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Technique for Design of Color Robust As-Built Optical Coatings

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ABSTRACT

This disclosure describes techniques for the design of optical coatings with low color variation in the presence of manufacturing tolerances, and which are robust to color as-built. Sample stacks of optical coatings are generated using a Monte Carlo technique based on initial design specification parameter(s) of an optical coating stack. The initial design parameter(s) are utilized as a starting point for the optical coating stack that meets color and reflectance requirements nominally prior to tolerances. Each sample stack applies an error in the design parameter(s) based on manufacturing (as-built) error distributions. A merit function that is indicative of the optical coating performance is evaluated for each as-built sample. The evaluated merit function is combined (summed) over all as-built samples, which is then minimized using an optimization method to yield an optimal as-built optical coating design specification.

KEYWORDS

- Optical coating
- Coating color
- Coating stack
- Layer thickness
- Monte Carlo simulation
- Merit function
- Manufacturing tolerance
- MacAdam Ellipse
- Dielectric material

BACKGROUND

Optical coatings are commonly used to configure the transmission, reflection, or polarization properties of optical components utilized in devices, e.g., Augmented Reality (AR) glasses, Virtual Reality (VR) glasses, etc. Optical coatings are typically composed of a combination of layers of materials (stack), e.g., dielectric materials. The properties of the coatings are dependent on the number of layers, their thickness, and refractive index differences between different layers. Variations in thickness of the different layers introduced due to manufacturing tolerances can cause coating colors to vary substantially.

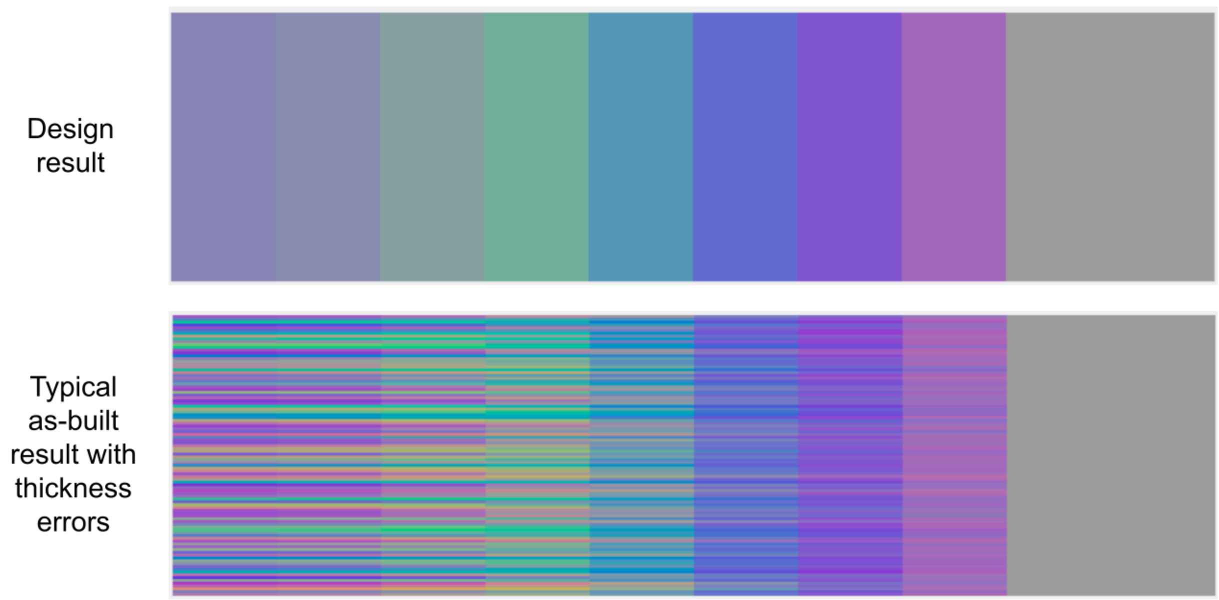

Fig. 1: Manufacturing errors cause variations in as-built optical coatings

Fig. 1 illustrates a design (desired) color palette of an optical coating and a corresponding as-built color palette that includes the effects of thickness errors in the layers due to manufacturing tolerances. As can be seen, there can be substantial differences between the as-designed and as-built optical coating performance.

DESCRIPTION

This disclosure describes techniques for the design of optical coatings with reduced color variation in the presence of manufacturing tolerances, and which are robust to color as-built.

Per techniques of this disclosure, sample stacks of optical coatings are generated based on initial design specification parameter(s) of an optical coating stack. The initial design parameter(s) are utilized as a starting point for the optical coating stack that meets color and reflectance requirements nominally prior to tolerances. Each sample stack applies an error in the design parameter(s) based on manufacturing (as-built) error distributions. A merit function that is indicative of the optical coating performance is evaluated for each as-built sample. The evaluated merit function is combined (summed) over all as-built samples, which is then minimized using an optimization method to yield an optimal as-built optical coating design specification.

