Plasma Assisted Deposition of Precision Optical Coatings over Extended Areas

A Thin Film Solutions Technical Brief

ABSTRACT

This paper describes use of a new plasma source for ionized plasma-assisted deposition of precision optical coatings over extended areas (>1m diameter), demonstrating refractive index uniformity/ reproducibility to <±0.2% for commonly used oxide coating materials such as titania, silica and aluminium oxide.

The primary design feature of the new source that enables extended area coverage and achieved uniformity/ reproducibility, is the ability to tune spatial distribution of ion current density independent of ion energy and plasma neutralization.

Demonstration of large area precision optical coating is shown using an edge filter design utilized in colour separation prisms. Low temperature processing (<100°C) is required as the prism face to be coated is part of a cemented assembly. Results demonstrate refractive index/ thickness precision and reproducibility to <±1% over a 1m diameter coating area.

INTRODUCTION

Ionised plasma-assisted deposition provides a processing method that enables dense stable optical coatings to be deposited at room temperature. Such ion or plasma assisted processes can be effectively used in vacuum processing of thin film coatings during electron beam, thermal or sputter deposition.

The energy imparted by the source to the growing film is capable of modifying the microstructure producing dense, near stoichiometric films that are impervious to temperature and humidity variations. Thin film deposition in the presence of energetic neutral ions imparts additional energy to the growing film, resulting in increased densification, spectral stability and general durability of optical coatings.

However, a major difficulty in using ion or plasma assisted processes for production is achieving necessary uniformity and reproducibility in deposited film optical properties, particularly over extended areas.

There are a variety of ion[1-4] and plasma[5,6] sources all of which rely on generation of electrons confined within a magnetic field to stimulate ionization of a working gas. Neutralization of the plasma is required to avoid charging effects, plasma voltage and hence variation in ion energy and localized discharges within the vacuum chamber.

The primary advantage of the plasma compared to the ion source approach is that the plasma fills the vacuum chamber and couples into the evaporant, inducing partial ionization. Moreover, with a plasma source the high density plasma is extracted via an electromagnetic field, providing wide coverage over large substrate area.

Commercial demands on optical coating production are driving the need for higher throughput processes, for applications such as flat panel displays, liquid crystal display (LCD) projection systems and visible/ thermal control coatings for low cost imaging systems.

To meet these demands requires coating over larger areas at low temperature. Moreover, an additional need is for optical thickness precision control to provide necessary optical coating spectral performance. Production implementation of such high throughput/precision processes requires both uniformity over extended areas and also reproducibility on a batch to batch basis.

As stated above ionized plasma-assisted deposition[5,6] provides a process which offers potential for large area coverage and low temperature processing.

The plasma source[6] described below provides a means of optimising spatial uniformity of the plasma and hence optical properties over extended areas. This is achieved without influencing other parameters which are necessary for reproducibility – primarily ion momentum[7] and plasma neutralization[6].

Construction and installation flexibility allows the plasma source to be placed at various baseplate positions to provide optimal plasma/ evaporant plume overlap for multiple material evaporation sources. Moreover, the plasma source can be retrofitted into different coating system configurations.

Specific application of the plasma source to ionized plasma-assisted electron beam deposition of precision colour separation edge filters, over a 1m diameter coating area, is described.

PLASMA SOURCE DESCRIPTION

A detailed description of the plasma source has been provided elsewhere[6]. As shown in Figure 1 the plasma source has a modular construction thereby providing various emitter configurations and output electromagnet coil geometries to tune output plasma current density and spatial distribution for specific process requirements.

The source incorporates a thermionic emitter material heated by an induction coil, which also provides radio-frequency energy within an electrically insulated cylindrical former. A cylindrical anode is concentric with the emitter and axially displaced, generating a potential difference between anode and emitter. The potential difference between anode and ground and axial magnetic fields causes the plasma to be extracted from the source.

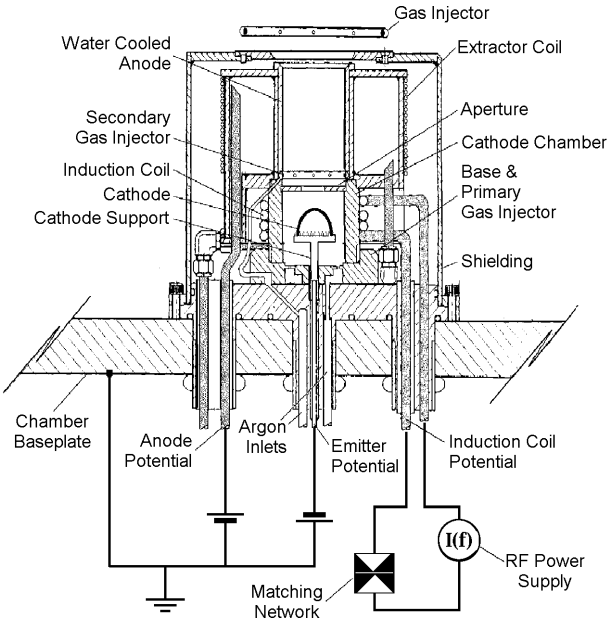

Figure 1. Cross-section of the plasma source.

