Improving Throughput of Ion Beam Sputtered Optical Films

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ABSTRACT

Ion Beam Sputtering has been the choice for leading edge optical coating manufacturing for more than three decades. During that time the technology has moved from the scientific lab to high volume production. Market forces continue to drive toward larger volume production of these high quality films. In order to meet these needs, increases in deposition rate and substrate lot size are required while maintaining the superior quality expected from ion beam sputtered films. The latest process development at high deposition rates of Ta_2O_5, SiO_2 and Nb_2O_5 are shown.

INTRODUCTION

Ion beam sputtering has been used to produce the most challenging optical coatings for more than 30 years. The lowest optical losses combined with smooth film and dense amorphous microstructure makes this an attractive option for most applications. Flexibility in use of dielectric, semiconductor or metal targets are also positive technical attributes. The historical drawback keeping ion beam sputtering from being used in more applications has been cost per part due to limited coating throughput. In the following, we will review the improvements made to the latest generation of ion beam sputtering systems to support increased throughput while maintaining the highest quality of optical films.

BACKGROUND

Ion Beam Sputtering (IBS) involves using a gridded ion source to produce a beam of ions which sputter material from a target surface. IBS removes material from a target and subsequently deposits this material with more average energy than evaporation, ion assisted evaporation or magnetron technologies. The additional particle energy paired with low operating pressures lead to extremely low defect levels and fully dense films with surface roughness of less than 0.1 nm. These advantages have been applied to the highest performance optical coatings over the past 30 years. Some of these applications include gyroscopic mirrors [1], telecommunication band pass and gain flattening filters [2], ultra-low loss and highly damage tolerant laser mirrors [3], fluorescence filters [4] and dispersion correcting optics. For more than fifteen years, many of these coatings have been done utilizing Veeco's SPECTOR® ion beam deposition tool.

Ion beam sputtering involves the ionization of a noble gas and acceleration of the generated ions. Ionization typically takes place via inductive coupling of an RF field into an insulating discharge chamber. The mechanism of the RF inductive coupling is analogous to a transformer where the RF coil acts as a primary and the plasma itself as a secondary. Energetic electrons collide with neutral atoms and create positively charged ions and more free electrons. These electrons continue to multiply through additional collisions and thereby fuel the creation of stable plasma.

Positive ions are extracted from the discharge plasma using an ion optics system that includes electrically biased grids with multiple circular apertures. The gridded ion optic assembly generates a collimated ion beam with tightly controlled energy. The ion optics are designed to provide optimum beam coverage over the sputtering target.

The ion beam system also includes a radio frequency neutralizer (RFN) located outside of the ion source. This device provides electrons for initial plasma discharge ignition as well as for ion beam neutralization. The RFN also uses inductive coupling to produce the plasma, but is biased to extract electrons instead of ions. Neutralization ensures that the ion beam is net neutral and prevents beam expansion due to ions' electrostatic repulsion. Another important function of the neutralizer is to prevent positive charge buildup on the insulating surfaces exposed to the ion beam.

Although ion beam sputtering systems have become the performance standard, market acceptance has been hampered by low deposition rate. Traditional ion beam sputtering has achieved between 0.1 and 0.25 nm/s deposition rates versus magnetron sputtering's 0.5 nm/s average rate and ion assisted deposition's 0.5 – 1 nm/s average rate. There are numerous

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Table 1: Single layers at high throughput conditions.

Deposited Material	SPECTOR® Deposition Rate	SPECTOR®-HT Deposition Rate	Roughness (RMS)	Stress
Ta_2O_5	0.18 nm/s	0.45 nm/s	< 0.05 nm	-180 MPa
Nb_2O_5	0.15 nm/s	0.3 nm/s	< 0.05 nm	-150 MPa
SiO_2	0.18 nm/s	0.6 nm/s	< 0.05 nm	-420 MPa

options available to increase ion beam sputtering system throughput, however, it must be verified that there is no reduction in film quality associated with system enhancements.

