Online re-optimization of optical filters on a production sputter tool

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This contribution presents a magnetron sputter deposition tool with broadband optical monitor and online re-optimization capability for high volume production. The layer termination relies on a comparison of the actually measured reflection spectrum with a pre-calculated target spectrum. Spectra recorded after each deposited layer are analyzed by the re-optimization module and–in case of significant deviations–layer thicknesses and target spectra for the remaining layers are recalculated. This technique significantly improves the performance and reproducibility in case of highly demanding coating designs and is able to correct abnormal production errors in individual layers, which will lead to coating failure without re-optimization.

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Modern deposition techniques like magnetron sputtering or plasma assisted e-beam evaporation allow for tight control of refractive indices and coating rate. Combined with an optical monitoring system, pre-calculated designs can be closely matched, leading to reliable production of optical interference filters for a wide variety of applications. However, with highly demanding customer requirements and ever tighter tolerances even small variations in deposition conditions may drastically reduce production yield.

In this contribution a magnetron sputter deposition system with broadband optical monitoring and a re-optimization unit is presented. Application examples for both performance improvement and error correction are shown.

Along with plasma ion assisted e-beam deposition, magnetron sputter processes are gaining importance in the production of optical interference filters. The Evatec MSP1001 is an example of a sputter coating tool which is excellently suited for the batch production of optical filters (Fig. 1). In addition to high film quality and large substrate coating area, two monitoring systems are of vital importance:

1) Plasma emission monitoring controls the amount of reactive gas in the sputter process, such that a high coating rate and refractive indices with low absorption are achieved.

2) Optical broadband monitoring (Evatec GSM1100BB) measures film growth *in-situ* and precisely terminates each layer.

The broadband optical monitor measures the reflectance spectrum at each rotation of the substrate drum and compares it with a pre-calculated target spectrum. If the difference between actually measured and target spectrum is minimal, deposition is stopped and the process switches to the next layer. It is shown that this monitoring and layer termination procedure lead to an automatic compensation of layer thickness errors for many designs, as long as the errors are not too large[1,2].

This deposition and monitoring technology allow for producing filters of medium complexity successfully and reproducibly without preliminary tests. For demanding filter designs, the monitoring data of a test run can be analyzed in order to optimize the monitor strategy.

In order to reliably coat even more demanding filters, a re-optimization unit was added to the monitoring system. This unit determines the coated layer thicknesses after each layer by fitting the multilayer design model to the spectrum measured at the layer end (Fig. 2).

If significant deviations from the thin film design are found, the thicknesses of the layers which are not yet deposited are optimized with the goal to reach the best agreement with the final target spectrum. The new layer thicknesses and target spectra for each layer are sent back to the optical monitor system and the next layer is deposited (Fig. 3).

Thanks to the mature and highly efficient algorithms[3] based on the OptiLayer thin film design software[4] analysis and re-optimization is performed typically in less than a second, such that the process time is not increased noticeably.

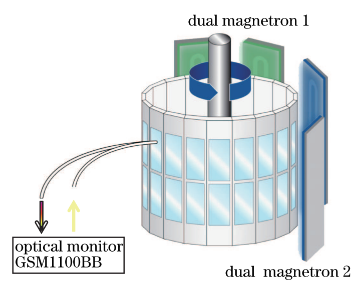

Fig. 1. Schematic of the magnetron sputter coating tool MSP1001 with optical broadband monitor.

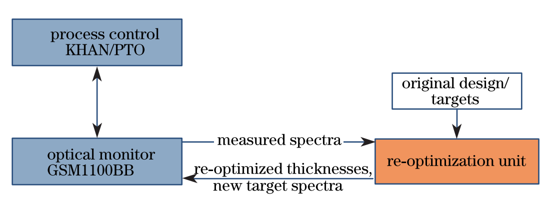

Fig. 2. Integration of the reoptimization unit in process control and optical monitoring.

It is important to note that layer termination (comparison of measured spectrum with pre-calculated layer target spectrum) and re-optimization (inverse thin film design problem) are based on completely different algorithms. In this way the stability of the monitoring and re-optimization process is increased.

