Characterization of an In-Situ Interferometry Setup for the APS Modular Deposition System

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Abstract

A Modular Deposition System is being commissioned at the Advanced Photon Source (APS) at Argonne, with the aim to develop and fabricate next generation thin film optics for APS beamlines. This sophisticated sputtering system incorporates advanced in-situ metrology and ion beam figuring capabilities for figure correction of mirrors and substrates up to 1.4 long. In-situ metrology will allow the system's operator to monitor the surface quality of an optic after each predefined number of successive coating and figure-correction steps without removing it out of the vacuum chamber so as not to compromise the mirror in-situ mounting and positioning accuracy. To this end the system is designed around a high speed interferometer with the reference mirror mounted on an in-house designed gimbal, which is located inside the vacuum chamber. Because the measurements must be done through a vacuum window, the question arises on the impact of such a window on the measurement data, especially when the mirror surface is tilted relative to the window or the windows becomes curved under the force exerted by the differential pressure. This project focuses on building an experimental setup to test the effect of the vacuum window at atmospheric pressure. These tests and measurements will provide details on how to mitigate these undesired effects.

The Advanced Photon Source

The Advanced Photon Source (APS) is a premier national research facility that provides high energy x-ray beams to over 5,000 scientists from around the world. X-ray based experiments encompass a broad swath of subjects including material science, biological imaging, and experimental physics.

The future APS upgrade will provide x-ray beams with unprecedented low emittance; a factor of about 50 improvement with coherent flux about 2 to 3 orders of magnitude higher compared to the APS today [1]. To preserve the intrinsic properties and coherence of these x-ray beams will require mirrors and thin film optics with unprecedented quality. For example, mirrors for <1 nm figure error and <0.15 nm surface roughness may be required. There are many experiments that require x-ray beams to have high spatial coherence for imaging and microscopy applications. Although x-ray mirror fabrication techniques continue to evolve, more progress is needed in metrology before the needs of the new generation x-ray light sources can be met [2].

The APS Modular Deposition System

To support the APS Upgrade Project and its future operations, the APS X-ray Science Division (XSD) Optics Group has commissioned an advanced modular deposition system (MDS) to develop advanced thin film optics including single and multilayer mirrors, 3-D thin film optics, and focusing mirrors. An in-vacuum DC brushless servo drive will provide precision positioning at 1nm resolutions over 4 meters. The MDS will be the world’s first thin-film deposition system with in-situ metrology and ion beam figuring (IBF) for 1.5 m mirrors [3]. Through the combination of the vacuum chamber, IBF, in-situ metrology, and deposition, the MDS will be capable of developing next generation x-ray mirrors.

For the in-situ metrology setup, a railing system moves the optical plate from the high speed interferometer to the IBF gun (shown in Figure 1).

Fig. 1: The APS Modular Deposition System

Mirror Figure Correction Using In-situ Ion Beam Figuring and In-situ Metrology

Within the vacuum chamber, the APS has integrated an in-situ interferometer which features high frame-rate collection speed. The MDS uses the ion beam figuring technique (IBF) to remove excess material from an optical substrate. IBF is a high precision technique used as the last step in x-ray mirror fabrication to remove smaller surface errors on the sub-nanometer scale [4]. This technique derives itself from the concept of sputtering which involves colliding ions with the surface atoms of the optic [5]. By using the IBF gun, the surface of an optic is deterministically eroded until the surface figure error is within tolerance. The erosion rate will depend on many environmental parameters, such as IBF system power, gas flow rate, and so forth. The basic process (shown in Figure 2) of correcting the figure of a mirror starts with measuring its surface using in-situ metrology. The measurement will detail a certain figure error, and if it is outside the threshold, it will need to be corrected using IBF. After one iteration of figure correction, the mirror is measured again, and if the figure error is within the threshold the figure correction process is complete. The process may require several iterations between metrology and figuring before a desirable result is achieved. An example image of an optic before and after undergoing IBF is shown below in figure 3.