Radio-frequency excitation of the emitter generates thermionic electrons, resulting in efficient plasma generation. The induced axial magnetic field in the vicinity of the cathode is de-coupled from a time invariant axial electromagnetic field at the anode.

Decoupling of plasma confining magnetic fields within the anode and cathode regions provides a means for separate control of source plasma spatial distribution within the chamber. This is achieved without influencing ion momentum - determined by anode/ cathode voltage, and plasma neutralisation - determined by RF power to the electron emitter.

Measurements of ion current density and ion energy were carried out with Faraday cups and Langmuir probes respectively. Figure 2a shows ion current density (ICD) over the radius of a 1m diameter calotte (spherical plasma source output to substrate distance is 60cm), together with refractive indices for TiO_2, Ta_2O_5 and SiO_2 (@ 550nm. Included is data for ICD and refractive indices (@550nm) for a stationary optical monitor witness piece located at the centre of the coating area.

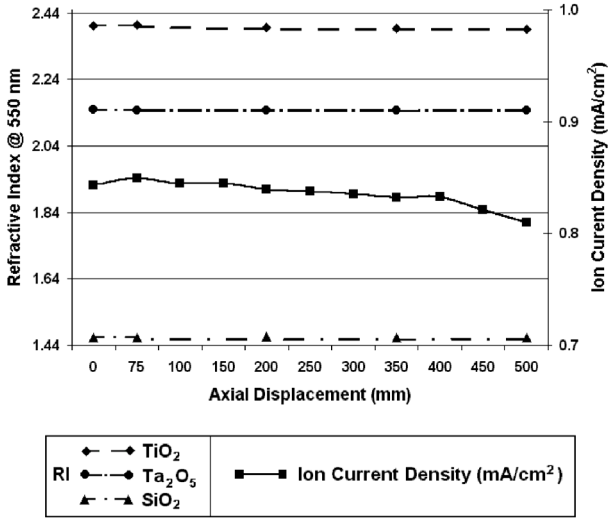

Figure 2a. Ion current density and TiO_2 refractive index (@550nm) profiles at a spherical source to target distance of 60cm. Plasma source is located halfway between centre and edge of the baseplate.

The ion energy typically corresponds to 80% of the anode to earth voltage. Typical ion energy of 80eV is utilised for assisted deposition of optical coatings.

Variation of TiO_2 , Ta_2O_5 and SiO_2 refractive indices (@550nm) as a function of ICD are shown in Figure 2b. Data indicates a threshold value at which constant refractive index is achieved. This result is in accord with the requirement for minimum ion/ adatom ratio to achieve film densification for a given material deposition rate.

Deposition rates for TiO_2, Ta_2O_5 and SiO_2 are 6, 8 and 10A/sec respectively.

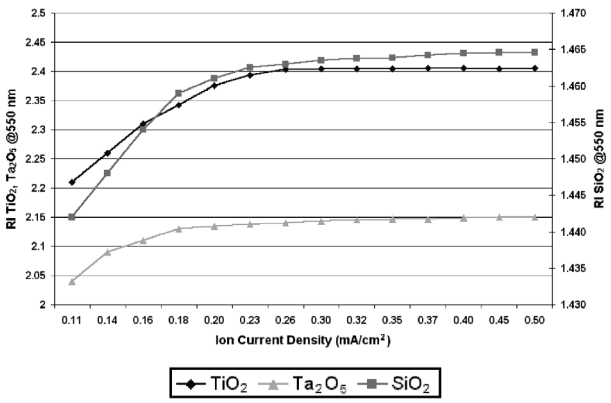

Figure 2b. TiO_2, Ta_2O_5 and SiO_2 refractive indices (@550nm) as a function of ion current density.

To ensure reproducibility in deposited film optical properties it is necessary to ensure that ICD at the substrate plane over the full coating area is significantly above the threshold ICD value. This ensures that resulting material refractive index is independent of ICD and deposition rate variations.

