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Towards a magnetic field separation in Ion Beam Sputtering processes

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ABSTRACT

Defects embedded in coatings due to particle contamination are considered as a primary factor limiting the quality of optical coatings in Ion Beam Sputtering. An approach combining the conventional Ion Beam Sputtering process with a magnetic separator in order to remove these particles from film growth is presented. The separator provides a bent axial magnetic field that guides the material flux towards the substrate positioned at the exit of the separator. Since there is no line of sight between target and substrate, the separator prevents that the particles generated in the target area can reach the substrate. In this context, optical components were manufactured that reveal a particle density three times lower than optical components which were deposited using a conventional Ion Beam Sputtering process.

1. Introduction

In the course of the rapid development of laser technology and modern optics, the demand for coatings with highest quality is increasing. In particular, the requirement of lowest loss optics has developed to a key position in high precision laser measurement technologies, with prominent applications for instance in atmospheric research, investigations in earth rotation or gravitational wave detection [1]. In this context, Ion Beam Sputtering (IBS) has been optimized to become a deposition process for thin films of superior optical quality with high precision in thickness and dispersion properties of individual layers even in complex coating systems. Though the IBS process allows for a deposition nearly free of contaminations, the particle density still constitutes a limiting factor in numerous applications of high end optical components. This particle contamination can be attributed to various factors including mechanical movements of vacuum components as for example the target mount or the deposition shutter. Furthermore, as a consequence of powder formation on the target surface during the sputter process, the creation of undesirable particles cannot be suppressed completely [2]. Usually, the embedding of micrometer size particles leads to topological irregularities and defects in the layers, which in turn increases scattering and reduces the laser power handling capability. Therefore, innovations in technology are desired to mitigate these types of particles in the coating process.

In order to minimize the particle contamination a separator based on a magnetic guiding process has been developed. In this context a magnetic separator, providing no line of sight between material generation and the coating process, is presented that is demonstrated to be suitable to remove undesired particles out of the film deposition process. By providing bent magnetic fields, it is possible to manipulate the trajectories of the charged coating material [3]. Due to the larger mass and relatively small charge of particles, they are only weakly influenced by magnetic fields and therefore spatially separated from the coating material in the curvilinear guiding tubes. In order to verify the forecasted reduction of particle contamination, the present investigation is focused on the manufacturing of optical coatings with low particle density. The optics for the demonstration are coated behind a bent magnetic separator and are compared to optics that are coated in a common IBS plant. The components are precisely evaluated regarding their particle density.

Finally, it is shown that the manufacturing of a partial reflector by the presented magnetic separator providing no line of sight between target and substrate yields a significant reduction in particle density during the coating process.

2. Setup of coating plant, guiding system and characterization of defect density

In the context of this research, an IBS coating system has been built as a three-chamber system. This chamber system consists of the process chamber, the coating chamber and the load-lock chamber. In the process chamber, the ion beam source, the neutralizer and the zone target table are implemented corresponding to the geometric set-up of a common IBS-process. In the experiments a Veeco 16 cm “High power” ion source is operated at 400 mA and 1200 V, respectively. The target holder allows for lateral translation of the target relative to the ion beam. The zone target consists of three target materials (Silicon/Aluminum-/Titanium). Depending on the relative location of the target to the ion

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beam, different proportions of two coating materials can be sputtered simultaneously by the ion beam. Consequently, the coating is manufactured in a reactive process by addition of oxygen.

In the process chamber as well as in the coating chamber the separator concept is implemented. The first part of the separator consists of the Transfer coil [4], which is arranged in the process chamber directly above the target. The linear Transfer coil has a line of sight between its apertures and furnishes the material guiding from the target to the Separator coil, which is positioned in the coating chamber. The separation tube consists of a bent coil and an internal carrier, so that the separator extends from the lower to the upper chamber. Fig. 1 shows the cross section of the coating plant and the magnetic separation device. The bent separator coil is connected to the outlet of the Transfer coil and prevents a line of sight between target and the exit of the separator.

Both coils are approximately 15 cm in diameter, and the bent coil accounts for a curvature radius of 1.5 m with a length of 90 cm. The Transfer coil can also be used separately. For an analysis of the development of the particle contamination the guiding systems are equipped with two substrate mounts. The reference position (position 1) is located behind the Transfer coil. In this position a direct line of sight exists and particles can reach the substrate directly. The second position (position 2) is located behind the bent guiding coil. In this configuration the particles cannot reach the substrate by a linear trajectory. In both positions, a static substrate or a planetary rotation unit can be installed. These both fixtures are applied for the determination of the lateral distribution of the coating material as well as for the manufacturing of optical components, respectively.