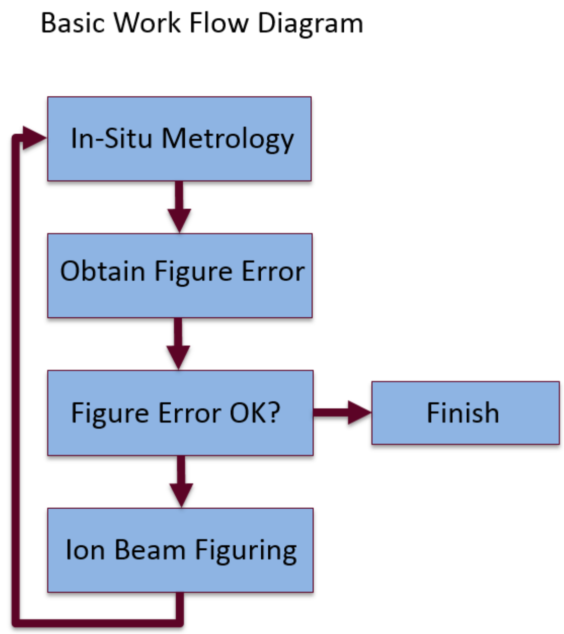

Fig. 2: Basic figure correction process

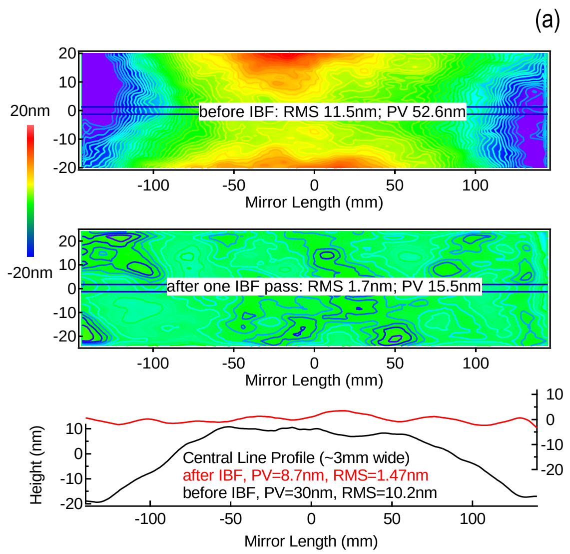

Fig. 3: Example mirror figure correction. R. Conley, "APS Deposition System", Argonne National Laboratory, 2016.

Because the mirror surface measurements must be done through a vacuum window, the question arises on the impact of such a window on the measurement data, especially when the mirror surface is tilted relative to the window or the windows becomes curved under the force exerted by the differential pressure. The present work focuses on building a test setup to evaluate the effect of the vacuum window at atmospheric pressure. The performed measurements will provide details on how to mitigate these observed effects, if any.

Experiment Setup

Preliminary tests to study the effect of the vacuum chamber window (VCW) were carried out in the APS metrology laboratory. Measurements were performed both in vacuum using a test chamber and at atmospheric pressure. Due to the modular deposition system being under construction, the present work focuses on measurements at atmospheric pressure using the setup (shown in Figures 4a and 4b). This setup consisted of a 100 mm x 20 mm x 20 mm Silicon mirror as the surface under test (SUT), a 20% reflective optic acting as the TF and a 4% reflective optic acting as the VCW.

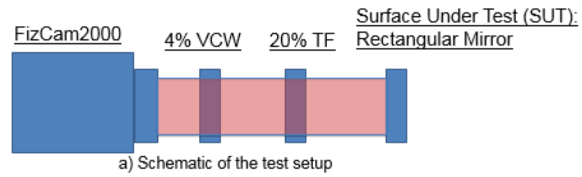

Fig. 4a: Schematic of the stationary setup

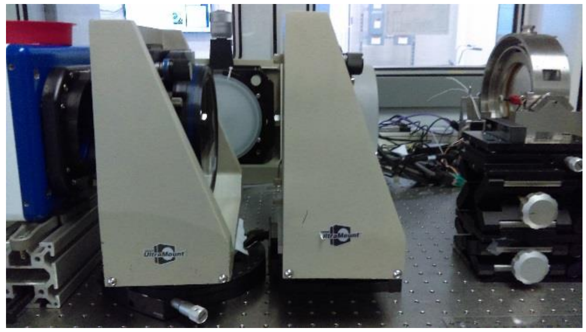

Fig. 4b (From left to right): FizCam2000, VCW, TF, SUT (Image of real setup)

Measurements

Several types of measurements were taken in various setups including stationary measurements with and without the vacuum chamber window and tilt measurements at different angles. Stationary measurements were taken to gauge the stability of the system. Tilt measurements were taken in order to observe the effect of tilting the vacuum chamber window.

