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DEPOSITION OF LOW LOSS MIRRORS USING SPECTOR®

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Introduction

Thin film specifications continue to push the envelope of manufacturing capabilities. Many advanced commercial and military applications require ultra low loss films that are extremely difficult to deposit using conventional Electron beam or Ion Assisted Deposition (IAD) technology. Ring Laser Gyroscope (RLG) mirrors for instance require high packing density, minimal defects, and negligible absorption. Veeco Instruments' SPECTOR Ion Beam Deposition system has demonstrated unparalleled performance in the manufacturing of such low loss films. In this paper we introduce the SPECTOR system and present data for RLG mirrors deposited using the system.

System Overview

The SPECTOR system is a Dual Ion Beam Deposition (DIBD) batch system equipped with a fully automated state of the art software interface that makes operation virtually turn key. At the core of its performance capabilities are two RF powered ion sources. These sources provide excellent beam current control and dramatically improve mean time between maintenance (MTBM) over alternative devices. Figure 1 shows a top down view of the SPECTOR system chamber geometry with areas of interest numerically identified. Items 1 and 2 are the 16cm and 12cm RF ion sources respectively. Item 3 is the target assembly with options for three or four different target materials. Item 4 is the planetary substrate fixture system consisting of four, 8 inch diameter planets. Item 5 shows the plenum where a single or dual cryogenic pump system is located.

Film deposition is achieved using the 16cm diameter RF ion source. The ions from this source are accelerated through a series of biased grid optics, toward the target [1]. The energy of these ions is sufficient to cause sputtering of the target material. This sputtered material is highly energetic and therefore generates films with excellent adhesion and high packing density. The 12cm diameter RF assist source is focused on the substrate and primarily serves to provide correct film stoichiometry and alleviate stress. Together these two sources operate in unison to produce films with optimal optical and physical properties.

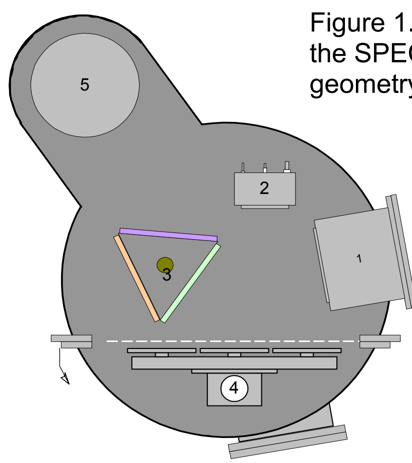

Figure 1. Top down view of the SPECTOR chamber geometry.

SAMPLE APPLICATION

Low loss mirrors are crucial components of Ring Laser Gyroscopes (RLGs) used for inertial navigation systems. The cavity of the gyroscope takes the form of an equilateral triangle. The He/Ne laser cavity has two circulating beams, one rotating in a clockwise direction and the other in a counter-clockwise direction. Mirrors are placed at the corners of the triangle with one mirror designed to transmit approximately 1% of the light. The two emerging beams from this mirror are combined to form an interference pattern, which is modulated by a beat frequency proportional to the rate of rotation. Spectral scatter from the low loss mirror surface substantially impacts the RLG system performance. The degree of scatter is a major contributor to a phenomenon termed 'lock-in'. Lock in occurs when the rotation rate is small leading to the frequency difference between the clockwise and counter-clockwise beams becoming remote. The effect is due to the interaction of the two beams, when upon reflection, a small amount of light is scattered back into the oppositely traveling beam. When the frequency difference becomes too small the counter propagating beams lock together giving a beat frequency of zero, thus showing no change in rotation when in reality there is. Another performance limitation for the RLG system is absorption. Absorption needs to be minimized in order to achieve the best possible signal to noise ratio. In addition, the lower the absorption the higher the level of finesse that is attainable for the mirrors. For these reasons the mirrors must be manufactured with extremely low defects and losses to optimize the performance of the RLG system.

LOW LOSS MIRROR DESIGN

To support the optical geometry and HeNe LASER frequency of choice, the optical thickness of the RLG mirrors are designed to provide a maximum reflection at 632.8nm S-polarization with a 45-degree incident angle. The materials used for deposition are SiO_2, Ta, or Ti. The reactive targets are used to produce the desired high refractive index oxides, namely Ta_2O_5 or TiO_2. Figure 2 shows the theoretical spectral shape mirror designed with SiO_2 and Ta_2O_5.

