# The NSLS-II Multilayer Laue Lens Deposition System

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## ABSTRACT

The NSLS-II[1] program has a requirement for an unprecedented level of x-ray nanofocusing and has selected the wedged multilayer Laue lens[2,3] (MLL) as the optic of choice to meet this goal. In order to fabricate the MLL a deposition system capable of depositing depth-graded and laterally-graded multilayers with precise thickness control over many thousands of layers, with total film growth in one run up to 100μm thick or greater is required. This machine design expounds on the positive features of a rotary deposition system[4] constructed previously for MLLs and will contain multiple stationary, horizontally-oriented magnetron sources. A transport will move a substrate back and forth in a linear fashion over shaped apertures at well-defined velocities to affect a multilayer coating.

**Keywords:** thin film, multilayer, Laue lens, sputter, deposition, x-ray, optics

## 1. INTRODUCTION

The NSLS-II MLL deposition system was designed specifically to address the challenges encountered in the growth of laterally-graded and depth-graded multilayers for application in transmission geometry as linear zone-plates. MLLs are fabricated by magnetron sputter deposition onto small silicon blanks. They consist of many thousands of layers (with a total growth thickness goal of about 100 microns) with a depth thickness that is graded according to the zone-plate law, and whose lateral gradient is twice the focal length of the MLL.

## 2. WEDGED MULTILAYER LAUE LENS DEPOSITION SYSTEM OVERVIEW

The system is a cryopumped linear deposition system comprised of five 304 series electropolished stainless steel sub-chambers of 23 feet total length. These five chambers consist of two 14" dia., 5' long gun chambers on either side of a smaller 2' long center chamber, and two 14" dia., 4' long chambers on each end as shown in Fig. 1. Substrates are loaded onto a linear-translation stage (referred to as the car) that moves one-dimensionally back and forth throughout the vacuum system, riding on a stationary base and rail assembly. This car is capable of passing over the gate-valve into the load-lock chamber by disconnecting from the process-chamber base and feeding into the load-lock via a dual axis friction-belt/gear rack setup. Once the load-lock is vented, the car may be hand-loaded onto a simple trolley (with dimensions identical to the main chamber rail) to completely remove it from the deposition system

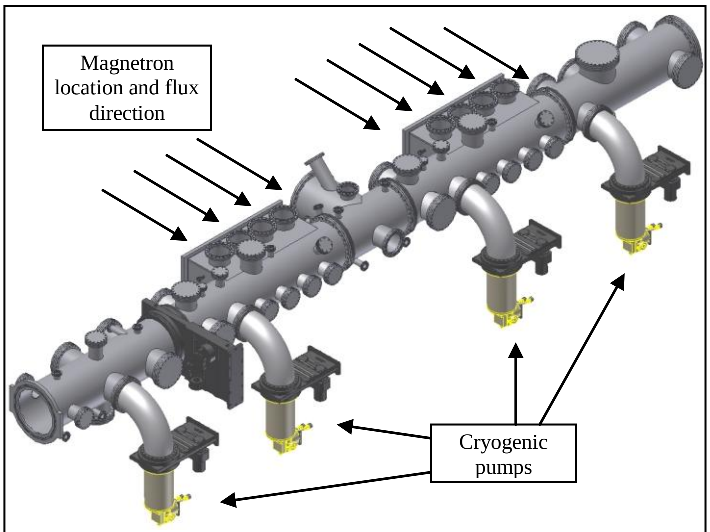

Fig. 1. NSLS-II multilayer Laue lens deposition system

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and into an adjacent class 10 clean-hood for substrate removal or mounting. The centrally-located analysis chamber contains multiple ports intended for in-situ measurement, including a normal-incidence port for use of a laser-based curvature measurement system capable of film stress measurement[5].

