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DIFFERENT PROPERTIES OF SiO_2 NANOSTRUCTURES WITH DIFFERENT WORKING GASES

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A large number of experiments were performed in order to obtain deposited thin films of SiO_2. An efficient method of depositing thin films of SiO_2 is by RF – magnetron sputtering. The aim of this investigation is to determine the influence of different working gases on deposition rate and optical SiO_2-nanostructure properties. We use Ar, Xe and Kr, as working gases to obtain different deposition rate. We observed a maximum deposition rate for Argon and a minimum deposition rate for Xenon. A variation of working gases shows no negative influence on the optical properties of SiO_2 films. Refractive index remains high for all different working gases.

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1. Introduction

Thin films of SiO_2 have a large number of applications, ranging from optical coatings to barrier films for food packaging. An efficient method of depositing SiO_2 thin films is Radio Frequency - Magnetron Sputtering [1,2].

The sputtering process may be defined as the ejection of particles from a condensed-matter target due to the impingement of energetic projectile particles.

Depending on the application, sputtering systems can assume an almost unlimited variety of configurations. The development of high performance magnetron sputtering sources that provide *(1)* relatively high deposition rates, *(2)* large deposition areas, and *(3)* low substrate heating, revolutionized the sputtering process by greatly expanding the range of feasible applications. For this work a parallel-plate diode configuration with a magnetron system was used.

Magnetron sputtering sources, which can be defined as diode devices in which magnetic fields are used in concert with the cathode surface to form electron traps which are so configured that the $\vec{E} \times \vec{B}$ electron drift currents form a closed loop [3]. This principle is schematically presented in Fig. 1.

The quality of deposited thin films depends strongly on the sputtering conditions. It is therefore necessary to select the magnetron sputtering parameters carefully to achieve the desired film properties. In order to optimise sputtering conditions we can change input power, total gas pressure and target-to-substrate distance. The result of the variation of these parameters was examined in another work at our institute [4]. The aim of this investigation is to determine the influence of different working gases on deposition rate, substrate temperature and optical film properties.

Sigmund [5] shows, that the sputter yield depends on the mass ratio between working gas and target material and on ion energy. The energy of the bombarding ions is mainly determined by the adjusted power input. Deposition rate is a function of sputter yield, total gas pressure and target-to-substrate distance. In our case, total gas pressure, target-to-substrate distance and input power remained constant to observe exclusively the influence of the working gas.

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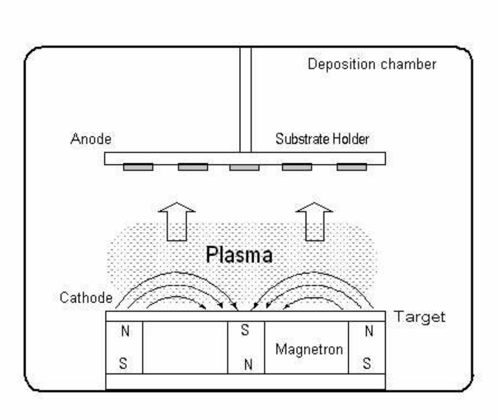

Fig.1. Schematic configuration of a magnetron sputter coating system.

2. Experimental

Thin film deposition has been carried out with an Edwards AUTO 306 plant equipped with a RF-Magnetron-Sputter device. The substrates were not heated nor rotated over the target.

The main adjustable process parameters are input power, total gas pressure and target-substrate distance. A thin film quartz monitoring system controlled film thickness during deposition.

For this investigation the input power was held constant at 500 W, total gas pressure was 5.0×10^{-3}mbar at a target-substrate distance of 60 mm.

Substrate temperature was measured immediately after deposition using a Pt-100 temperature sensor connected to a calibrated digital multimeter.

Optical characterization and determination of refractive index and film thickness of SiO_2 films on B270-Glass substrates has been performed with a spectral photometer Perkin Elmer Lambda 19 using transmission- and reflection-spectra and calculations based on the work of Swanepoel [6].

3. Results and discussion

The sputtering rate is a function of target material mass, sputter yield, kind of working gas and ion current density [7-9]. Inserting Sigmunds formula for the sputter yield in this relation one gets a mass ratio factor, which reaches a maximum, if the mass of the impinging particles is equal to target mass. Combination of sputtering rate and total gas pressure determines the total effective deposition rate.

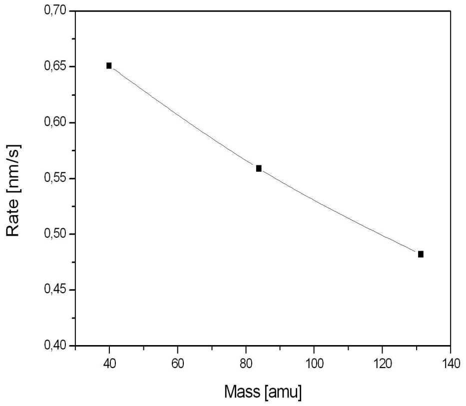

Fig. 2. Variation of deposition rate as a function of working gas mass (Ar, Kr and Xe).