One set of two mirrors was produced using quarter-wave stacks of SiO_2 and Ta_2O_5 (sample ID's 1758 & 1790) and another set of two was produced using quarter-wave stacks of SiO_2 and TiO_2 (sample ID's 1674 & 1675). Both sets of mirrors used the same number of layers in order to show direct comparisons. Overall losses and surface roughness measurements were performed on both sets of samples.

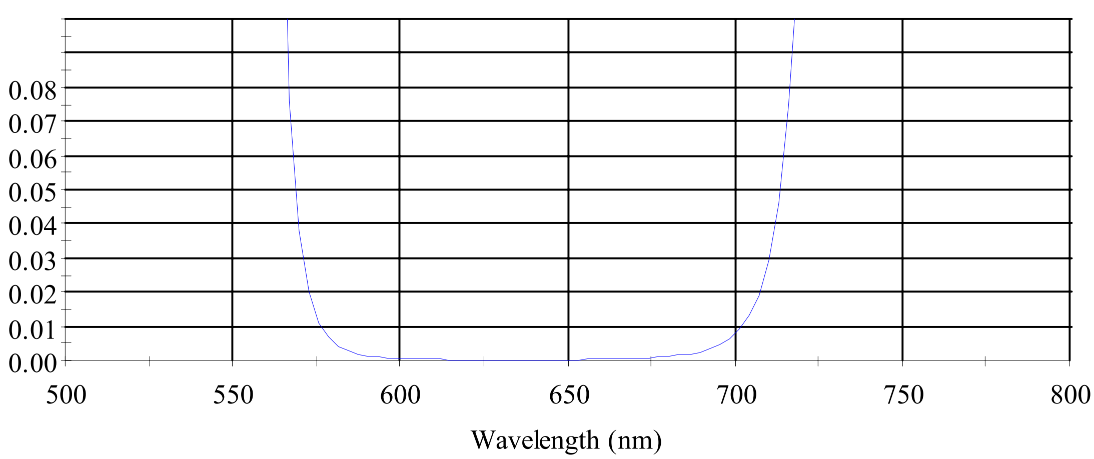

Figure 2. Theoretical spectral shape of RLG mirror deposited with SiO_2 and Ta_2O_5.

Process Preparation

Clean substrates and a low particle density manufacturing environment are critical to successfully produce low loss low defect films. Particles within the films cause growth defects, which in turn exacerbate light scatter and negatively impact overall loss. For this reason the SPECTOR® system was operated in a class 100 cleanroom where all samples were washed using a spin cleaner and high purity isopropyl alcohol. Once clean, the substrates are blown off with a dry nitrogen gun equipped with a 0.2-micron filter and static neutralizer. This eliminates the surface charge on the substrate thereby reducing electrostatic attraction of nearby particles. Lastly, special care is taken in preparing the vacuum chamber for low particle generation as an added step to minimize in-situ substrate contamination.

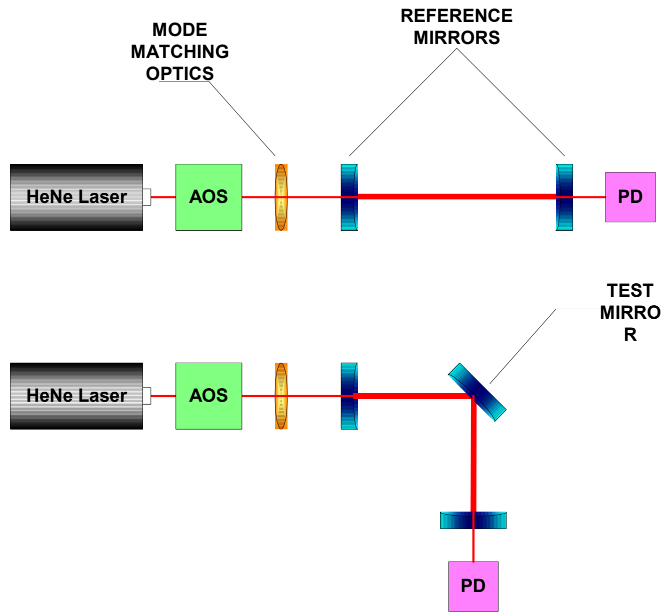

Figure 3. Simplified Optical Schematic of the reference and Sample Cavity Ring-Down Systems Used to Determine Loss.

Results

Loss Measurement

The exceptionally high reflectance of these mirrors requires use of special loss measurement metrology. Total loss and transmission values were determined using laser cavity ring-down. In addition, surface scatter measurements were performed using the total integrated scatter technique. The cavity ring-down method is a technique that measures the time rate of decay of a light pulse trapped in an optical cavity.

