The Effect Of Phase Distortion On Interferometric Measurements Of Thin Film Coated Optical Surfaces

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This paper discusses difficulty in accurately interpreting surface form data from a phase shifting interferometer measurement of a thin film interference coated surfaces.

PHASE-SHIFTING INTERFEROMETRY

Phase-shifting interferometry is a metrology tool widely used in optical manufacturing to determine form errors of an optical surface. The surface under test generates a reflected wavefront that interferes with the reference wavefront produced by the interferometer [1]. A phase-shifting interferometer modulates phase by slightly moving the reference wavefront with respect to the reflected test wavefront [2]. The phase information collected is converted into the height data which comprises the surface under test[3].

Visibility of fringes in an interferometer is a function of intensity mismatch between the test and reference beams. Most commercially available interferometers are designed to optimize fringe contrast based on a 4% reflected beam intensity. If the surface under test is coated for minimum reflection near or at the test wavelength of the interferometer, the visibility of the fringe pattern can be too low to accurately measure.

OPTICAL THIN-FILM INTERFERENCE COATINGS

Optical thin-film interference coatings are structures composed of one or more thin layers (typically multiples of a quarter-wave optical thickness) of materials deposited on the surface of an optical substrate. The goal of interference coatings is to create a multilayer film structure where interference effects within the structure achieve a desired percent intensity transmission or reflection over a given wavelength range. The purpose of the coating defines the design of the multilayer structure. Basic design variables include:

- Number of layers
- Thickness of each layer
- Material of each layer

The most common types of multilayer films are high reflector (HR) and anti-reflection (AR) coatings. HR coatings function by constructively interfering reflected light, while AR coatings function by destructively interfering reflected light. These coatings are designed to operate over a specific wavelength range distributed around a particular design wavelength.

To produce the desired interference effects, thin-film structures are designed to modulate the phase of the reflected or transmitted wavefront. The nature of the interference effect depends precisely on the thickness of each layer in the coating as well as the refractive index of each layer. If the thickness and index of each layer is uniform across the coated surface, the reflected wavefront will have a constant phase offset across the surface. However, if layer thicknesses or index vary across the coated surface, then the phase of the reflected wavefront will also vary. Depending on the design of the coating and the severity of the thickness or index non-uniformity, the distortion of the phase of the reflected wavefront can be severe. [4]

Layer thickness non-uniformity is inherent in the coating process and is exaggerated by increasing radius of curvature of the coated surface.[5] All industry-standard directed source deposition processes (thermal evaporation, sputtering, *etc)* result in some degree of layer thickness non-uniformity.[5] Even processes developed to minimize layer non-uniformity, such as those used at Optimax, will still result in slight layer non-uniformity (within design tolerance).

TESTING COATED OPTICS INTERFEROMETRICALLY

Phase-shifting interferometers use phase information to determine the height map of the surface under test. However, surfaces coated with a thin-film interference coating can have severe phase distortion in the reflected wavefront due to slight layer thickness non-uniformities and refractive index inhomogeneity. Therefore, the measured irregularity of a coated surface measured on a phase shifting interferometer at a wavelength other than the design wavelength, may not represent the actual irregularity of the surface.

Even using a phase shifting interferometer at the coating design wavelength does not guarantee accurate surface irregularity measurements. If a coating has very low reflectance over any given wavelength range (such as in the case of an AR coating), the phase shift on reflection with wavelength will vary significantly in that range.[7] Figure 1 shows an example of how the phase can vary with coating thickness variations.