Molecular masses of the involved materials are the following: SiO_2: 60, Argon: 40, Krypton: 84, Xenon: 139. This induces a maximum deposition rate for Argon and a minimum deposition rate for Xenon confirmed by the experiment.

Substrate temperature results from exposure to radiation and the number and energy of depositing and bombarding particles [10]. We observed a direct relation between deposition rate and substrate temperature, which leads to the conclusion that temperature increase due to total deposition time and radiation is of less importance than the influence of deposition rate. This fact might vary, using substrates with different thermal conductivity and heat capacity than B270 glass.

Table 1. Overview of the results.

	d [nm]	t [min]	T [°C]	U [V]	n
Ar	605	15.5	165	-1129	1.46
Kr	738	22	143	-1200	1.47
Xe	867	30	128	-1258	1.47

Explanation of the table: d: obtained film thickness; t: total time of deposition; T: substrate temperature immediately after deposition; U: target voltage during deposition for an adjusted input power of 500 W; n: obtained refractive index of the SiO_2 films at 550 nm

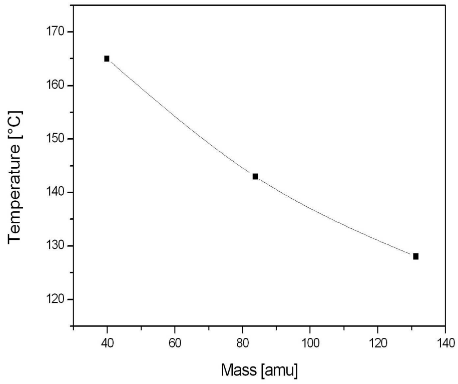

Fig. 3. Substrate temperature in dependence of mass of working gas at 5×10^{-3}mbar and 500 W.

Target voltage is the voltage between the target as cathode and the grounded substrate holder as the anode of the discharge, as well as the grounded chamber walls.

The configuration of our AUTO 306 sputter device allows for the adjustment of either negative target voltage or input power. In the first case, the matching unit varies input power to gain the required voltage and in the second case, voltage between the electrodes is varied to remain on the adjusted input power level. In this investigation we adjusted the input power.

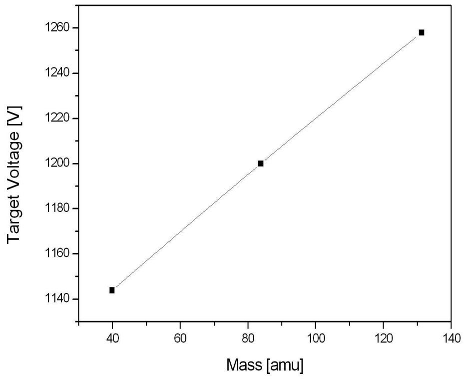

Fig. 4. The increase of negative target voltage for a constant input power of 500 W with different working gases (Ar, Kr, Xe).

By changing the mass of the working gas, which is positively ionised in the plasma, the ion current density, measured by the automatic matching unit, decreases, moving to higher molecular masses. In order to keep the input power constant, it is necessary to accelerate the ions more. Therefore, the negative target voltage in respect to the grounded substrate holder and chamber walls increases with higher molecular mass of the working gas.

The characteristic of sputtered coatings is usually good adherence to the substrate with a density close to bulk material. The refractive index of the film is closely related to film density. Therefore the refractive index is a representative characteristic for the quality of a thin film.

A variation of working gases shows no negative influence on the optical properties of SiO_2 films. The obtained refractive indices are in the range of the well-documented films sputtered with argon of increasing kinetic energy as working gas. An increase of mass of the working gas could have a positive influence on the refractive index of sputtered SiO_2 films, due to a higher densification of the growing film by highly energetic bombarding particles. But this needs to be proved by additional measurements.

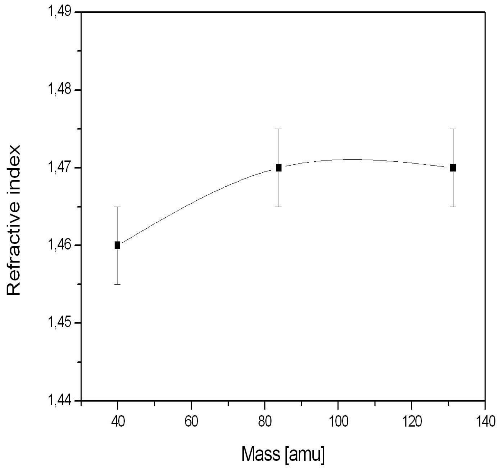

Fig. 5. Refractive index of sputtered SiO_2 films with different working gases (Ar, Kr, Xe).

4. Conclusions

Variation of working gases for RF-Magnetron Sputtering is not very common, but shows useful results for the films, depending on the application of the coating.

Argon is commonly used as working gas, it is reliable and not too expensive and shows the highest deposition rate for most materials.

Moving to working gases of higher mass leads to a lower deposition rate, because of a larger mass difference between working gas and target material.

Substrate temperature is lower, using working gases with a higher mass, which leads to the conclusion, that deposition rate causes in this case the main contribution for a higher substrate temperature.

Refractive index remains high for all different working gases.

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