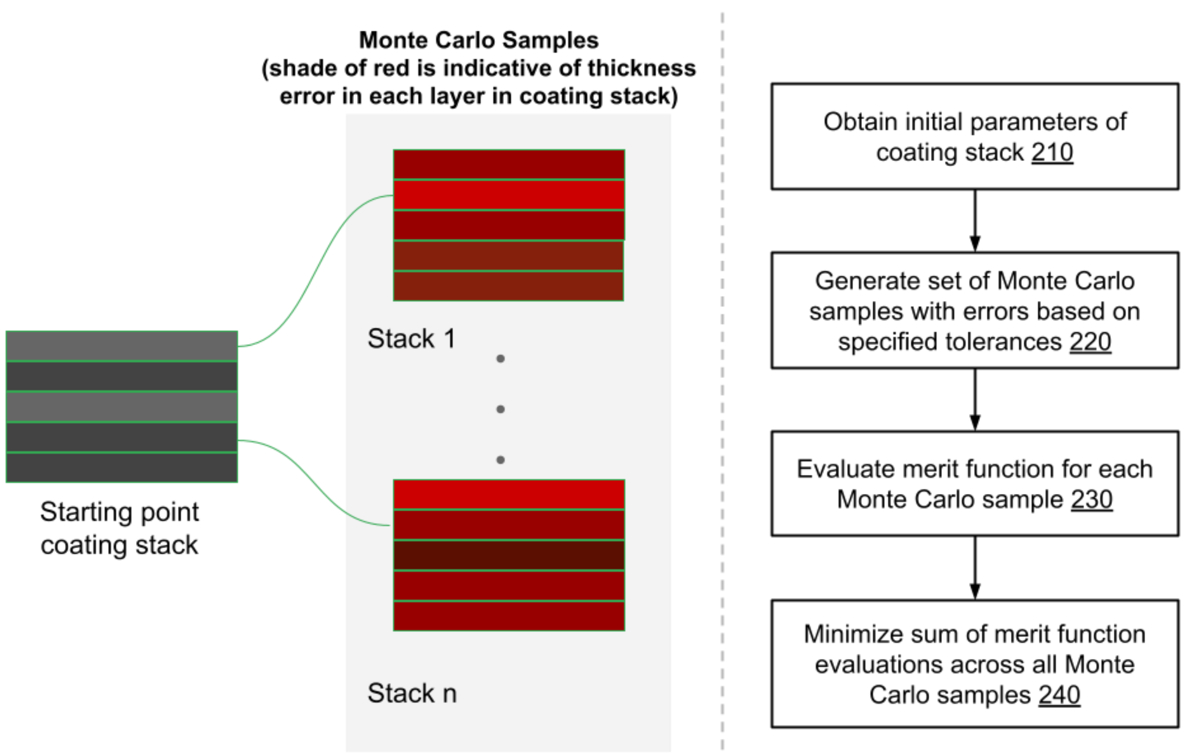

Fig. 2: A merit function is minimized over a set of Monte Carlo samples

Fig. 2 depicts an example workflow for the determination of an optimal as-built optical coating design specification, per techniques of this disclosure. As depicted in Fig. 2, a coating stack initial design (starting point) that meets nominal design specifications, e.g., nominal color and reflectance targets, is obtained (210). Based on the initial design, multiple Monte Carlo sample stacks are generated (220). Each sample stack includes a fixed number of layers. Each layer of the stack can introduce errors in the thickness and/or refractive index based on manufacturing tolerances.

A merit function, $e(s)$, is constructed that returns a real number for a given stack based on its color variation. The color variation is bounded by a corresponding MacAdam ellipse, which represents all color variations which are indistinguishable to the average human eye. The contour of a MacAdam ellipse represents just-noticeable differences of chromaticity. The merit function is evaluated for each Monte Carlo sample (230), denoted by $e\ (s_n)$.

Merit function evaluations across the Monte Carlo samples are summed and minimized over all Monte Carlo samples (240) to yield optimal parameters, e.g., thicknesses for each layer in the stack. Mathematically, the optimization can be expressed as:

> $Minimize\ \sum_n \quad e\ (s_n)$ subject to a threshold reflectance being met and wherein the color lies within the MacAdam Ellipse.

Techniques of this disclosure can be utilized to find optimal thicknesses that yield minimum color variation with respect to MacAdam Ellipses, given a coating starting point (specifically, the refractive index and thickness, and number of layers).

CONCLUSION

This disclosure describes techniques for the design of optical coatings with low color variation in the presence of manufacturing tolerances, and which are robust to color as-built. Sample stacks of optical coatings are generated using a Monte Carlo technique based on initial design specification parameter(s) of an optical coating stack. The initial design parameter(s) are utilized as a starting point for the optical coating stack that meets color and reflectance requirements nominally prior to tolerances. Each sample stack applies an error in the design parameter(s) based on manufacturing (as-built) error distributions. A merit function that is indicative of the optical coating performance is evaluated for each as-built sample. The evaluated merit function is combined (summed) over all as-built samples, which is then minimized using an optimization method to yield an optimal as-built optical coating design specification.

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