Simple Ion Beam Solutions

IBAD coatings: Tracking Uniformity Changes

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For batch coating tools such as the Techne dual ion beam deposition system, reproducible run-to-run performance is expected. One key performance metric is the uniformity of the coating produced. With motivation to ensure process stability, this article will discuss a method for tracking changes in the uniformity, or drift. Examples are presented and discussed.

Introduction

Ion beam sputter deposition with an assist ion beam has been used in industry for years to produce dielectric coatings used for optical devices [1-3]. A dual ion beam system utilizes two sources as depicted in Figure 1. One ion beam source (deposition source) is directed at a target material to be sputtered. The system geometry is designed so the sputtered target material arrives at the substrates while ions from the second source (assist source) are also arriving. This paper will examine and discuss the substrates being coated.

In order to produce uniform coatings with an IBAD tool, some machines will utilize a planetary type fixture for substrate manipulation. Small substrates are loaded onto planet holders which are in turn mounted to a hub. The hub revolves around a sun gear which forces the planets to simultaneously orbit and rotate. The gearing is selected so planetary position does not repeat for several cycles.

The motion of the planetary substrate holder will then average the arriving sputtered material. Coating produced on a planetary may be sufficiently uniform for many applications. For others, shadow masking may be used to further improve the uniformity of the coatings or maximize production yields.

A common definition for coating uniformity is presented in Equation 1, where t_{MAX} and t_{MIN} are the maximum and minimum coating physical thickness for a given coated area, respectively [4]. Instead of thickness, center wavelength (λ) maximum and minimum could also be used for optical filters (Equation 2). A typical uniformity specification for a planetary fixture is ±0.5 % over the planet's diameter.

$$Uniformity = 100 \cdot \left(\frac{t_{MAX} - t_{MIN}}{t_{MAX} + t_{MIN}}\right) \; [\pm\%] \; (1)$$

or

$$Uniformity = 100 \cdot \left(\frac{\lambda_{MAX} - \lambda_{MIN}}{\lambda_{MAX} + \lambda_{MIN}}\right) \; [\pm\%] \; (2)$$

Equations 1 and 2 describe the magnitude of the uniformity but fail to describe how the thickness (or wavelength) varies over the planet from run to run.

Approach

In practice, the thickness (or wavelength) is typically measured from the center of the planet out to a specific radius with specific intervals (generally, azimuthal symmetry is assumed and should be verified). As an example, data in Figure 1 show the center wavelength of filters deposited on three consecutive runs on a Techne system. Center wavelength is plotted from the center of the planet (radius = 0) to the just beyond the planet edge (radius = 90 mm) every 10 mm. The uniformity for these data is presented in Table 1.