EXPERIMENTAL RESULTS

Experimental work was performed in a 1200mm production box coater equipped with a plasma source located halfway between the centre and edge of the baseplate. The chamber was pumped by a 15,200l/s diffusion pump supplemented by a Meissner baffle for efficient water pumping. Film thickness and deposition rate monitoring was via a commercial deposition controller and optical monitor. Two 12kW electron beam sources were used for evaporation of the coatings.

Properties of single films of titanium dioxide (TiO_2) and silicon dioxide (SiO_2) were characterised using various plasma conditions and material evaporation rates. Precision multilayer dielectric edge filters has been demonstrated. Results are described as follows.

TiO_2 and SiO_2 deposition

TiO_2 and SiO_2 films were evaporated onto borosilicate glass witness pieces located across the 1110mm-diameter substrate calotte, deposited at room temperature with ionised plasma assist. The spectral transmission curves were plotted and the refractive index and dispersion characteristics calculated.

Figure 3 shows the refractive index for TiO_2 and SiO_2 @550nm averaged over three radial calotte positions (extreme radial positions used). Spread in average across the calotte is within measurement accuracy (±0.2%).

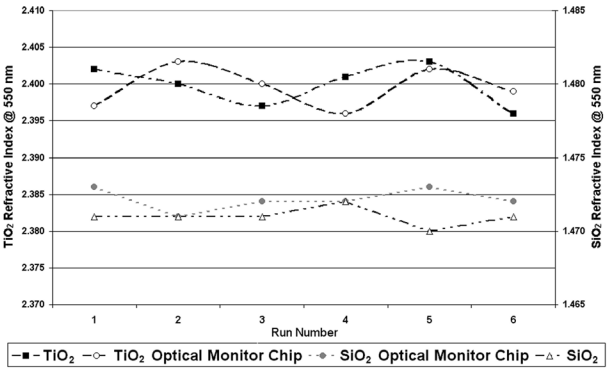

Figure 3. Refractive index of TiO_2 and SiO_2 @550nm for six consecutive coating runs.

Also shown in Figure 3 is the refractive index for TiO2 and SiO2 @550nm for an optical monitor witness piece, maintained stationary during deposition, located at the centre of the coating area. Data from Figure 3 illustrates the degree of reproducibility on a run to run and across the coating area.

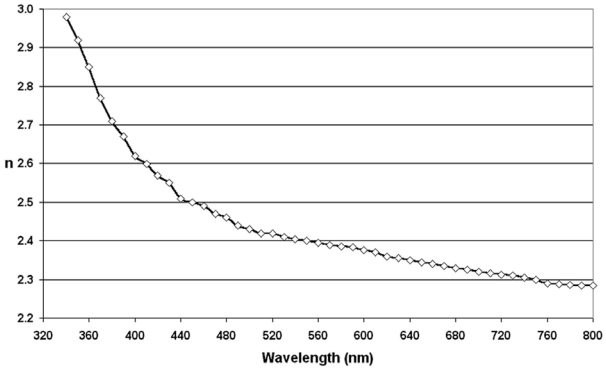

Figure 4a TiO_2 dispersive characteristic

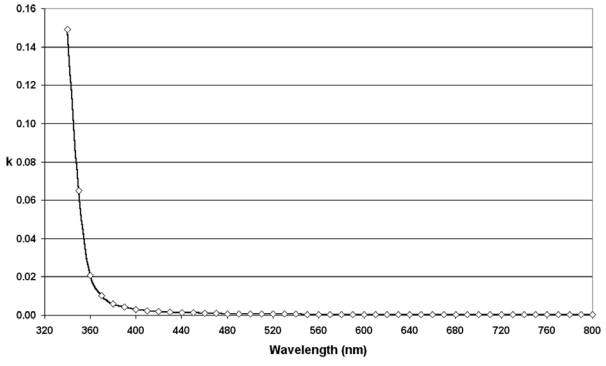

Figure 4b TiO_2 extinction coefficient.

Figure 4a and b show the dispersive characteristic and extinction coefficient values respectively for ionised plasma assisted deposition of TiO_2. This data was

obtained from ellipsometric measurements[8]. Results indicate low absorption films over the visible/ near infra-red spectral regions.

Multilayer edge filter

A long-pass edge filter was designed for operation at 45° angle of incidence using the dispersive indices calculated from the material spectral data. This filter is utilised within a colour separation prism, primarily to control and spectrally shape the appropriate polarisation states for blue and red colour channels.