The optical cavity is comprised of two or more highly reflective mirrors. As the light bounces back and forth inside of the cavity a small portion is transmitted through each mirror. This transmitted light is monitored at one of the mirrors as a function of time. The resulting exponential signal decay (I) can be expressed as

$$I = I_o \exp^{[-(1-R)\, tc/2L]}$$

Where (I_o) is the initial signal magnitude, (1-R) is the cumulative transmission through the mirrors assuming no absorption or scatter, (t) is time, (c) is the speed of light, and (L) is the cavity length. In order to measure the total losses of a sample, the first step is to measure its transmission at a 45-degree incident angle s-polarization. Next, two standardized mirrors, of known optical properties, are used to characterize the total loss of a reference cavity (refer to the upper schematic depicted in Figure 3). Lastly, the sample mirror is introduced into the cavity as shown in the lower schematic of Figure 3. Although the geometry of the cavity is different than the reference, the total cavity length is the same and thus associated losses are constant. The total decay time is then re-measured. Subtracting out the total loss of the reference cavity, the transmission loss of the sample mirror, and the surface scatter, gives the absorption of the sample. More detailed reviews of the technique are available in [2-4]. Figure 4 shows the actual signal decay profiles from the reference cavity and the cavity with sample ID # 1758 installed

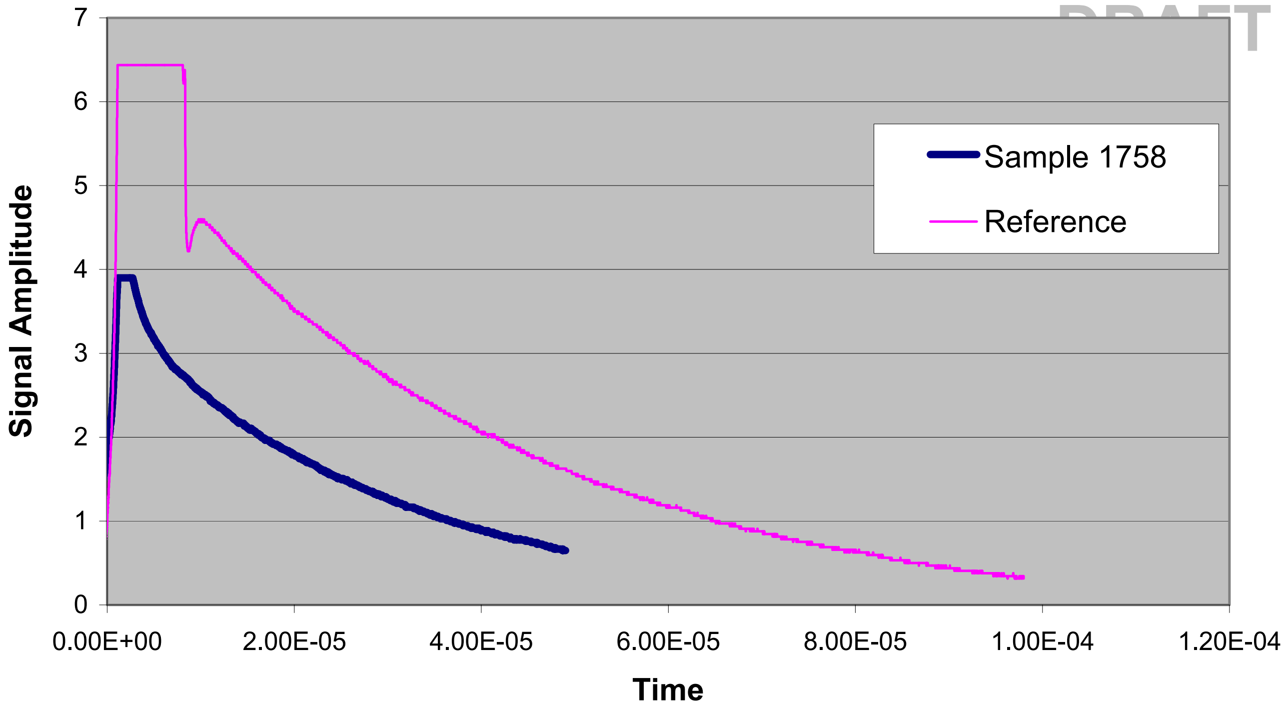

Figure 4. Cavity Ring-Down Decay Signature of Reference and Sample Cavity.

