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Sputtering of dielectric single layers by metallic mode reactive sputtering and conventional reactive sputtering from cylindrical cathodes in a sputter-up configuration

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ABSTRACT

In today's sputtering solutions in the field of precision optics, usually planar targets are used which suffer from inhomogeneous surface erosion. This leads to a drift in uniformity over time, higher material costs and in the case of reactive sputtering an increased tendency to form arcs which cause particle generation. In this paper an approach is presented that overcomes the disadvantages planar magnetrons present to sputtering. A rotating turntable coater was equipped with two dual cylindrical magnetrons in a sputter-up configuration. Thin films prepared by metallic mode reactive sputtering as well as reactive mid-frequency sputtering were investigated. Properties of Ta_2O_5 and SiO_2 such as film stress, optical density and surface roughness are discussed. It is sown that the coatings are suitable for applications in precision optics.

1. Introduction

The manufacture of multilayer optical precision coatings requires films with very good and constant uniformity, precise and stable optical constants, virtually no optical shift caused by porosity, low defect contamination and no losses. Basically, the ever increasing demands on individual optical interference coatings of high quality are an ongoing challenge. Magnetron sputtering batch coaters represent one of the developments in the area of highly flexible and high precision optical coating machines [1–3]. However, the present coaters use planar targets which suffer from inhomogeneous erosion (i.e. in a standard configuration with static magnets) [4] and possibly from particles created in the different process modes [4–7]. Different approaches have been undertaken to decrease the defect densities for example with the CleanMag concept [8], where the magnets are moved in order to influence the plasma density and thus the layer properties such as the particle contamination. To overcome these problems in precision optical coatings, SiO_2 and Ta_2O_5 were deposited by cylindrical magnetrons and investigated by using the Enhanced Optical Sputtering System (EOSS) [9,10]. Cylindrical targets have been used in large area coating machines for several years now [11–15]. The main reason for the success in large area production was the much higher cost efficiency [16] of these cathodes. However, the intrinsic stability of cylindrical targets is also supposed to improve other factors that enhance the performance of a coating machine such as the stability and reproducibility of the refractive index of the coated films. Depending on the specific application in precision optics, layer uniformities of better than 0.5% are required. These uniformities must be realized for multilayer stacks usually ranging from 50 to a few 100 layers with a typical overall stack thickness of typically 5–30 μm while scattering and absorption have to be kept at very low values. It is well known that especially for very thick optical coating stress plays an important role, as it is able to bend the substrates and thus influence the performance of the optical filters.

Starting in 1984, the Optical Coating Laboratory (OCLI) began to investigate the so called MetaMode™ process [17] to increase stability and throughput and to overcome issues with reactive sputtering [18]. Based on this process with the modifications of a sputter up system with extreme gas separation between the sputtering and the RF plasma driven oxidation zone this paper investigates the adequacy of this approach for optical precision coatings with a few modifications to the process presented by OCLI.

2. Experimental details

2.1. Deposition setup details

The deposition apparatus called EOSS [9,10] was used in all experiments presented in this paper. The machine was manufactured in close collaboration with FHR Anlagenbau GmbH and is set up with two double cylindrical magnetrons (SCI Inc.), a plasma source and optical monitoring (Figs. 1–3). Every target as well as the plasma source

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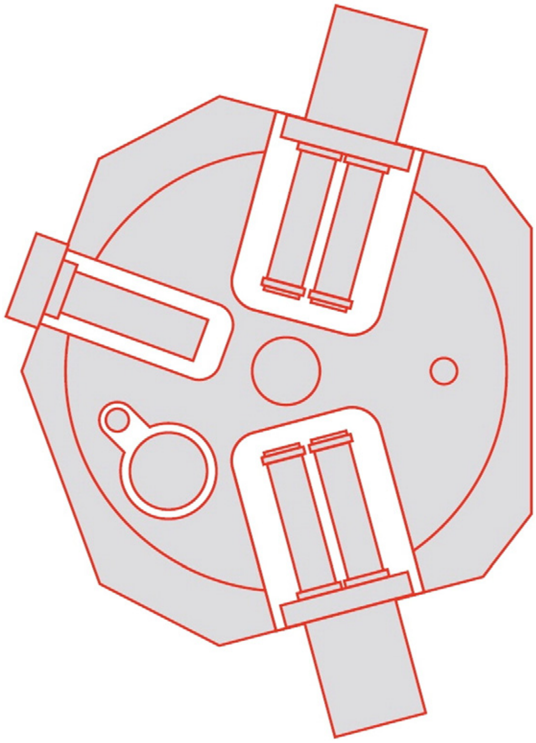

Fig. 1. Top view of the coating setup, 2 SCI double magnetrons, 1 single magnetron, a plasma source and optical monitoring port.