EXPERIMENTAL CONDITIONS

There are five primary means which have been employed for increasing the throughput of the latest ion beam systems:

1. Improving rate through increased flux and energy of ions impinging on the target surface
2. Increasing flux uniformity on target leading to more uniform material distribution at substrate
3. Increasing use of reactive sputtering
4. Improving the sputtered material collection efficiency
5. Increasing substrate capacity

All of these techniques were applied to evolve Veeco's SPECTOR® system to the new SPECTOR-HT™ (High Throughput) system.

The standard ion beam sputtering source and ion extraction grids were redesigned to increase the ion beam voltages from the standard 1250 eV to 1500 eV while increasing the beam current from 600 mA to higher than 1000 mA. Since sputtering rate increases linearly in this energy and current range, this modification doubles the sputtering rate. In addition to being able to handle higher beam power, the grids were designed to illuminate the target with a specific beam pattern [5, 6]. By coupling these grids with a rotated target arrangement the target utilization was increased from about 19 % to 45 %, reducing both maintenance time and changes in uniformity due to target erosion.

Also, while reactive sputtering of metallic targets has been the norm in ion beam sputtering of optical films for many years, when sputtering SiO_2 the standard process has been to sputter from a quartz target. To increase the throughput of the coating system, reactive sputtering from a silicon target was implemented. This doubled the deposition rate and increased the lifetime of the target.

Finally, a new planetary system was designed which is capable of capturing more of the sputtered material. The planetary system consists of four planets, each with a 310 mm diameter. The total coated area is approximately 3000 cm^2. This is more than twice the available area of the legacy SPECTOR® planetary. With geometry optimization and implementation of a deposition mask the cross-planet uniformity was improved from the traditional 1 % to 0.5 %. The planetary system was also designed to be capable of transmission optical monitoring directly on the parts being coated to further increase the yield of the system.

EXPERIMENTAL RESULTS

After combining all of the modifications into a new coating platform, single layers of Ta_2O_5, Nb_2O_5 and SiO_2 were all deposited to determine the improvement in throughput. Table 1 shows the deposition rate comparison of the SPECTOR® and SPECTOR®-HT. The two to three time increase of the deposition rate is especially significant considering the increase in load capacity from 1300 cm^2 to 3000 cm^2.

As can be seen in Table 1, the surface roughness of the single layer films after coating were on the order of 0.5 Angstroms. These film results match what is expected from the best ion beam sputtered films. The compressive stress recorded is also in the expected range. Significantly increasing the deposition rate of these materials has not had a negative impact on the roughness or stress.

In addition to roughness, it is important that the ion beam sputtered films at high throughput do not show absorption losses. A high reflector mirror (HL^16 H) was designed for 99.9996 % reflection at 635 nm using Ta_2O_5 and SiO_2. Figure 1 shows the s and p polarization spectrophotometer scan of these reflectors.

Measurement of absorption and scattering off the exceptionally high reflectance of these mirrors requires utilizing cavity ring down spectroscopy (CRDS). CRDS measurements utilize the constructive interference occurring in a resonant optical cavity. Power builds up in the cavity during a laser pump cycle and a series of resonant power peaks occur at the pump wavelength. The pump laser is put through a chopper with a known duty cycle. During the dark period of the pump laser duty cycle the decay time of the power peaks occurring in the cavity can be measured. The decay time of the resonance is directly correlated to the optical loss of the cavity [7]. CRDS allows measurement of optical losses less than a single part per million (ppm).