The first example shows the capability of the deposition system to correct errors in the process using re-optimization. For this purpose, the 13th layer of a green transmitting filter was intentionally coated 10% thicker than designed. Without re-optimization this leads to a result which does not fulfill the specifications: the transmittance in the pass-band is significantly reduced and the edges are shifted (Fig. 4).

If re-optimization is active, the monitor spectrum is analyzed after each layer. After layer 13, the re-optimization unit detects a significant deviation and calculates new layer thicknesses and target spectra for the remaining layers. The result shows a very good agreement with the original design (Fig. 4).

The second example shows the improvement of the performance of a bandpass filter with 27 nm full width at half maximum (FWHM) using re-optimization. This sensitive design was used in recent publications for comparing characterization algorithms[5] and for demonstrating online re-optimization[6]. The agreement between design and measured spectra in the transmission range is very good both with and without re-optimization (Fig. 5). But without re-optimization, the spectrum is shifted about 1 nm to shorter wavelengths and a small dip around 535 nm can be observed. Using re-optimization, even these small deviations are corrected.

The third example shows a triple bandpass filter with high transmittance in the blue, green, and red spectral range and blocking in between. The spectral result without re-optimization shows obvious deviations of edge

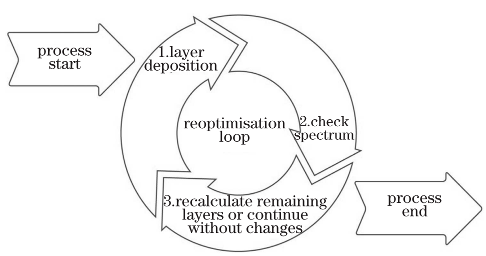

Fig. 3. Re-optimization loop is run through after each layer of the coating process.

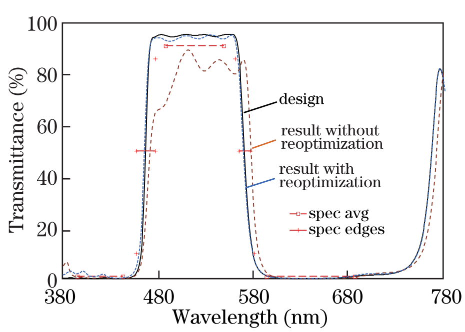

Fig. 4. (Color online) Green filter: intentional error in layer 13 is corrected by re-optimization.

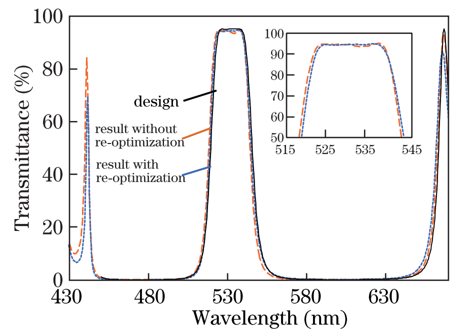

Fig. 5. (Color online) Narrow bandpass filter: optimum agreement between design and measured spectrum thanks to re-optimization.

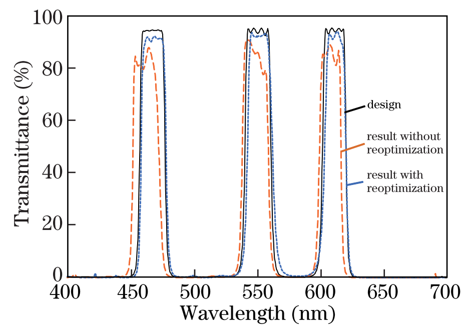

Fig. 6. (Color online) Triple bandpass filter with and without re-optimization.

positions and transmission bands from the design spectrum (Fig. 6). A possible approach to achieve a better result would now be to analyze the monitoring spectra and to adapt the monitor strategy or coating design. In order to reduce development time of this filter, this approach was not chosen, but in-process re-optimization was utilized. In this way, the next coating run led to a filter which shows a good agreement with the design spectrum (Fig. 6).

In conclusion, this letter explains the in-process re-optimization as an addition to a magnetron sputter production tool. Three application examples demonstrate that 1) the spectral performance of demanding filters can be significantly improved and that 2) abnormal production errors in individual layers can be corrected using in-process re-optimization.

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