The purpose of the stationary measurements is to get an idea of the systematic errors and gauge overall setup stability. “Stationary” in this context is defined as the processing of measurements without altering any component in the setup. In order to verify the stability of the setup (shown in Figures 5a and 5b), a series of 5 stationary measurements were taken in 1 minute increments for 2 scenarios: setup with VCW and setup without VCW. All difference subtractions were taken with respect to one another and were compiled into two sets of graphs to compare the shapes of the measurements with each other (shown in Figures 6a and 6b). Observations of the shapes of the measurements in the graphs show that they are quite similar to each other with minimal differences.

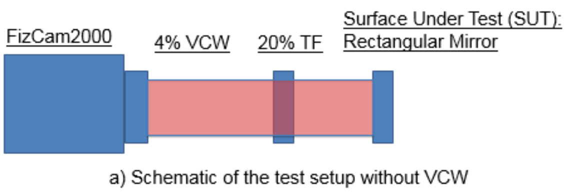

Fig. 5a: Schematic of stationary setup without VCW

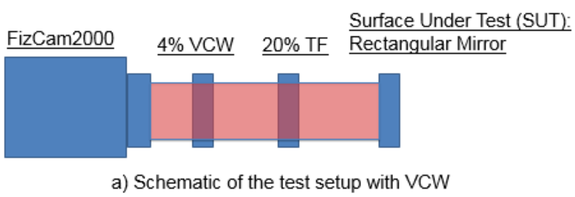

Fig. 5b: Schematic of stationary setup with VCW

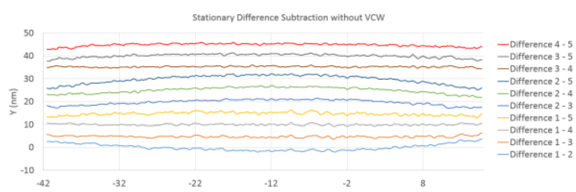

Fig. 6a: Stationary Difference Subtraction without VCW

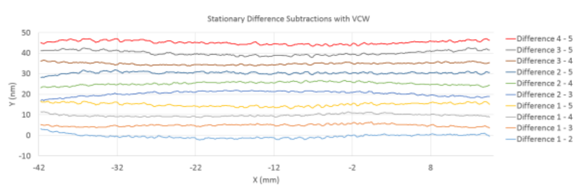

Fig. 6b: Stationary Difference Subtraction with VCW

Measurements up to this point have dealt with the vacuum chamber window at normal incident to the FizCam2000. However, it is also worth investigating the effect of tilting the vacuum chamber window at various angles (schematic shown in Figure 7) as a way to determine the level of aberrations introduced by the VCW. Since the FizCam2000 technology relies on spatial phase shift interferometry to obtain quick phase-shift measurements, the system centers around a pixelated mask with each pixel containing a unique phase shift [6]. In order to exclusively interrogate measurement errors due to the variation in optical path of the optics in the beam path and exclude measurement errors that are caused by refractory shift of light onto neighboring pixels in the interferometer, all measurements were taken where the VCW tilt angle maintains the optical path within individual pixels. The tilt angle that was found to limit the beam span to no more than one pixel (100 microns) was 1.81°. Step sizes of 0.36° were taken and difference subtractions were used to observe the difference in profiles with respect to 0°.

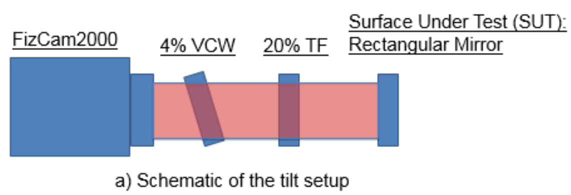

Fig. 7: Schematic of the VCW tilt setup

Ideally, difference subtractions should result in a line profile of 0, but actual measurements are affected by measurement noise as well as by systematic errors due to the interferometer optical system aberrations and ray trace errors.

