Magnetron Sputtering System for Small Batch High Throughput Production

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ABSTRACT

Magnetron sputtering is a key thin film deposition technology widely acknowledged to produce the highest quality optical coatings. This paper describes a small batch size high throughput sputter system utilizing reactive sputtering process.

The machine is compact and highly automated, employing a vacuum load lock to maximise throughput and minimise maintenance. Substrates are mounted on a vertical rotor which rotates during deposition, ensuring thickness uniformity levels ≤ ±1% are achieved.

The machine platform can support two sputter deposition configurations. Sputtering of metal followed by oxidation by a compact DC plasma source to deposit low absorption oxide material and secondly closed field magnetron (CFM). The CFM process does not need an auxiliary ion or plasma utilizing sub-oxide targets, removing the need for active control of the reactive sputter process.

Deposition of single layer material is described for both configurations together with multilayer optical coatings. Both configurations produce oxide refractive indices close to that of the bulk material. The films are spectrally stable due to the absence of porosity. The absorption is also exceptionally low due to the efficiency of oxidation.

CFM sputtering produces low stress, dense optical coatings with outstanding durability. Coatings can be applied to mineral glass as well as to a variety of plastics including hardcoated CR39 and polycarbonate making the system suitable for application to ophthalmic and precision optics.

High throughput deposition of high quality metals has also been demonstrated.

INTRODUCTION

Multilayer optical coatings are important in a number of applications including precision optics, fiber optical telecommunications and ophthalmic lenses. Magnetron sputtering has a number of advantages over conventional physical vapour deposition techniques such as electron beam and thermal evaporation. For example, the kinetic energy of the sputtered atoms is typically 10 times higher than that of evaporated species resulting in much harder and much more adherent coatings. The energy of the process also removes the need for substrate heating during deposition. This means that deposition is carried out at room temperature allowing different materials such as glass and plastic to be coated even in the same batch.

Compact magnetron sources are also capable of high deposition rates which result in fast process cycle times. This paper describes a small scale high throughput sputter machine with loadlock delivery of substrates into the deposition chamber. This ensures main deposition chamber is always maintained under vacuum.

The machine can be offered in one of two configurations: i) two magnetrons with metal targets with a separate plasma source[1]. Sputter deposition of metal and subsequent oxidation of thin metal layer with a separate plasma source.

Second configuration is based on four magnetrons in a closed field magnetron (CFM) configuration[2].

It has been reported previously 4, 5 that CFM reactive magnetron sputtering produces dense, smooth, spectrally stable metal-oxide optical coating material with refractive indices typically close to that of the bulk material. The thin films also exhibit low stress. CFM can utilize either metal or sub-oxide targets.

SYSTEM DESCRIPTION

Magnetron sputtering system for small batch high throughput production is shown in Figure 1 – system name is “PlasmaCoat™”.

The PlasmaCoat™ uses a patented reactive magnetron sputtering process to produce dense optical coatings with outstanding durability. Coatings can be applied to mineral, glass as well as to a variety of plastics including hardcoated CR39 and polycarbonate.

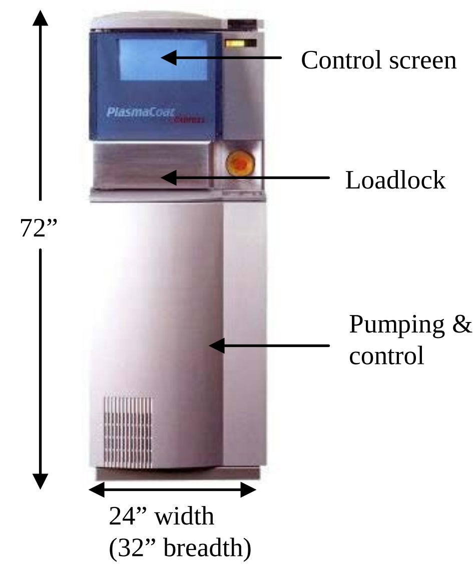

Figure 1 PlasmaCoat™ system

The machine is usually supplied for deposition of multilayers of two materials. Silicon dioxide is the low index material and zirconium oxide is supplied as the high index material. These materials are ideal for applications for precision optics applications.

The machine is compact and highly automated. It is easy to use and staffs need only a few hours training. The machine is addressed via a simple keypad display. Once the substrates are loaded, subsequent operation is completely automatic. It employs a vacuum load lock to maximise throughput and minimise maintenance.

