Versatile Shutter Control of Radial Thickness Distribution for Figured Multilayer Fabrication

Tadashi Hatano, Hiroo Umetsu, Minaji Furudate and Masaki Yamamoto

Research Institute for Scientific Measurements, Tohoku University
Katahira 2-1-1, Aobaku, Sendai 980-8577, Japan

Layer thickness of reflecting multilayers for normal incidence soft X-ray imaging mirrors needs to be controlled over the substrate because the angle of incidence at the curved surface is dependent on the radial distance from the optical axis. For the concave mirrors in Schwarzschild configuration, for instance, multilayer period must be about 10% thicker at the edge than at the center. The radial distribution of the deposition rate has been controlled typically by a mask fixed in front of a substrate, where the mask shape was optimized through a trial-and-error method. For the deposition figuring of aspherical mirrors, Oshino et al. [1] proposed a method to fabricate a layer with desired radial thickness distribution of rotational symmetry, in which the deposition shutter is scanned in linear motion at a programmed speed in front of a rotating substrate. This method should be widely adaptable to produce figured mirrors, though the effective deposition rate will be limited to a half of the deposition rate with the shutter opened.

In this report, we present an improved design of a deposition shutter for a better deposition rate using a triangle shaped shutter as shown in fig. 1. The angle of vertex is 60°. The shutter covers the whole substrate at $x = 2R$, where x and R are the position of pointed end of the shutter and the radius of the substrate, respectively. For multilayer fabrication, the deposition materials are switched at this shutter position. The shutter is opened fully at $x = -R$. As the shutter moves from $x = 2R$ to $x = -R$ and vice versa, the deposition rate at a distance r from the center of the substrate, $Y_r(x)$, can be deduced from the exposed fraction at r as a function containing $\arccos(x/2r)$. The thickness distribution $Y(r)$ of a layer is written as

$$Y(r) = 2\int_{-R}^{2R} \frac{Y_r(x)}{v(x)}\,dx + T ,$$

where $v(x)$ is the opening and closing speed and T is the duration of full exposure at the turn. The desired thickness functions $Y(r)$'s for the curved mirrors of various specifications can be obtained by adjusting $v(x)$ and T.

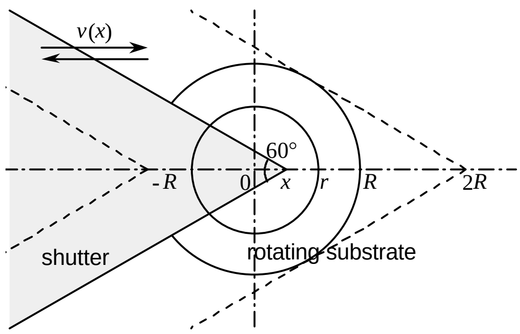

Fig. 1. Schematic illustration of a triangular deposition shutter.

We calculated $v(x)$ and T for coating a Schwarzschild objective with a Mo/Si multilayer for microscopy at a wavelength of 13.5 nm. For a 46 mm diameter concave mirror of a radius of curvature of 50 mm, the maximum speed and acceleration of the linear motion required were both of practical values of 12 mm/sec and 4.2 mm/sec^2, respectively [2]. On the basis of above concept, we are developing an ion beam sputtering apparatus with a programmable shutter and a rotating substrate stage. A conventional pulse motor drive was used to control the shutter in this specification. This system will be also useful to fabricating aspherical mirrors by depositing thick monolayers on spherical surfaces.

[1] T. Oshino, N. Katakura, and K. Murakami: *JSPE Proc. 2nd US-Japan Workshop on Soft X-ray Optics, Yamanaka-ko Nov. 1996*, pp.528-540.
[2] T. Hatano, H. Umetsu and M. Yamamoto: *Proc. 9th Int. Conf. Prod. Eng., Osaka Aug. 1999*, pp.292-297.