Particles and defects on or in the coating of optical components induce a higher scattering signal level as the coating itself. Thus, the particle density of a sample can be determined via a Fast Total Scattering (Fast-TS) measurement setup, which scans the entire surface of an optic in the timescale of few minutes [5]. For the measurements presented in this study the distance of the measurement points (spatial step) is adjusted to 25 μm for the two dimensional TS mapping. The dynamic range of the TS method covers more than 7 orders of magnitude. Consequently, the procedure is much more sensitive to particles than an optical microscope. A particle in a TS mapping is defined by an increase of ten percent above the background level in the scattering signal [6]. In the TS measurement procedure a Gaussian beam is focused on the surface to a full width at half maximum beam diameter of 90 μm on the sample surface plane. The sensitivity of the measurement concept was qualified on the basis of lithographically structured samples and reaches values around 100 nm. For the spatial resolution, which is mainly limited by the actual beam diameter on the test surface, 50 μm distance of two particles with a size of 1 μm can be considered as a typical specification of the TS-system. The setup of the Fast-TS complies with the international standard ISO 13696 [7], and the geometric requirements of the standard do not allow for the application of a higher numerical aperture. The consequence of the measurement approach is that an absolute measurement of the defect size is not possible, which is mainly well-founded by the Gaussian characteristic of the test beam. For example, a small particle with high scattering affects a high signal at low intensities, and consequently, the extracted particle sizes are typical overestimated, which is a general tendency of the procedure. Nevertheless, the Fast-TS is the method of very high sensitivity adapted to particle inspections on relatively large surface areas. This advantage qualifies the method as an effective tool for the determination of defects on thin film samples allowing for a detailed assessment on the basis of scattering mapping. In this context, also the statistic of the scattering centers on the test surface can be calculated applying analysis software developed at the Laser Zentrum Hannover. The calculated distributions are compared as relative values to investigate the influence of different coating process parameter on the particle generation.

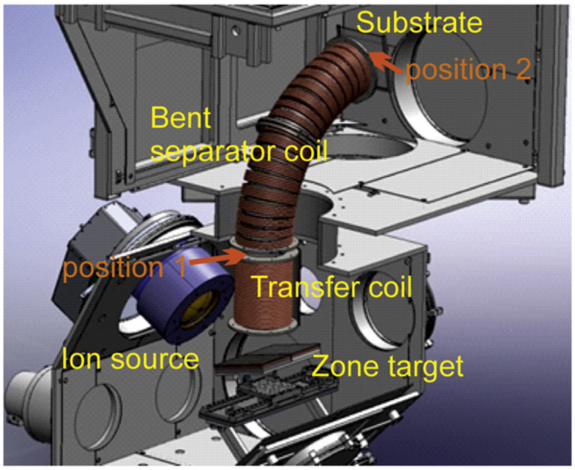

Fig. 1. Setup of the magnetic separator.

3. Experimental results

3.1. Lateral distribution

In the first step of the experiments, the deposition rate and the lateral distribution of the coating material have to be measured and optimized. For this purpose, static substrates were coated with single layers of different coating material compounds at substrate position 2 (Fig. **1**). In these experiments, 230 × 230 × 1 mm^3 Borofloat® glass plates were used. The lateral distributions of the coating material were determined using photometric transmittance measurements, which were fitted by the thin film software SPEKTRUM [8]. For the mapping of each sample approximately 500 measurement positions were evaluated. For the transmission measurements, a fiber coupled spectrophotometer was constructed and optimized for a small test spot size of 1 mm on the sample in order to achieve a high spatial resolution. Fig. **2**b–d displays the lateral distributions of binary oxide coatings deposited via the Transfer- and the Separation coil, respectively. The measured distributions reveal thickness profiles with pronounced shapes and typically maximum rate in the center of the guided coating material for titania, silica and alumina, respectively.

It was observed, that the guiding efficiency and therefore the local maximum rate depend on the sputtered species, especially on its ion mass and the ionization energy. As expected, the guiding efficiency decreases with increasing atomic mass. The dependence of the guiding efficiency on the ion mass, which is defined by the ratio between the deposition rates at the entrance and the exit of the Separation coil is depicted in Fig. **2**a. The relevant position of the quotient is displayed in Fig. **1** labeled as position 1 and 2.

For the production of an alternating layer stack, a sufficient deposition rate, and a sufficient refractive index contrast have to be achieved, because the number of layers that is needed to reach a specified reflectivity is directly related to the refractive index contrast. As indicated in Fig. **2**a, the guiding efficiency for alumina is two times higher than for silica or titania. According to Fig. **2**b)–d) the deposition rate of alumina is more than three times higher than for silica and more than two times higher than for titania, respectively. Taking into account these relations, a fraction of alumina is mixed into silica and titania in order to optimize the production efficiency of the process. In view of the achieved improvement in optical quality and stoichiometry, the slight consequent reduction in refractive index contrast of the related ternary compounds was accepted for the subsequent investigations in the particle contamination.

The defined mixing of the materials is adjusted via mechanical movement of the zone target of high and low refractive index coating material within the sputtering ion beam. In this arrangement the mixture ratio is defined by the respective material areas interacting with the ion beam profile. For the high refractive material considered in