Substrates are mounted on a vertical rotor which has up to six positions for substrates. Figures 2 shows a) substrate carousel and b) substrate carousel mounted within loadlock with door open.

Substrate capacity (up to six 70mm dia.) mounted on a 200mm drum diameter.

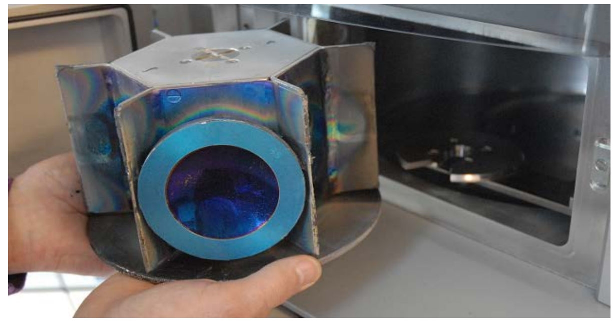

Figure 2a Substrate carousel

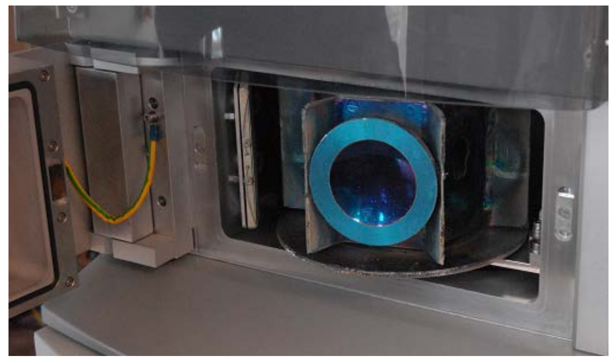

Figure 2b Substrate carousel mounted within loadlock chamber

Once loadlock is pumped out the rotor lifts the substrate carousel into the deposition chamber. A gate valve separates loadlock and deposition chamber ensuring deposition chamber is always maintained under vacuum. The system is ready to deposit in less than 10 minutes after pumpdown is initiated.

Figure 3 shows top view of the chamber for two configurations. 3a shows two magnetrons with plasma source

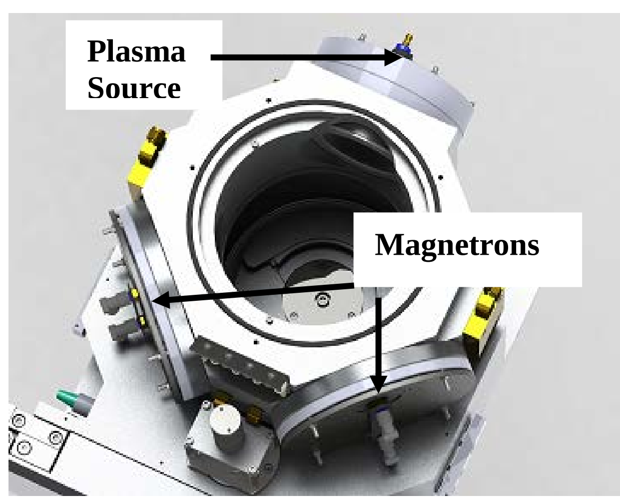

Figure 3a Top view of deposition chamber with two magnetrons (6” diameter) and plasma source

Figure 3b shows top view of deposition chamber with four magnetrons (6” diameter), configured in a CFM format.

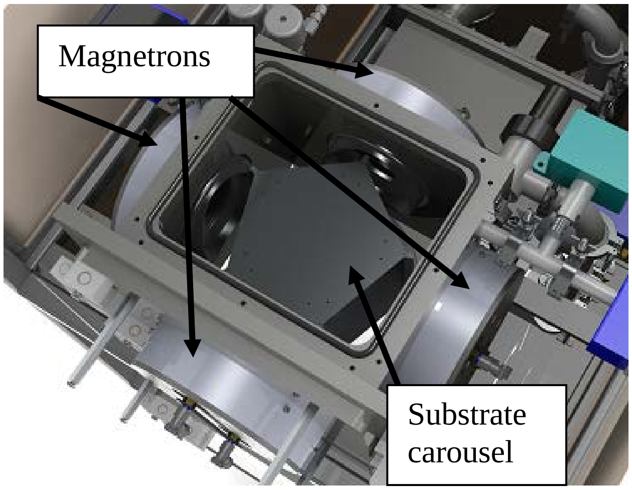

Figure 3b Top view of deposition chamber with four magnetrons (6” diameter), configured in CFM format