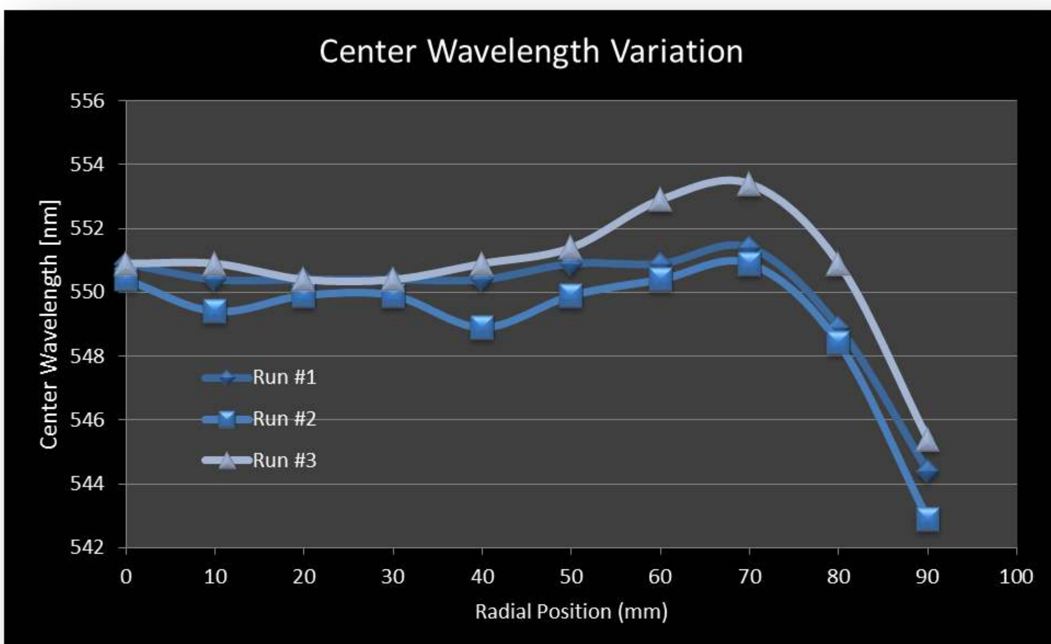

Figure 1. Planetary center wavelength data from 3 consecutive runs.

Run	Uniformity to 80 mm
1	± 0.23%
2	± 0.23%
3	± 0.27%

Table 1. Uniformity of data in Figure 1 using Equation 2.

The uniformity for Runs 1 and 2 is the same, however, the center wavelength curve in Figure 1 is slightly different. In other words, the curve is slightly different for each run, but the uniformity does not indicate change.

To quantify how much the center wavelength curves are evolving, each data point on the curve can be compared to the same data point on the curve from the previous run. For example, let x_i represent the normalized center wavelength at a given radial location. Let x_i' represent the normalized center wavelength at the same radial location but on the next run. We can then implement a root mean square difference approach as defined by Equation 3 to determine the difference or drift in profiles. By squaring the difference between the two points (which eliminates cancelation) and averaging over the number of data points (N), the magnitude of drift (D_{rms}) between the two curves can be obtained.

$$D_{rms} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - x_i')^2}{N}} \quad (3)$$

To illustrate how to implement Equation 3, first, the data in Figure 1 are normalized with respect to their average center wavelength. For each run, the average wavelength is nearly 550 nm and the normalized data are shown in Figure 2. The data values in Figure 2 are in Table 2 which also illustrates how the steps are performed to estimate drift (D_{rms}).

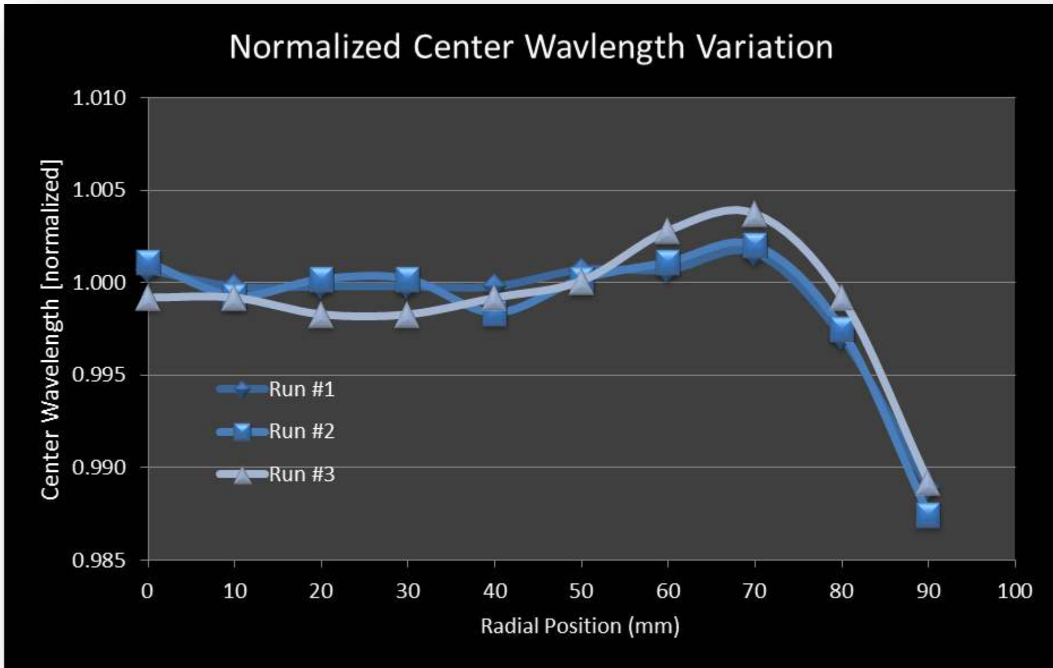

Figure 2. Data from Figure 1 normalized using average center wavelength.