## 3. LINEAR-DRIVE SYSTEM AND BASE ASSEMBLY

A key component of the deposition system is the linear substrate translation assembly. A one-piece, precision ground base plate of about 15 feet in length is held independently of the vacuum chamber walls through pins to the exterior support frame via flexible bellows. This design allows the entire motion system to maintain alignment and position without any influence by the inevitable vacuum chamber compression and flex during multiple pump-down cycles and process runs. In order to further maintain planarity in the linear drive system this base rail contains multiple liquid cooling channels that pass through the chamber walls and run the entire length of the rail which will be circulated by a precision chiller. Fixed to this base plate are two sets of recirculating ball guides, with a full-length stationary linear motor magnet channel and high-bandwidth optical encoder. A representative drawing is provided in Fig. 2. The drive system will provide a linear speed range of between 0.01 inches/sec (250 μm/sec) and 9 inches/sec (230 mm/sec), with a maximum acceleration of at least 5 inches/sec$^2$ (127 mm/sec$^2$). More importantly, the substrate stage linear velocity at any speed and position over the 32” wide magnetron area in both gun chambers is expected to be repeatable to within 0.01%. As this is a multilayer coating system, maintaining smooth, reliable substrate velocity is more important than absolute positioning accuracy (in other words, $\Delta V > \Delta X$). This design allows for programmable and reversible linear motion of hundreds of thousands of cycles per MLL growth run. A capability to program the drive system where each 1-mm of position may have a set, different velocity (a velocity map) will allow large, laterally-graded multilayers to be produced. Future use of substrate voltage biasing (non-plasma generating) is anticipated; therefore, the entire vertical substrate plate is electrically insulated by ceramic interconnects.