EXPERIMENTAL RESULTS

SINGLE LAYER

Two Magnetron/ Plasma Source (Fig 3a)

Single layer results for a thick (336nm) zirconia layer are shown in Figure

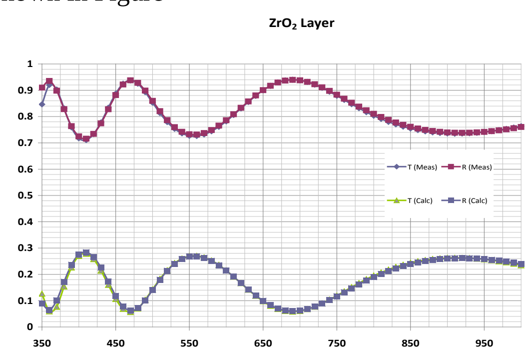

Figure 4 Spectral transmission of a thick zirconia layer

Measurements shown in Figures 5a and b are made with an Aquila nkd 800 variable angle spectrophotometer. n and k are derived from fit to transmission and reflection measurements shown in Figure 4. The k value is < 10^{-6} for both zirconia and silica.

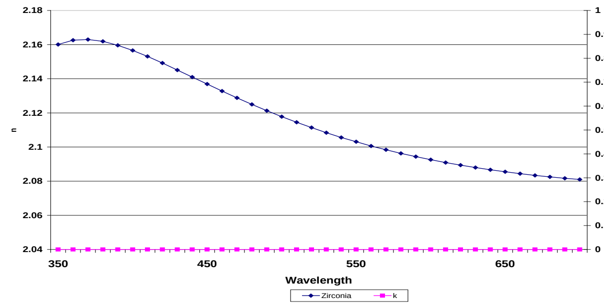

Figure 5a n and k for zirconia

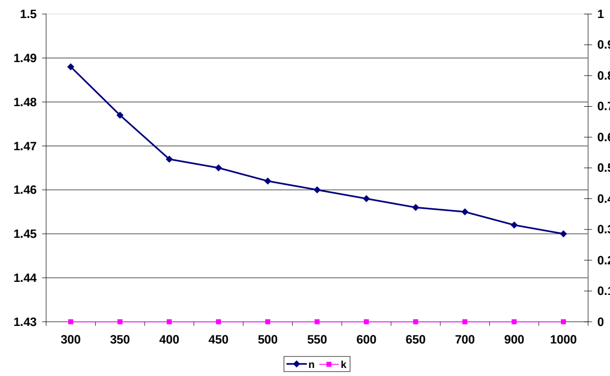

Figure 5b n and k for silica

Closed Field Magnetron Configuration (Fig 3b)

A table of the optical properties of the most important metal-oxides deposited using CFM sputter configuration is shown in table 1.

Material	Refractive Index	Absorption
SiO_2	1.47	$<1x10^{-6}$
Nb_2O_5	2.37	$5x10^{-5}$
ZrO_2	2.10	$<1x10^{-6}$
TiO_2	2.45	$3x10^{-4}$
Ta_2O_5	2.17	$1x10^{-5}$
HfO2	2.08	$1x10^{-5}$

Table 1 The refractive index and extinction coefficients (@550nm) for a range of metal oxides

The refractive index of these oxides is close to that of the bulk material, due to the high energy of the process. The films are spectrally stable due to the absence of porosity. The absorption is also exceptionally low due to the efficiency of oxidation.

MULTILAYER DEPOSITION

Two Magnetron / Plasma Source (Fig 3a)

Edge Filter

Spectral transmission for three separate deposition runs of a 63 layer ZrO_2 / SiO_2 edge filter are shown in Figure 6. Comparison with theory also shown.

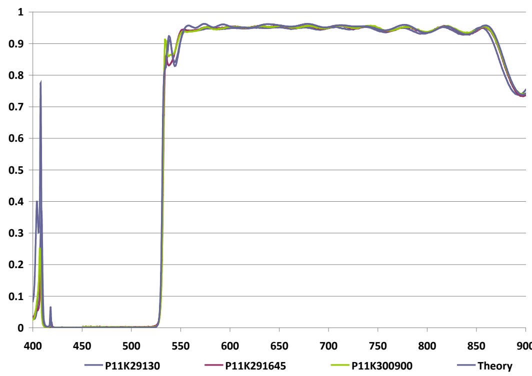

Figure 6 Spectral transmission characteristic for three repeat runs of a 63 layer zirconia/silica edge filter. Theory added for comparison

Thickness control via power / time. Reproducibility < ±1nm (<± 0.2%).