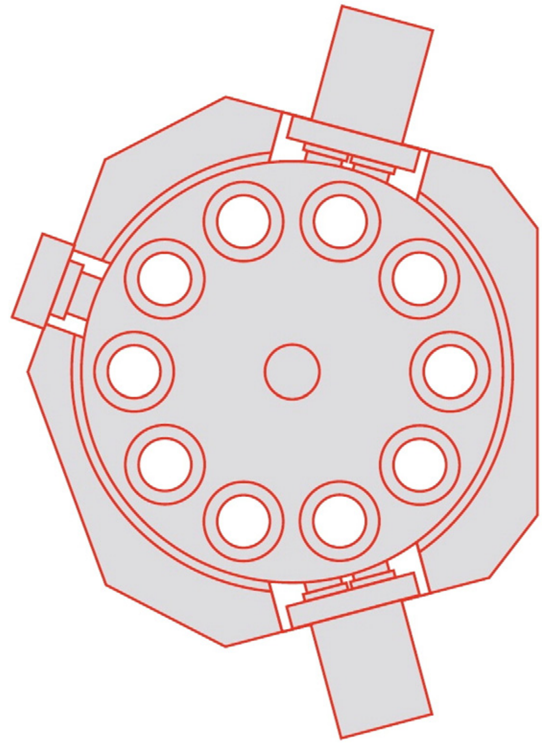

Fig. 2. Top view of the coating setup, showing the substrate carrier turntable above the coating positions.

are arranged in a sputter-up configuration to ensure a low particle contamination level of the thin films. Two mid-frequency power generators (Hüttinger MF 3020) with a power of up to 20 kW per double magnetron are used that are set up at a frequency of approximately 40 kHz.

The turntable can hold up to 10 carriers with a diameter of up to 200 mm and a maximum thickness of 50 mm. The usual setup consists of one monitoring carrier (witness substrate) and up to 9 carriers that hold the production substrates. The substrates are moved into the deposition chamber and back by a robot system from a magazine holding up to 12 carriers. From a vented state of the main deposition chamber a residual pressure of less than 10^{-4} Pa is reached within an hour and a residual pressure of approximately 10^{-5} Pa within a day which allows for maintenance without extended downtimes. The magazine chamber itself is equipped with a turbo molecular pump as well. 10^{-4} Pa are usually reached within 15 min. A complete charging of the main turntable can be done in approximately half an hour. The magazine is used to change monitoring substrates during the manufacturing process as well.

All coatings were manufactured with active rotation of the substrate turntable at a speed of 250 rounds per minute. With reactive sputtering, process control and stabilization was realized by oxygen partial pressure control using lambda probes (Zirox GmbH, Germany) with the generators' output power as control value. With non-reactive sputtering, oxidation was realized by an additional plasma source. For each of the three stations (Ta_2O_5, SiO_2 and plasma source) the sputter gas can be adjusted individually with regard to pressure and mixture ratio. The separation ratio was higher than 1:200. The target cylinder rotation speed was set to 5 rpm in the experiments presented here.

A shutter system positioned directly below the substrates (above the magnetrons) is used to start and end the coating process without significant impact on the process stability itself. The shutter is synchronized with the rotation of the substrate turntable and thus allows precise shutter opening and closing for improved carrier-to-carrier homogeneity.

The substrate temperature can be heated up to at least 300 °C by a heating system in the cover plate of the OCLI coating system, which means that the substrates are heated from their backside. The substrate temperature can be monitored and controlled by either a pyrometer or two available flexible resistance thermometers on top of the substrate turntable.

2.2. Process details

In order to create films in different sputtering modes and compare the layer properties, 150 nm thick layers were prepared. In the case of Ta_2O_5 films direct transmission monitoring on a witness Schott B270 substrate was used. However only one dispersion was used to describe all growing Ta_2O_5 films during the variation of parameters which lead to thickness deviations up to 4 nm due to the variation in refractive index. In order to monitor the growing of the SiO_2 films, the monitoring substrate was pre-coated with 150 nm Ta_2O_5 to create a sufficient contrast. Each pre-coated monitoring substrate was used for five consecutive coatings of SiO_2 which lead to thickness deviations up to 7 nm.

For the metallic mode reactive sputtering, similar to the MetaMode™ [4,17], the target was sputtered in pure argon atmosphere at a defined argon flux (pressure). The target power in the mid-frequency mode at approximately 40 kHz was held constant as well. The plasma source was working in pure oxygen atmosphere at a defined oxygen flux (pressure) and a defined power. Due to the rotating turntable the coatings were created sequentially: metal atoms were coated on the substrate while passing the sputtering targets. As the turntable moved to the plasma source the metal atoms were oxidized.

In the first series of experiments the target power was varied. The second series investigates the influence of the argon flux at the target (sputtering pressure) while keeping the target power at a constant value. Subsequently, the influence of the plasma source on the growing film was investigated. In a third series of experiments the impact of the power of the plasma source was investigated. In a fourth series