Such prisms are utilised within LCD projection systems for accurate control of colour balance in projected images. Due to the cemented prism assembly, coating of this particular multiplayer edge filter is carried out at room temperature.

Coating runs were performed and the spectral performance (p- and s-polarisation transmission states) assessed against the theoretical design as shown in Figure 5. Close agreement between theory and practical results were obtained, and the blocking bandwidth achieved was within ±0.7% of the theoretical predictions. This indicated that the theoretical index and dispersion models of the individual materials were correct.

Figure 6 shows reproducibility for three consecutive runs.

In agreement with the TiO_2 and SiO_2 single layer work summarised in Figure 3, reproducibility on a coating run to run basis is maintained for the multiplayer dielectric edge filter.

One additional feature observed was the lack of fringe edge effects near the substrate support. This is thought to be due to the presence of low energy field effect electrons that neutralise the plasma space charge in the vicinity of the substrate. Lack of neutralisation here can distort the electric field near the substrates, resulting in film thickness variations where the substrate is supported by the metal surround.

Other coating materials

Trials have been carried out for aluminium oxide (Al_2O_3), and tantala (Ta_2O_5). Results for tantala show an index value of 2.075 at 1550nm, which has application in DWDM/ GFF/ ultra-steep edge telecoms filters.

CONCLUSION

A versatile plasma source has been described for ionised plasma-assisted deposition of thin films. The independent magnetic field confinement in the cathode and anode regions of the plasma source provides a means of control of plasma spatial distribution within the vacuum chamber. This is achieved without significantly influencing other prime plasma source parameters which influence uniformity/ reproducibility of resulting film optical properties, thereby overcoming one of the problems associated with plasma sources.

Resulting uniformity/ reproducibility in optical properties has been demonstrated for single layer thin films and also a precision edge filter.

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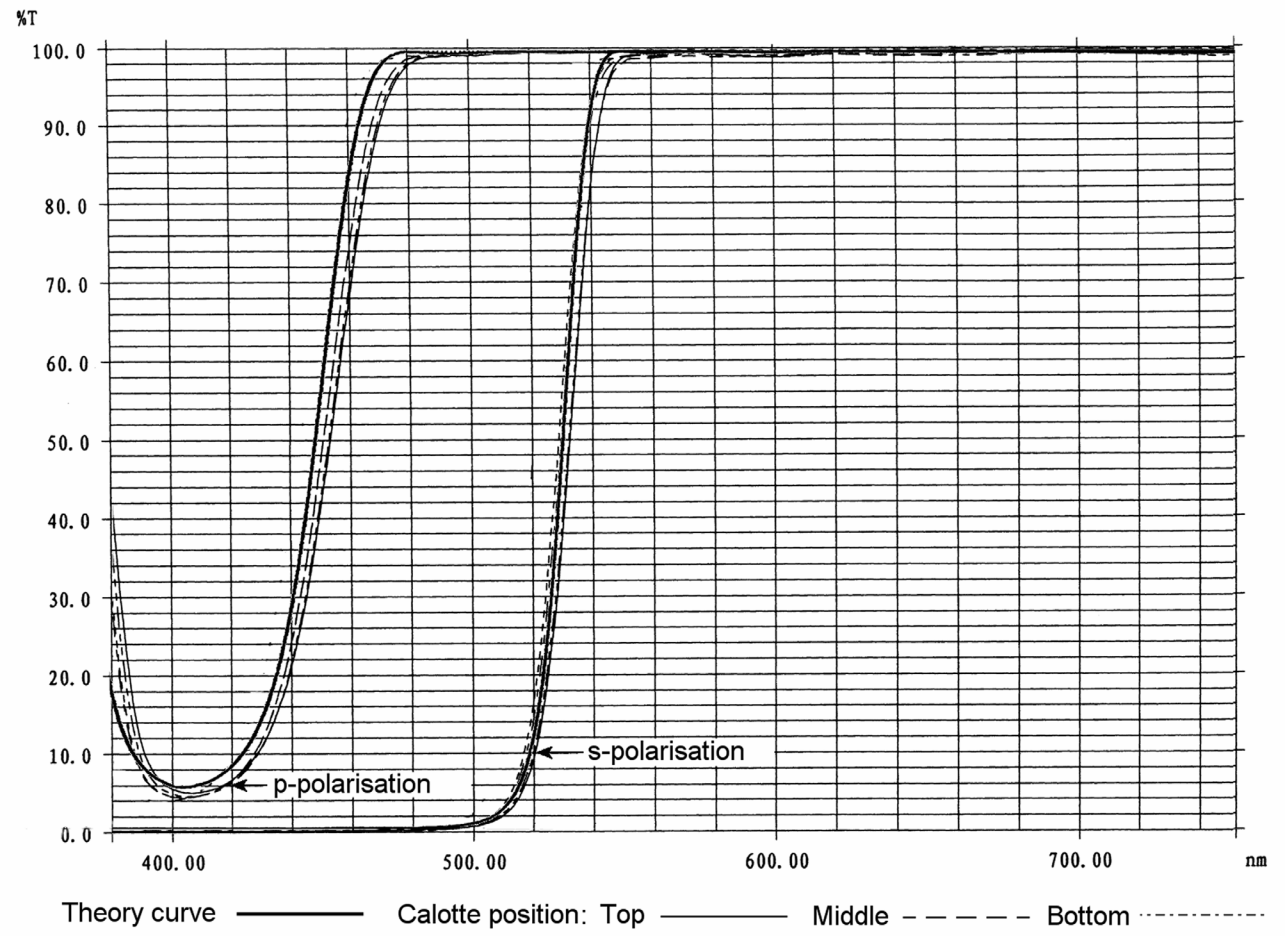