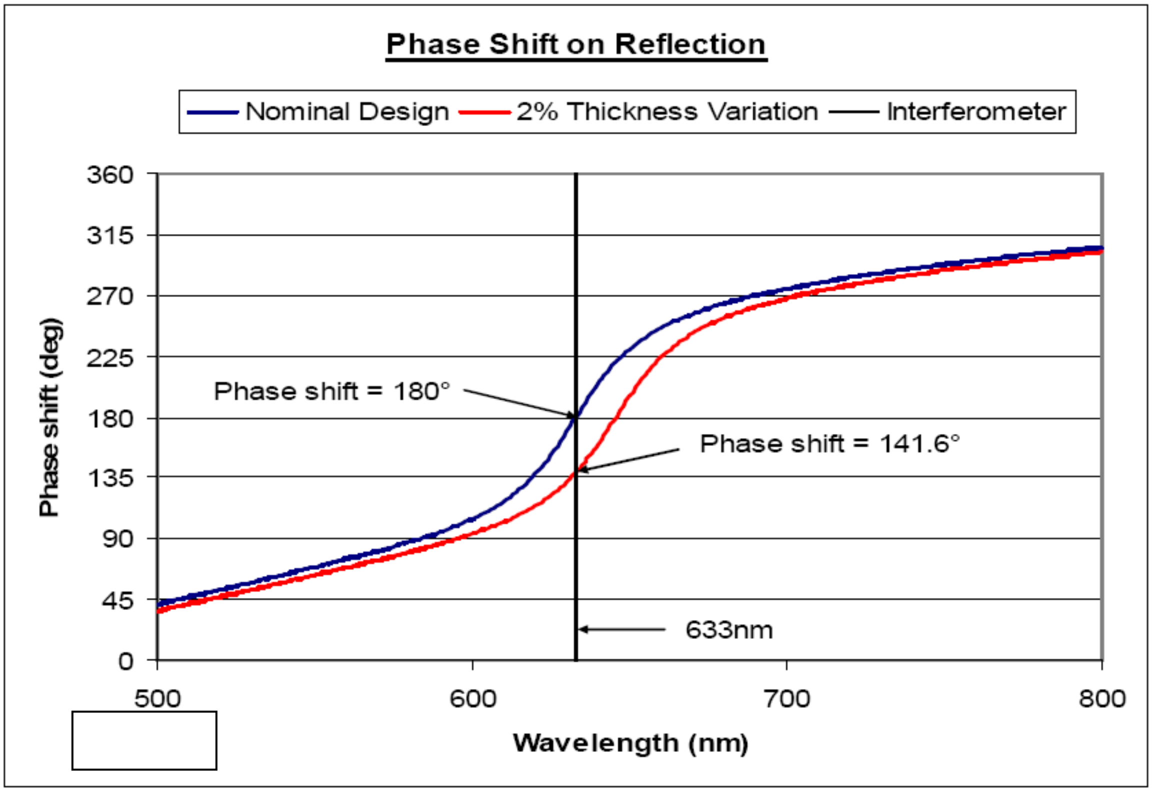

Figure 1

In this particular case, if a point at the lens edge has the nominal coating thickness and the coating at lens center is 2% thicker, expect ~38° phase difference in the measurement (~0.1 waves). This will erroneous be seen as height by the interferometer, despite the actual height change in this case being less than 7nm (~0.01 waves). Also, depending on coating design, low fringe visibility may inhibit measurements.

There is an extreme method to determine the irregularity of a thin-film interference coated surface by flash coating it with a bare metal mirror coating. A metal mirror coating is not a thin-film interference coating, and the surface of the mirror represents the true surface, This relatively expensive process requires extra time, handling, and potential damage during the metal coating chemical strip process.

CONCLUSIONS

- There can be practical limitations to getting accurate surface form data on coated optical surfaces due to issues with phase distortion and fringe visibility.
- The issues are a function of thin film coating design particulars and the actual deposition processes.

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[1] R.E. Fischer, B. Tadic-Galeb, P. Yoder, *Optical System Design*, Pg 340, McGraw Hill, New York City, 2008
[2] H.H. Karow, *Fabrication Methods For Precision Optics*, Pg 656, John Wiley & Sons, New York City, 1993
[3] MetroPro Reference Guide OMP-0347J, Page 7-1, Zygo Corporation, Middlefield, Connecticut, 2004
[4] H.A. Macleod, *Thin Film Optical Filters*, Chapter 11: Layer uniformity and thickness monitoring, The Institute of Physics Publishing, 2001.
[5] R.E. Fischer, B. Tadic-Galeb, P. Yoder, *Optical System Design*, Pg 581, McGraw Hill, New York City, 2008