Scottish Research Partnership in Engineering

National Manufacturing Institute Scotland

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intellemetrics

JAVAC 嘉森真空科技

Investigation of Innovative Process Control Technologies for Manufacturing of High Precision Optical Film Stacks in Drum-Sputter Coaters

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Introduction

- Thin film optical filters are an enabling technology, our phone screens, spectacles, fiber optic broadband telecoms, and more, all lean heavily on this technology. The global market for optical coatings was valued at $17 billion in 2021 and is expected to grow by 9.2% each year to 2030; Furthermore, drum-sputter coaters are becoming a larger percent of this market year by year.

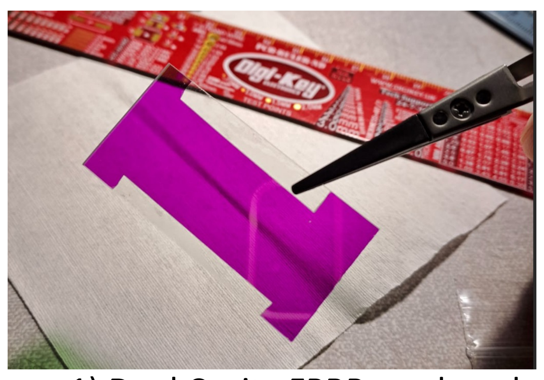


Figure 1) Dual Cavity FPBP produced at TFSI using drum-sputter coating

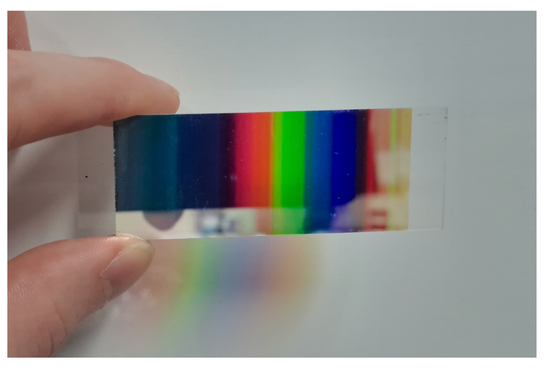


Figure 2) LVF produced at TFSI in a drum-sputter coater

- Optical Monitoring is an essential technique in the production of complex optical filters, but is still largely unproven on drum-sputter coaters. The feasibility of integrating this technique into drum-coaters is the primary goal of this project, and is being done in collaboration with our partners at Intellemetrics Global Ltd.

Theory

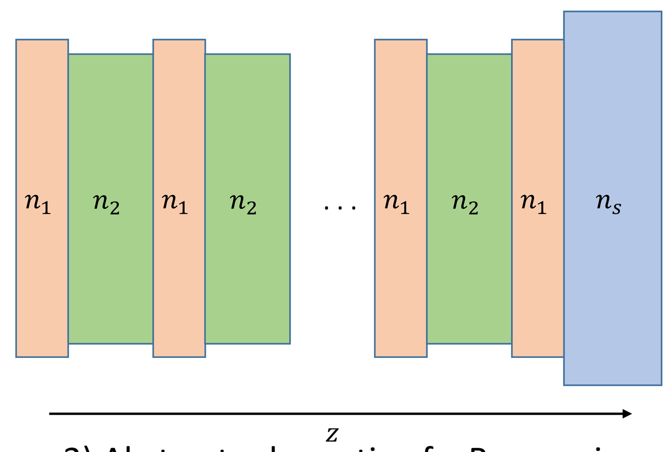


Figure 3) Abstract schematic of a Bragg mirror (very simple and common) coating composed of layers of high (n_1), and low (n_2) refractive indices upon a glass substrate (n_s); n_0 is the ambient medium

- Optical thin film filters are composed of many thin transparent layers stacked on top of one another. Typically, each individual layer is on the order of 10's or 100's of nanometers in thickness.
- The thickness of each layer determines the performance of the filter. Often these layers are highly sensitive to errors; small unintentional variation can lead to the specular properties of the filter being destroyed.

