In-situ re-optimization for new levels of process control in optical thin films

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Abstract:

This paper presents the benefits of using a magnetron sputter deposition tool equipped with broadband optical monitor and a new “online re-optimization capability” for high volume, high accuracy production. While conventional layer termination by the optical monitor relies on a comparison of the actual measured reflection spectrum with a pre-calculated target spectrum, for “in-situ re-optimization” spectra recorded after each and every 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 automatically. This new technique significantly improves the performance and reproducibility in case of highly demanding coating designs

• It can correct abnormal production errors (e.g. power outage) in individual layers which would otherwise lead to coating failure and batch loss

• It reduces process development time and costs prior to production for complex designs

• It enables new approaches to manufacturing including so called “Wafer Level Optics” on 4, 6 and even 8 inch wafers with the required accuracy and repeatability for significant manufacturing cost savings in processing of photodiode wafers

Introduction:

Modern deposition techniques like magnetron sputtering or plasma assisted e-beam evaporation allow for good control of refractive indices and coating rate. Combined with an optical monitoring system, pre-calculated designs can be matched well, leading to reliable production of optical interference filters for a wide
variety of applications. However, with increasingly demanding customer requirements and ever tighter tolerances even small variations in deposition conditions may drastically reduce production yield for some applications. The efficiency of online process re-optimization can be demonstrated using a magnetron sputter deposition system with broadband optical monitoring. The application examples in this review show how both performance improvement and error correction can be achieved.

Production Set Up: Magnetron sputter with BB optical monitoring

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

- 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.

- Optical broadband monitoring Evatec GSM1100BB measures film growth “in-situ” and precisely terminates each layer using measurements direct on the substrate.

Figure 1: Schematic and front view of magnetron sputter coating tool MSP1001 with optical broadband monitor
The broadband optical monitor measures the reflectance spectrum during deposition of the layer at each rotation of the substrate drum and compares it with a pre-calculated target spectrum. When the difference between actually measured and pre-determined target spectrum is minimal, deposition is stopped and the process switches to the next layer. This optical monitoring and layer termination procedure leads to an automatic compensation of layer thickness errors for many designs, as long as the errors are not too large [1,2]. This type of deposition and monitoring technology allows for producing filters of medium complexity successfully and reproducibly without preliminary tests saving expensive set up time and costs. As the filter designs then get more complex, the monitoring data of a test run can still be analyzed in order to optimize the monitor strategy and achieve the best monitoring conditions.

The principle of re-optimization

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 termination (Fig. 2).

![Diagram](image)

Figure 2: Integration of the re-optimization unit in process control and optical monitoring

If significant deviations from the expected thin film design are found, the thicknesses of the layers which are not yet deposited are recalculated and optimized with the goal to reach the best agreement with the final filter target spectrum. The new recipe, including layer thicknesses and target spectra for each layer are implemented
automatically in the Khan Process Controller and GSM optical monitor system. The next layer is deposited and after termination the re-optimization process is repeated until all layers are complete (Fig. 3).

Figure 3: The re-optimization loop is run through after each layer of the coating process

The use of efficient algorithms [3] based on the OptiLayer thin film design software [4] analysis means that re-optimization is performed typically in less than a second so process time is not increased noticeably. 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.

Application examples of re-optimization

Example 1: Batch recovery after abnormal mid process error

To simulate the effect of an unplanned or abnormal production error, the 13th layer of a green transmitting filter was intentionally coated 10% thicker than designed. If the rest of the processes is then completed 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 how the process is recovered with a very good agreement with the original design (Fig. 4).

**Example 2: Process improvement in sensitive designs**

The second example shows the improvement of the performance of a band pass filter with 27nm 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 spectrum in the transmission range is very good both with and without re-optimization (Fig. 5). But without re-optimization, the spectrum is shifted ca. 1nm to shorter wavelengths and a small dip around 535nm can be observed. Using re-optimization, even these small deviations are corrected.
Figure 5: Narrow bandpass filter: optimum agreement between design and measured spectrum thanks to re-optimization

**Example 3: Reduction in process development time & costs**

The third example shows a triple band pass 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 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 lead to a filter which shows a good agreement with the design spectrum (Fig. 6).
Summary

This article explains in situ-process re-optimization as an addition to a magnetron sputter production tool. Three examples demonstrate how the spectral performance of demanding filters can be significantly improved, abnormal production errors in individual layers can be corrected or process set up time and costs reduced. Where coating needs to be performed on valuable substrates materials or on wafers with many prior processing steps the improvements in accuracy and repeatability can lead to significant reduction in manufacturing costs. For the latest information about Evatec and the in situ re-optimization tool visit http://www.evatecnet.com/products/optics-tool-box/in-situ-re-optimisation

References