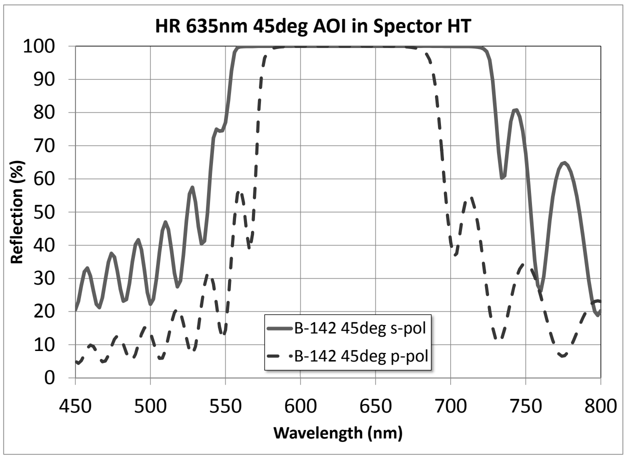

Figure 1: Ta_2O_5 / SiO_2 99.9996 % high reflector at 45 degrees showing S & P polarizations.

Measurements have been made on optics produced with the Veeco SPECTOR®-HT deposition tool utilizing CRDS. These measurements yielded 6 ppm total loss at 45 degrees with a Ta_2O_5 / SiO_2 optic and 19 ppm with a Nb_2O_5 / SiO_2 optic. These results are similar to other mirrors produced by ion beam sputtering which are commercially available [8]. The slightly higher optical loss with the Nb_2O_5 / SiO_2 optic is expected due to the measurement wavelength of 632.8 nm and the higher refractive index of the Nb_2O_5 material.

High performance anti-reflection (AR) coatings were also produced. These films were analyzed at 8 degree angle of incidence utilizing a Perkin Elmer Lambda 1050 UV/Vis/NIR Spectrophotometer. The typical industry performance is 0.1 % reflection. The ion beam sputtered films achieved 0.01 % reflection as shown in Figure 2.

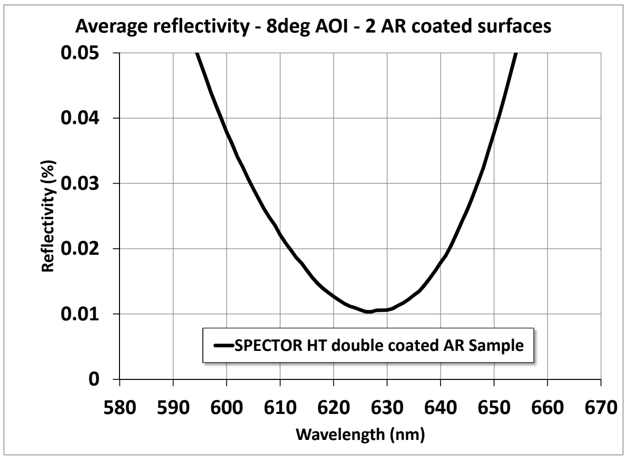

Figure 2: High performance AR coating.

The absolute level of the AR coating in Figure 2 is impressive but a practical improvement on this would be the inclusion of wider spectrum. Figure 3 shows the results of a 12 layer AR coating designed for a broad range of wavelengths. This coating was designed to eliminate reflection in the 450-650 nm range. The deposition run was performed three times to validate continuous system performance.

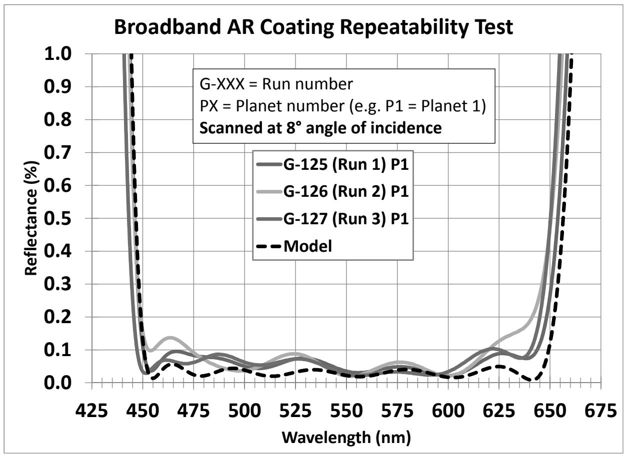

Figure 3: Broadband AR coating – Three run repeatability test.