$$c_i = \begin{bmatrix} \cos\phi & i\sin\phi/N \\ i\sin\phi\, N & \cos\phi \end{bmatrix}, \quad Q = \begin{bmatrix} 1 & 1 \\ n_0 & -n_0 \end{bmatrix}^{-1} \left\{ \prod_i c_i \right\} \begin{bmatrix} 1 & 1 \\ n_s & -n_s \end{bmatrix} \quad T = \left| \frac{1}{Q_{00}} \right|^2 \frac{\Re[n_s \cos\theta_s]}{\Re[n_0 \cos\theta_0]}, \quad R = \left| \frac{Q_{10}}{Q_{00}} \right|^2$$

Optical Monitoring

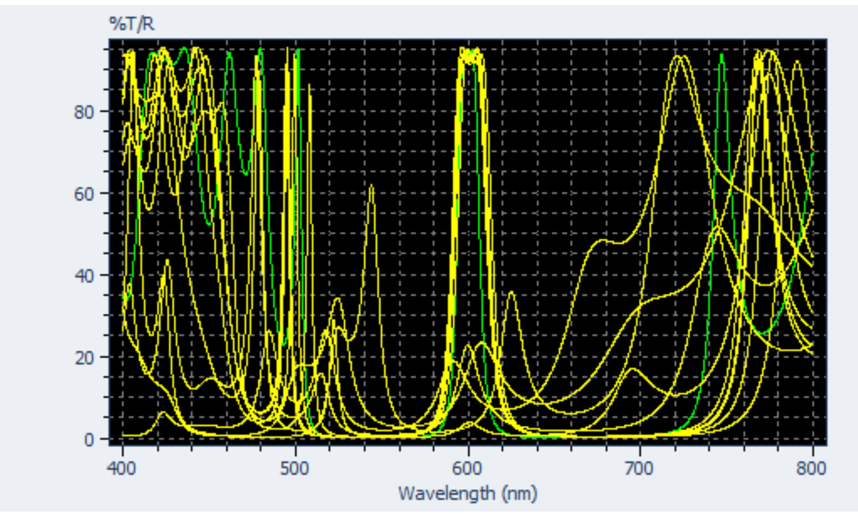


Figure 4) Expected yielded filters without optical monitoring (5% cut error, QCM)