Radial position (i) [mm]	Run 1	Run 2	Run 3	Run 2-1 $(x_i - x_i')^2$	Run 3-2 $(x_i - x_i')^2$	D_{rms}
0	1.00071	1.00111	0.99919	1.64E-07	3.68E-06	0.14%
10	0.99980	0.99929	0.99919	2.56E-07	9.76E-09	0.04%
20	0.99980	1.00020	0.99829	1.63E-07	3.67E-06	0.14%
30	0.99980	1.00020	0.99829	1.63E-07	3.67E-06	0.14%
40	0.99980	0.99838	0.99919	2.00E-06	6.57E-07	0.12%
50	1.00071	1.00020	1.00010	2.54E-07	1.03E-08	0.04%
60	1.00071	1.00111	1.00282	1.64E-07	2.92E-06	0.12%
70	1.00161	1.00202	1.00373	1.65E-07	2.91E-06	0.12%
80	0.99707	0.99747	0.99919	1.60E-07	2.96E-06	0.12%
D_{rms}				0.06%	0.15%	

Table 2. Data points from Figure 2 and calculation of D_{rms}.

Note that drift (D_{rms}) can be estimated for either a comparison between runs or for a given radial location. For example, the difference between Runs 2 and 1 requires summing and averaging data in column 5 then taking the square root so D_{rms} is 0.06%. Similarly, D_{rms} at a given radial location can be estimated summing and averaging data in a row. For example, D_{rms} is 0.04% at radial locations 10 and 50 mm.

Precision and Interpretation

For the example above, the original data was limited to a measurement precision of ±0.5 nm implying 3 significant figures are reasonable. This limitation results in very similar values for x_i and D_{rms} observed in Table 2. For the data in Figure 1, a 0.5 nm shift is about the same as drift of 0.09%. Improvements with measurement precision would provide better resolution.

The root mean square allows for a comparison between runs or radial locations. In Table 2, the drift between wavelength profiles from Runs 1 and 2 is 0.06% (less than the measurement precision). The drift between Runs 2 and 3 is 0.15%. For radial location comparisons, more runs should be utilized to improve statistical significance. In any case, it should be noted that D_{rms} will always be positive for any comparison examined and the larger the percentage, the more change has taken place.

Case Studies

Next, a quick demonstration of using drift (D_{rms}) values to monitor uniformity changes is presented in Figures 3 and 4. For these plots, 8 back-to-back runs were performed on the Techne system. After each run, center wavelength data were measured (similar to Figure 1) and the uniformity and drift values calculated. Figure 3 shows the uniformity improving after the first run, but the drift starts to increase with the last few runs. Drift with radius is plotted in Figure 4 which shows minimal change after 8 runs near 40 to 50 mm.

Drift calculations/measurements offer another tool for monitoring the stability of an IBAD system such as the Techne. Investigations into how drift is affected with changes to system hardware (e.g. cleaning of grids, aging of targets, planetary wobble) are planned.