AR Coating

AR coating is a two layer ZrO2 26.5nm | SiO2 114.3 nm design, glass coated both sides. Design wavelength 460nm.

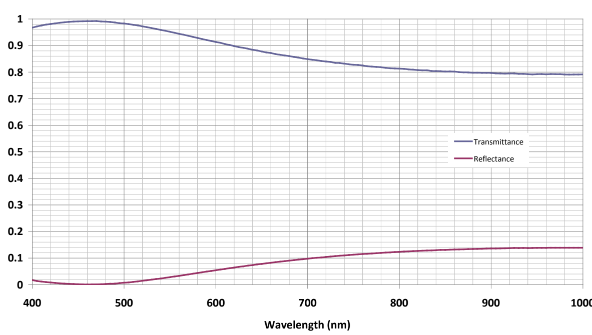

Figure 7 Spectral transmission and reflection for a glass substrate coated both sides with an anti-reflection coating at 460nm

Match with theory indicates excellent reproducibility run to run (<(± 0.2%).

Closed Field Magnetron Configuration (Fig 3b)

Edge Filter

Measured performance for (closed field magnetron deposited) three consecutive coating runs of a 19-layer Nb_2O_5 / SiO_2 edge filter and comparison with theoretical design

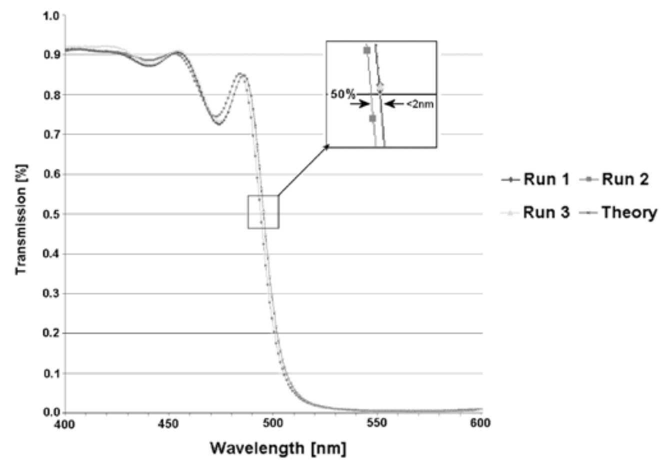

Figure 8 Measured performance for three consecutive coating runs of a 19-layer Nb_2O_5/SiO_2 edge filter and comparison with theoretical design

Thickness control via power/ time. Reproducibility <±1nm (<± 0.2%).

AR Coating

AR coating on CR39 ophthalmic lens is shown in Figure 9. AR design is a four layer Nb_2O_5/ SiO_2.

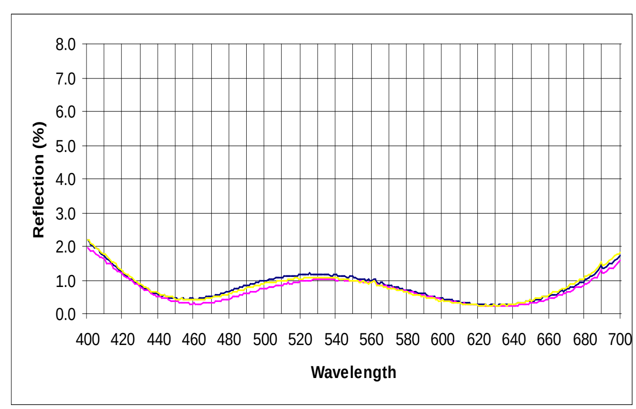

Figure 9 Measured performance of three consecutive runs of a four layer Nb_2O_5/ SiO_2 multilayer on CR39 ophthalmic lenses

Thickness control via power / time. Reproducibility <±2nm (<± 0.4%).

CONCLUSIONS

A small batch high throughput sputter deposition system has been described. The system (termed PlasmaCoat Express™) uses patented reactive magnetron sputtering processes to produce dense optical coatings with outstanding durability. Coatings can be applied to mineral, glass as well as to a variety of plastics including hardcoated CR39 and polycarbonate.

Use of a loadlock to maintain main deposition chamber under vacuum provides a fast time pumpdown time (< 10 minutes) to required vacuum for deposition.

Two patented sputter deposition configurations are available, offering flexibility for a wide range of process requirements.

REFERENCES

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4. D.R. Gibson et al, *SVC 51st Annual Technical Conference Proceedings*, 2011, 241