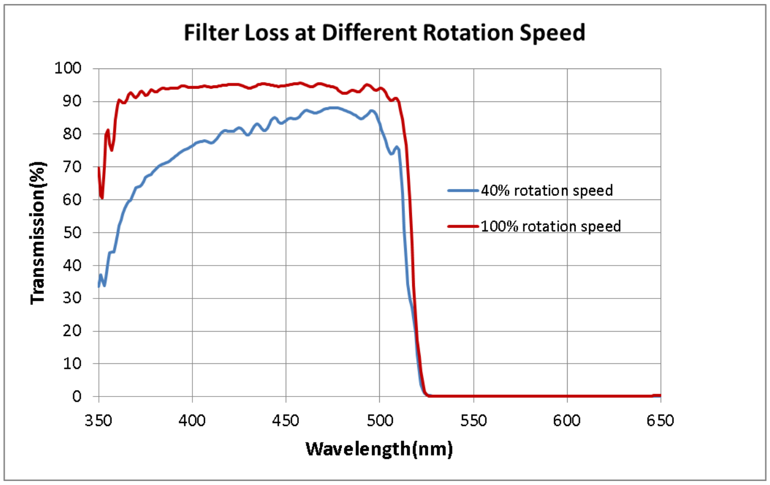

Fig. 4. Comparison of the passband loss of the sputtered short-pass filters at two different rotation speeds. The design and the other process parameters are the same except the substrate rotation speed.

3. Conclusions

It has been demonstrated that using plasma assisted pulsed DC magnetron sputtering technology, high performance, low loss optical coatings can be realized using oxide materials such as Ta_2O_5 and SiO_2, with fast deposition rate and large substrate area.

4. References

[1] O. D. Vol'pyan and P. P. Yakovlev, "Investigation of SiO2 optical films produced by reactive ac magnetron sputtering," J. Opt. Technol. **71** (7), July 2004.

[2] J. Musil, et al, "Reactive sputtering of thin films: present status and trends," Thin Solid Films, 475 (2005) 208-218.