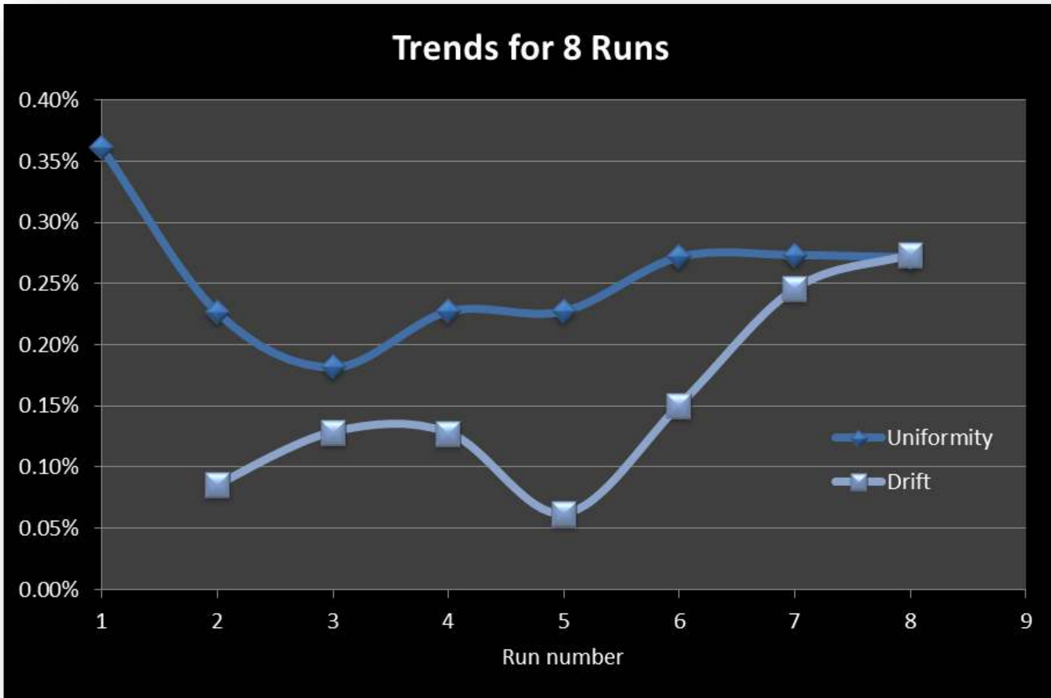

Figure 3. Uniformity and drift data for 8 back to back runs.

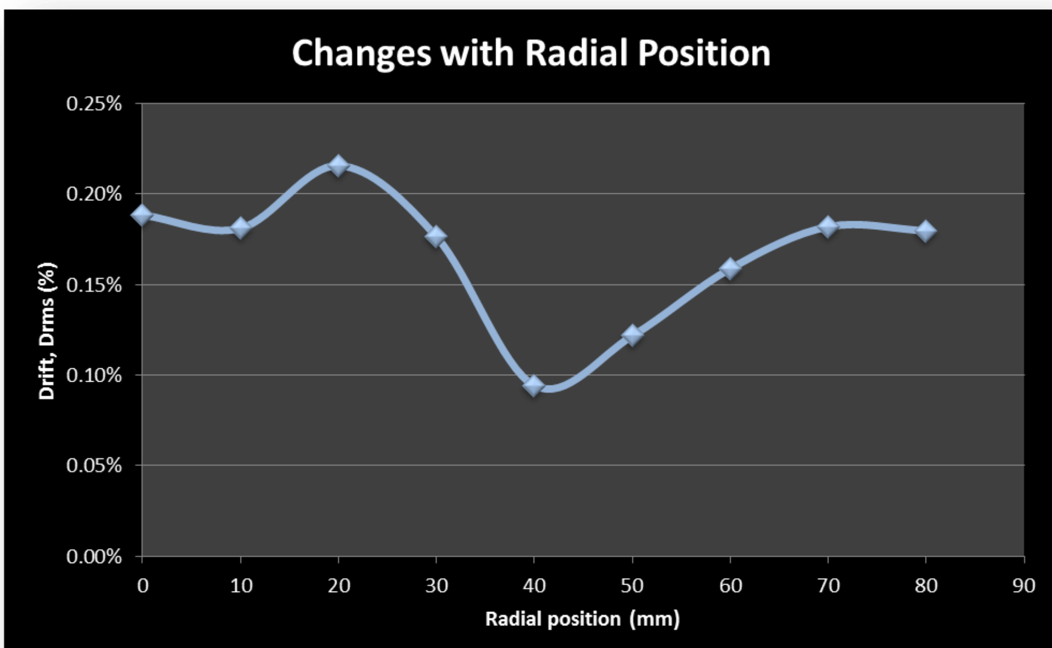

Figure 4. Drift data for planetary radial positions for 8 runs.

Conclusions

This article discussed the method for calculating the root mean square difference between two profiles used to determine uniformity. An equation for drift (D_{rms}) was presented with examples. A few case studies were also shown. It is hoped drift calculations offer another tool for monitoring the stability of an IBAD system such as the Techne. Future investigations are planned.

References

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