Final results for all samples are shown below in parts per million (ppm):

Sample ID	Materials	Total Loss	Transmission	Scatter	Absorption
1758	SiO_2, Ta_2O_5	7.8	3.9	0.8	3.1
1790	SiO_2, Ta_2O_5	8.5	3.9	0.9	3.6
1674	SiO_2, TiO_2	20.8	1.7	1.1	18
1675	SiO_2, TiO_2	24.1	1.5	1.1	21.5

Some important points to comment on are the observed differences in the total loss and transmissions between the mirrors deposited using Ta_2O_5 versus TiO_2 for the high index material. The lower losses in the Ta_2O_5 mirrors were expected due to the inherently higher losses of TiO_2 films and the associated differences in process conditions used for deposition. The lower transmission values of the TiO_2 mirrors was expected due to the higher TiO_2 index relative to Ta_2O_5 resulting in a higher degree of reflection given the same number of quarter-wave stacks.

<u>Surface Roughness</u>

Rough surfaces typically indicate a higher degree of columnar growth and growth

nuclei whereas smooth surfaces tend to be characteristic of a dense microstructure and low defect densities. In order to accurately measure the surface profile of the deposited film; all mirrors were deposited on pre-characterized, super-polished zerodur. This allowed us to compare the surface before and after coating. Figure 3 shows the resulting interferometer surface scans of sample #1790 (typical of all samples) before and after deposition. The surface roughness after deposition is within the error bars of the metrology, 0.52 Å versus

0.53 Å. This signifies that the deposited films have a sufficient amount of densification that the original surface roughness was replicated. All other samples showed similar results.

Summary

Increasingly stringent ultra low loss mirrors are required for many current and emerging industrial and military applications. Such films are characterized by high packing density, ultra-low absorption and low defects. Conventional manufacturing equipment such as Electron beam or IAD technology, are typically inadequate for manufacturing films of this caliber. In contrast, Veeco Instruments' SPECTOR® Ion Beam Deposition system has repeatedly proven its capability to produce mirrors with losses lower than 5ppm and with film packing densities sufficient to maintain pre-deposition substrate RMS values. This level of performance has made SPECTOR® the process system of choice for low loss mirrors.

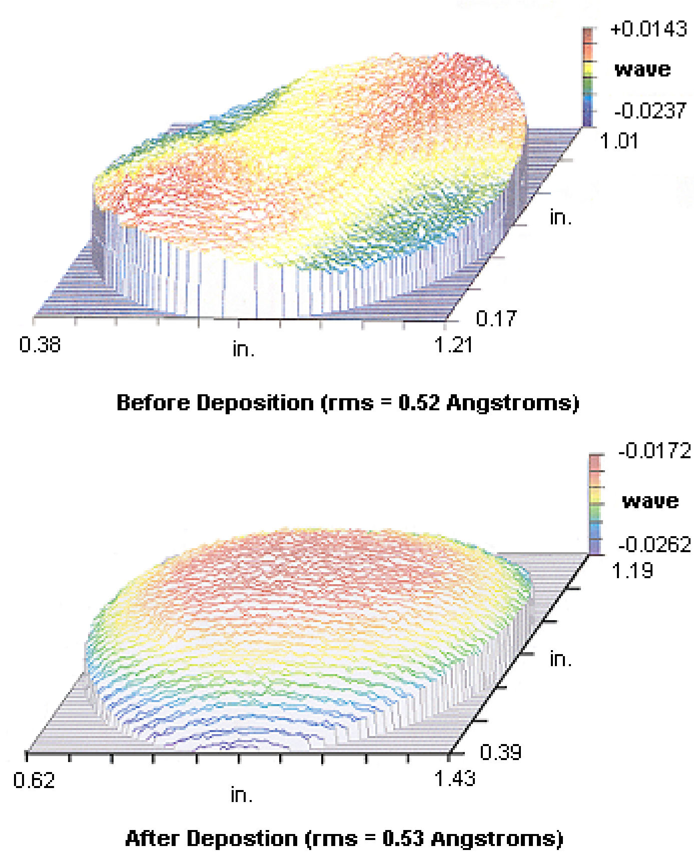

Figure 5. RMS Comparisons of Before and After Deposition.

References

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3) Busch K W and Busch A M (eds) 1999 *Cavity-Ringdown Spectroscopy (ACS Symp. Series)* vol 720 (Washington, DC; American Chemical Society)
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