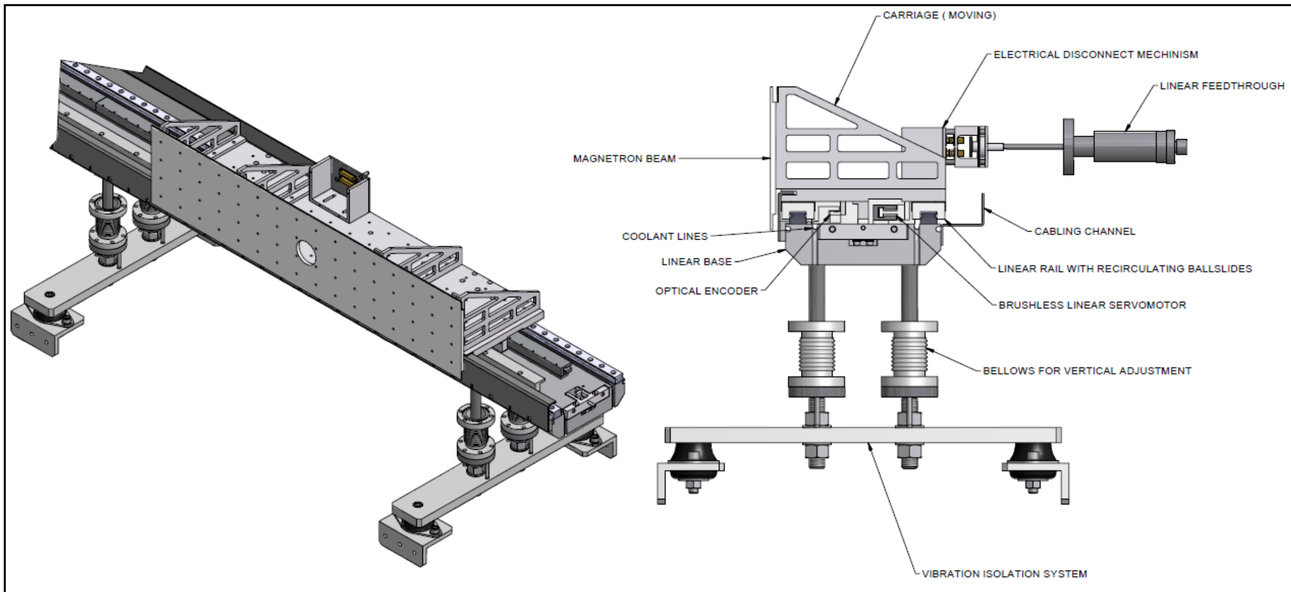


Fig. 2. Linear drive system and base assembly

## 4. MAGNETRON SOURCES AND POWER SUPPLIES

In order to affect a multilayer growth of thousands of layers and up to 100 microns of total growth, a procedure for automatic growth without breaking vacuum or perturbing the plasma with accumulated film flaking has been developed in which eight main magnetrons are used sequentially to grow each successive layer in the stack. This method has the positive attribute of only requiring *1/x* total film growth from *x* amount of magnetrons. This leads to a corresponding reduction in growth rate decay due to target erosion, reduced thermal loading per magnetron, and, the potential ability to grow a much thicker multilayer onto a single substrate before accumulated film flaking starts perturbing the plasma, causing disruptions in the layering. An important consideration regarding this method is that each magnetron will require independent growth rate calibration; it is expected that each MLL growth will have a periodic error (although expected to be exceedingly small) which repeats every n layers. An example inverse d-spacing plot is shown in Fig. 3 with greatly exaggerated magnetron-to-magnetron growth rate error where the Fresnel zone plate law is still fulfilled.

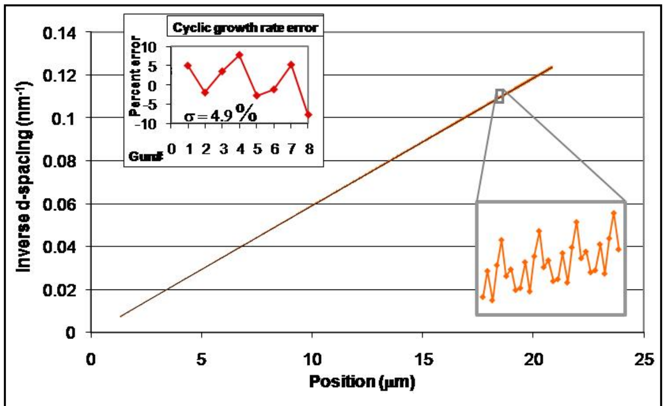

Fig. 3. Multi-gun inverse d-spacing simulation

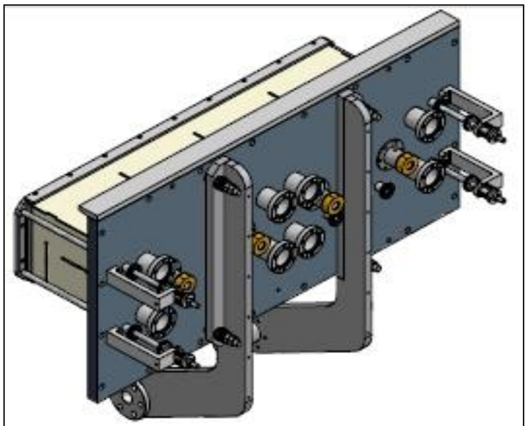
Fig. 4. Magnetron door and mask frame

For the machine under development, a total of eight main magnetrons were chosen as an appropriate amount in order to reach a compromise between system complexity, cost, and MLL growth requirements. Four magnetron sources are mounted in line on each door of the two 5’ gun chambers. The magnetrons must sputter horizontally inwards onto substrates held vertically on the linear translation stage. These doors feature differentially-pumped o-ring seals both around the perimeter and for all magnetron penetrations. To allow for optimum flexibility, the door framing and door combination may be extracted from the deposition system to allow for better access to the underside of the gun chambers or in order to perform work or modifications to the magnetron doors in the future. As shown in Fig. 3, an aluminum square shroud is rigidly attached to the door, and an adjustable frame to secure a figured-mask for growth of profiled film gradients[6] is positioned just around the outside of this square shroud and provides 6 degrees of freedom in order to compensate for any non-co planarity between the linear translation system and the single-piece invar mask. A ninth magnetron, located in the landing chamber, is intended for growth of a central zone compensation layer, described below.