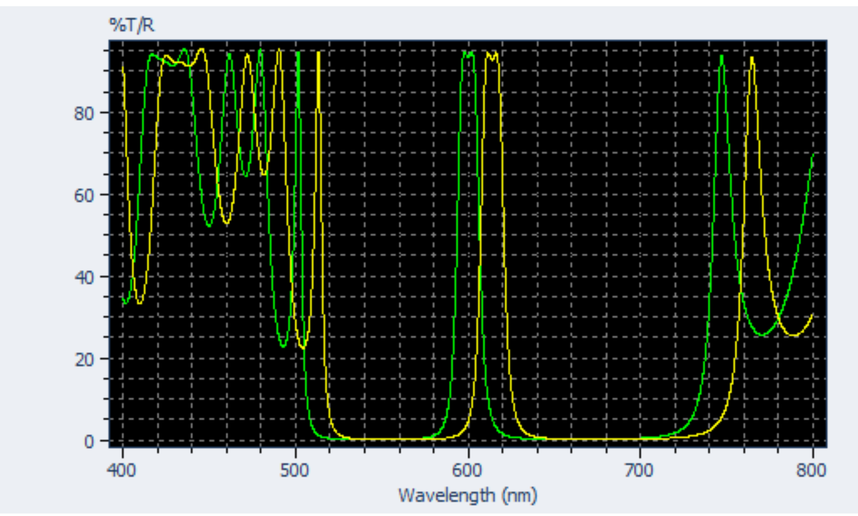
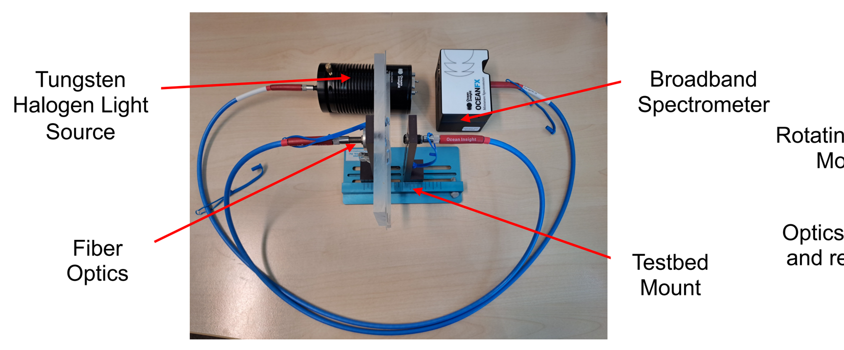
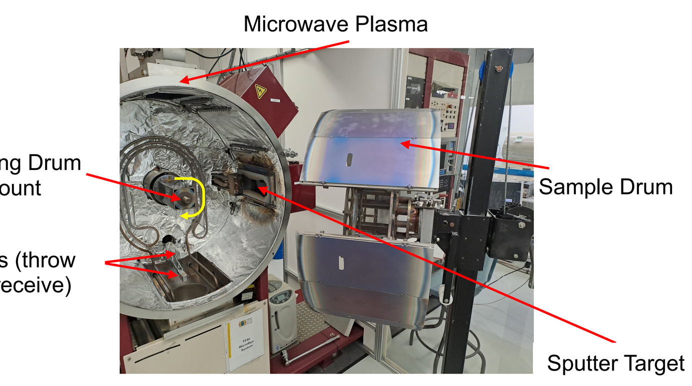


Figure 5) Expected yielded filters without optical monitoring (5% cut error, OMS)

- Typically, the thickness of a layer is controlled by a quartz crystal microbalance (QCM), which is calibrated to measure the thickness of the deposited layer.
- However, QCM knows nothing of the thickness (and errors) of the previous layers. Meaning that performance of the filter will drift away from the designed performance over the course of the deposition process.
- The solution is optical monitoring (which measures filter transmission), which can correlate errors between layers during deposition, and allow industrially relevant coatings that are sensitive to error – excluding the use of QCM - be manufactured accurately and reliably.
- This can be observed in Figures 4) and 5) which compares a series of 10 virtual depositions using QCM and OMS.





Figures 6) Broadband monitoring configuration (on test bed platform). 7) Microdyn Plasma Assisted Sputter system with bespoke OMS optics installed

Optical Monitoring Process Schematic

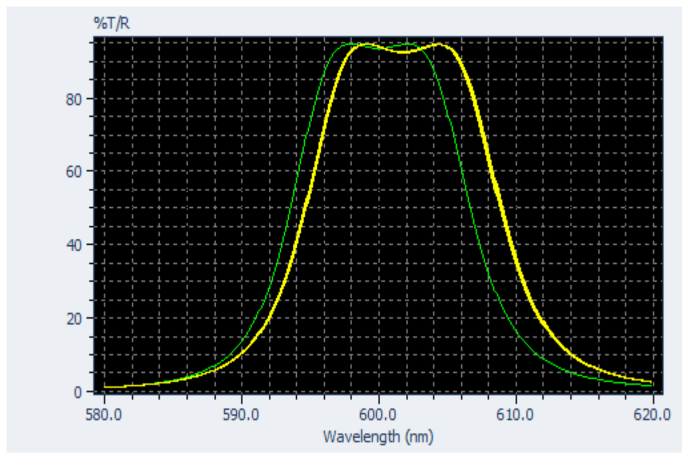


Figure 8) Virtual Deposition of designed filter, green trace is theory, yellow traces are results of virtual runs