Results and Discussion

One of the methods used to evaluate the effect of the vacuum chamber window was to do a difference subtraction between the setup with and without the vacuum chamber window while it was positioned at normal incidence, or 0° to the FizCam2000.

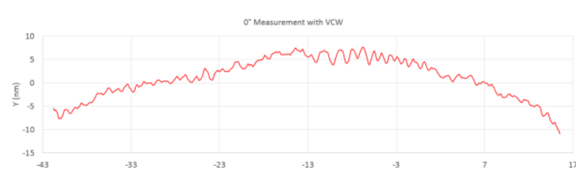

Fig. 8a: Measurement taken with VCW at normal incidence (0°), RMS = 20.55 nm

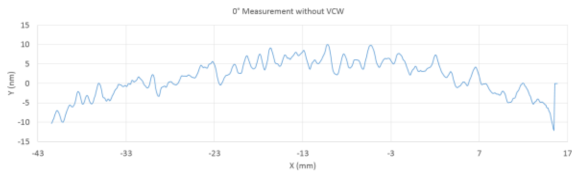

Fig. 8b: Measurement taken without VCW at normal incidence (0°), RMS = 20.52 nm

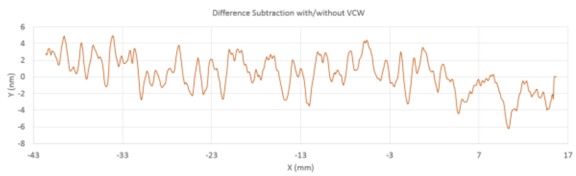

Fig. 8c: Difference subtraction profile, RMS = 1.7 nm

The difference profile came out to have an RMS value of about 1.7 nm; a reasonable value when one considers the fluctuations present in an atmospheric pressure setup.

The data for the vacuum chamber window tilt measurements was also compiled into two different graphs showing the measurements that were taken and the difference subtractions between those measurements with respect to 0° along with their respective RMS values (shown in Figures 9a, 9b, 9c, and 9d).

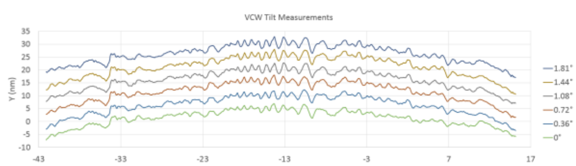

Fig. 9a: Graph of VCW Tilt Measurements

Tilt	RMS (nm)
1.81°	3.088
1.44°	3.405
1.08°	3.052
0.72°	3.128
0.36°	3.229
0°	3.095

Fig. 9b: Table of RMS values with respect to the tilt angle

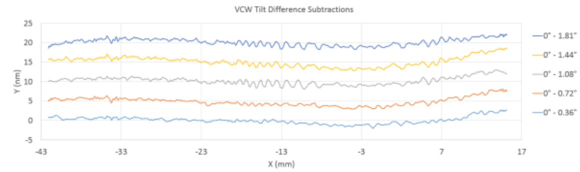

Fig. 9c: Graph of VCW Tilt Difference Subtractions with respect to 0°

Line Subtraction #	RMS (nm)
0° - 1.81°	0.676
0° - 1.44°	0.888
0° - 1.08°	0.784
0° - 0.72°	0.808
0° - 0.36°	0.678

Fig. 9d: Table of RMS values with respect to the line subtraction number

The data analyzed from the tilt measurements and differences seems to show that there is a similarity among the different positions of the vacuum chamber window. The shapes of these measurements also seem to be similar to each other as seen by their RMS values. This could suggest that the VCW has negligible effect on the measurement. Any minimal contribution to the measurements could be coming from various environmental factors such as air turbulence or temperature.

Conclusion and Future Plans

The results of the experimental data suggest that the vacuum chamber window has negligible effect on the measurement of the surface under test. This finding paves the way towards design of an in-situ metrology instrument for mirror figuring.

Due to the limited amount of time for this project, the work could not be completed. Further experimenting will need to be conducted in order to verify this finding. The present experiment did not include variations in the setup such as a different environment (i.e vacuum chamber) or different types of mirrors (i.e curved surfaces). Future tests will be conducted in the MDS actual vacuum chamber to obtain more representative results. The reference flat will then mounted inside the vacuum chamber using in-house designed gimbal. This will provide more a more accurate evaluation of the actual setup.

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