The magnetrons are SunSource[7] stationary magnet direct-gas injection and are for use with three-inch diameter, 0.25” thick targets. Two 1kW (1kV, 1A typical) DC supplies are backed with a pulsing unit, such that the magnetrons may be operated in either standard DC mode, arc-suppression mode, or 20 kHz pulsing mode. Supply power, voltage, current, arc events, and total integrated energy output are read and logged by the system PC or otherwise derived. RF power relays are configured in two banks enabling each supply set to operate any of the two sets of magnetrons (four magnetrons for one set, and five for the other set)

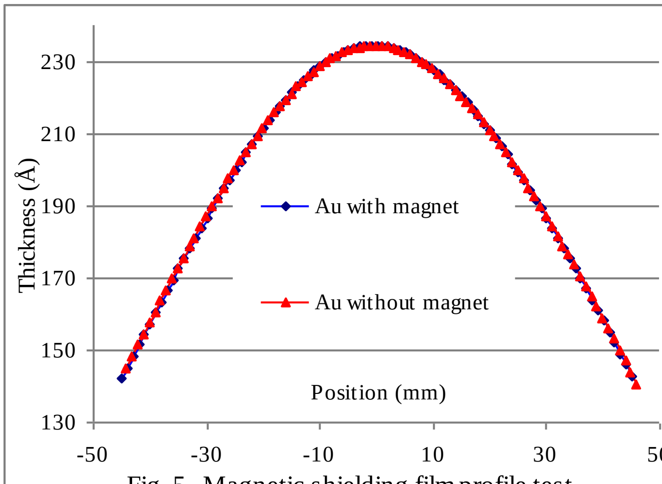

Fig. 5. Magnetic shielding film profile test

The in-vacuum linear motor system is expected to provide the most appropriate motion platform; However, serious concern revolved around potential conflicts between using both magnetron deposition sources and the in-vacuum linear motor. The linear drive system has a variable magnetic field due to the moving dual potted coils, the magnetrons ignite plasma, and in addition, both apparatus possess high strength permanent magnets. In order to fabricate extremely precise laterally profiled coatings, the magnetic field from the magnetrons must remain stable and without any influence from external dynamic fields. Any measurable effect to the magnetron field profile should disrupt the electron raceway or guide the plasma, both of which are critical to film growth. In order to mitigate this effect, the entire linear motor magnetic track is shielded in vacuum with a very high magnetic permeability nickel-iron alloy that is mechanically bent and formed to cover the entire length. In order to maintain permeability, the alloy is annealed after forming. For the deposition system, the linear motor magnetic track is about 200mm away from the substrate face, and another 70mm away from the magnetron face. Two test coatings were executed in a rotary deposition system using an identical direct-gas injection magnetron; one of Au on a stationary Si wafer, and another of Au on a stationary Si wafer with a shielded 300mm length of linear motor magnet directly behind the substrate, at most 2mm away. Both samples were measured with computer-controlled spectroscopic ellipsometry, and found to have identical thickness profile distributions, as shown in Fig. 5.

## 5. PUMPING SYSTEM AND GAS CONTROL

High vacuum pumps are required to pump the vacuum chamber to $2 \times 10^{-8}$ Torr within 16 hrs. To achieve this, four 3,000 l/s (air pumping speed) cryogenic pumps are used; one mounted on each gun chamber, one mounted on the load-lock chamber, and one mounted on the landing-chamber. Two types of cryopump isolation valves are available; the landing zone and load-lock chamber valves are three position type, and the gun chamber pump valves are "infinite position" type pressure controlling gate valves with capability to run in either closed-loop downstream gas control mode, or as simple throttling valves. Long sweep 90 degree elbows, as shown in Fig. 1., are intended to provide some level of protection to the valves and pumps from stray deposition accumulation from the extremely thick multilayer growths.

As the magnetrons are the direct gas-injection type, each of the 9 magnetrons has a corresponding single mass flow controller to ensure identical flow volume for each magnetron. Normal deposition will occur with the chamber pressure feedback controlled upstream by a thermally-stabilized MKS Baratron capacitance manometer.

## 6. CONCLUSIONS

The new NSLS-II multilayer Laue lens deposition system has been designed from the beginning as a unique machine for fabrication of entirely new advanced x-ray optics. The growth process has a high probability for success and the system will also prove useful for a variety of other types of multilayer and single layer coatings in support of the new synchrotron. The in-vacuum linear motion system is very aggressive, and thin-film coating tests have proven that with proper shielding a linear motor may be used in conjunction with magnetron sputter deposition with no measureable influence upon each subsystem. Any system environmental drift has been minimized or eliminated through best-effort engineering practices.

## ACKNOWLEDGEMENTS

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