The HR and AR coatings prove low loss optical coatings are still achievable with high throughput ion beam sputtering. Additionally, excellent run to run repeatability for the broadband AR has been demonstrated. This data supports stable system performance over a period of many deposition runs.

All of these coatings were produced using time control for layer thickness. For more complicated coatings a transmission optical monitor is available. This has allowed deposition of optical filters like the band pass filter with wide blocking range shown in Figure 4. This coating is made up of 198 layers, is 15 microns thick and was deposited in 14 hours.

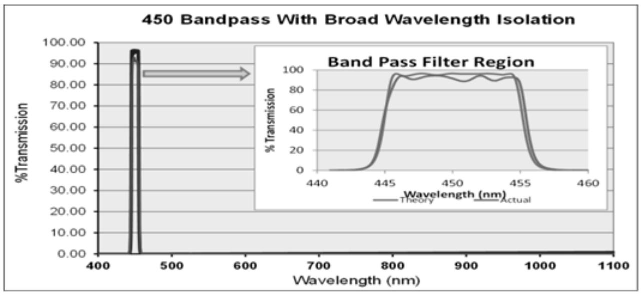

Figure 4: Band pass filter by optical monitor control on planetary.

Fluorescence filters, along with other growing applications, make extremely high optical density (OD) devices commercially important. Since fluorescence levels can be very low, reliable fluorescence detection is only possible with the complete exclusion of the excitation light. A bandpass filter with very high optical density was made specifically for this application and is shown in Figure 5.

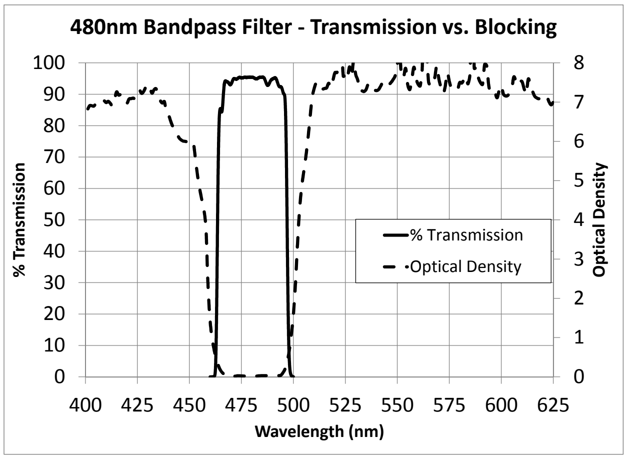

Figure 5: Band pass filter with >OD6 blocking.

Even without a backside anti-reflective coating, a photometric scan shows transmission around 95 % and excellent blocking. This filter was deposited with Nb_2O_5 and SiO_2 and has a thickness of 15 microns. The design was coated in a single deposition run which included both optical monitoring control as well as time-power layers.

The limit on the ability to accurately measure blocking performance of greater than OD6 to OD7 can become an issue with this type of specification [9]. Measuring the steepness of the blocking density near the bandpass region is affected by these limitations. The reality is the OD7 blocking to full transmission region is sharper than the blocking density scan indicates. This high OD scan was accomplished with an OD3 neutral density filter on the reference leg of the spectrophotometer to be able to measure these extremely low levels of transmission.

CONCLUSIONS

It has been shown that increasing deposition rate two to three times with more ion beam power and reactive sputtering, while doubling the planetary size, increases the throughput of ion beam sputtered coatings. This has been demonstrated with a SPECTOR®-HT platform which has demonstrated a throughput increase of 400% compared to the SPECTOR® with a planetary fixture. At the increased throughput ion beam sputtered films are still able to achieve surface roughness of approximately 0.05 nm and create >99.999 % reflection mirrors. A detailed body of work supports the performance of the high throughput process on the SPECTOR®-HT.

ACKNOWLEDGEMENT

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