Figure 5. Spectral edge transmission for p- and s-polarisation states – comparison of theory and experiment

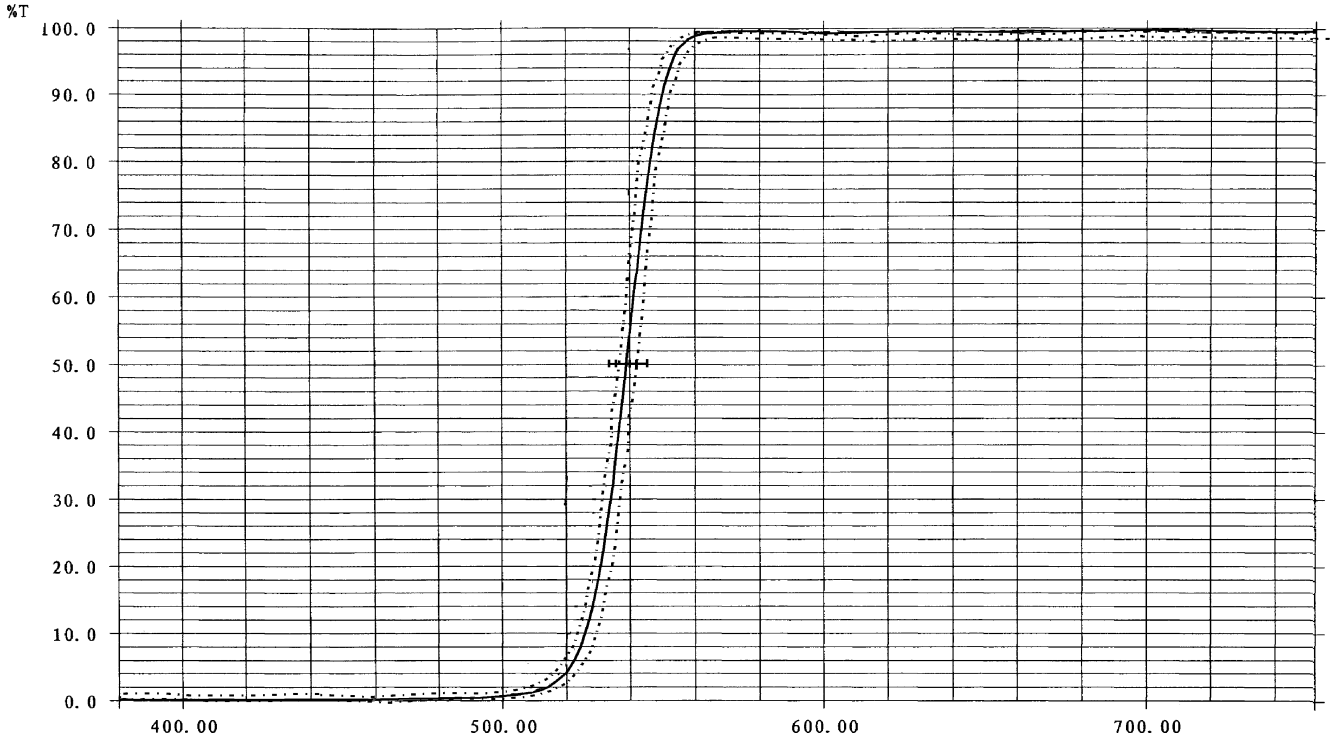

Figure 6. Reproducibility in edge filter edge s-transmission for three consecutive coating runs.