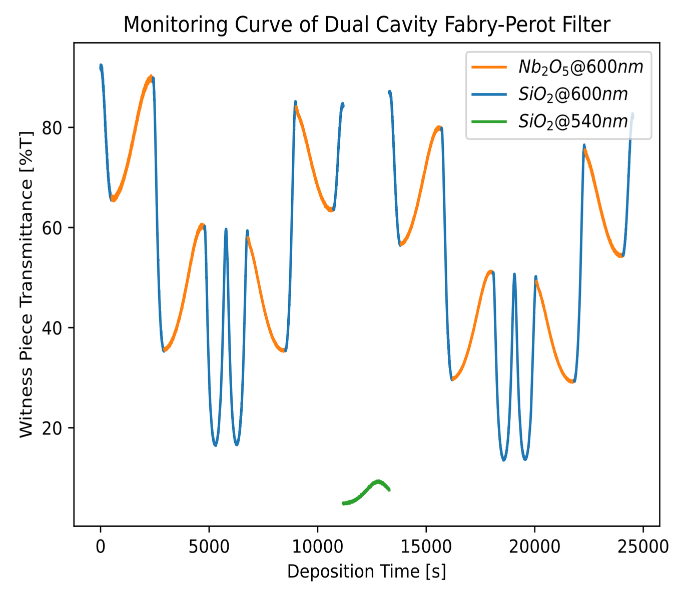


Figure 9) Measured transmittance of the filter during deposition

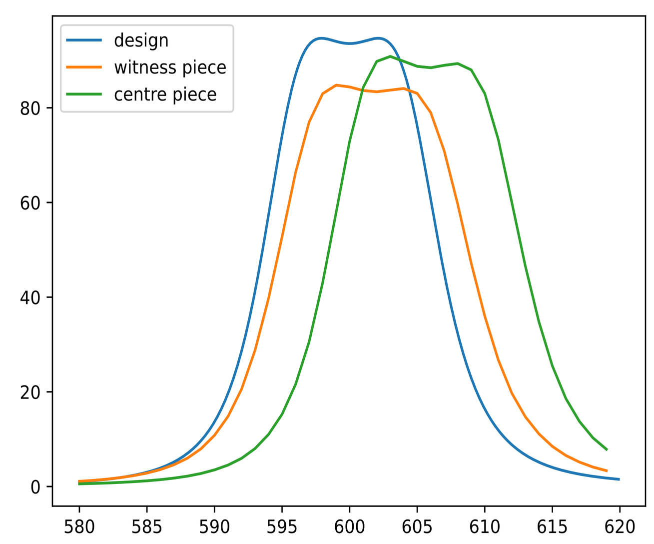


Figure 10) Measured transmittance of the filter during deposition

Expected Outcomes and Impact

- Using the large amounts of data captured by the OMS (in particular, the broadband OMS / BBM) to produce real time data analysis of the deposition process. This will require new software to be developed, so that the data can be processed quickly and without the need for active user input, which in this case would be highly suited to real time characterisation of optical inhomogeneity. While some research has been done on this in the past, data processing has been conducted *ex-situ* and therefore is not useful for process control.
- To identify sources of error during the deposition process that are inherent in drum sputter coaters, and developing abatement strategies and techniques, such as reducing background noise, variable angle during deposition, etc. High off axis rejection optics should minimise most of the chamber noise; a novel witness piece that is curved so the monitoring ray is always incident to the surface of the piece is currently under development, and any noise from either the sensor, or the light source can largely be dealt with programmatically.
- Implementation of an algorithm for multilayer depositions. It is necessary in broadband optical monitoring, to determine the errors in physical thickness of the previous layers, so that the subsequent layers can be reoptimized to compensate for subsequent errors. Much work has been done in this area, however the current algorithms used are computationally inefficient; recent work in AI synthesis of thin film optical filters may prove useful for *in-situ* refinement of film structure owing to its ability to refine/synthesis filters with minimal iterations.

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