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Development of an Ion Beam Sputter Deposition System for Producing Complex-Shaped X-ray Mirrors

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Abstract

We developed a figuring system based on sputter deposition with the aim of establishing a fabrication method for complex-shaped X-ray mirrors. The spatial resolution is essentially determined by the size of the spot profile. In this study, we developed a sputter deposition apparatus using minute pinholes to limit the deposition area, with which deposition spots less than 100 μm in diameter could be produced. Interferometric measurements revealed that surface profiles of the deposition spots were smooth enough to reflect X-rays without scattering.

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Keywords: ion beam sputter deposition; differential deposition; X-ray mirror; numerical controlled processing

1. Introduction

Sputter deposition is a thin film coating technology used to produce high purity and homogeneous films on a substrate. [1,2] One important application of this technology is to produce high-reflection coatings for X-ray mirrors from heavy metals such as Rh, Pt, or Ni. In combination with a substrate-polishing process, sputter deposition can be used to produce an X-ray mirror with a root-mean-square (RMS) roughness of a few angstroms.

In addition to surface coating, figure control is also possible using sputter deposition. Differential deposition has been developed as a method to improve the figure accuracy. [3,4] In this method, a slit is placed in front of the substrate to limit the spatial extent of deposition. Behind the slit, the substrate is translated with a changing velocity to control the thickness profile. The optimum velocity pattern is calculated in advance from the deviations between the measured data and design data for the mirror. For example, in areas where the deviation is large, the substrate is moved slowly to reduce the deviation. Figuring a freeform mirror with a coating thickness of several nanometers is possible with this method because the deposition rate is few nm per minute. [5] Thus, sputter deposition can be used to produce a smooth and precisely figured X-ray mirror surface.

However, conventional differential deposition cannot be used to produce complex-shaped surfaces such as a steeply curved or a discontinuous surface because the width of the deposition spot is a few millimeters. Fabrication with a spatial resolution of higher than 100 μm is a difficult but important issue.

For example, the recently proposed ring-focusing mirror, which can be used to shape an X-ray beam into a ring, has a singular point at the center of the mirror. Although several micromachining processes such as laser machining [6], micro electrical discharge machining (micro EDM) [7], single point diamond turning (SPDT) [8], and focused ion beam machining [9] have been proposed and developed, none of these methods can produce an atomically smooth surface or provide nano-level surface control. Micro-patterning with a shadow mask can generate a deposition spot with a diameter of less than 10 μm; however, this technique has not been applied to differential deposition. [10] A micromachining method with the characteristics of differential deposition has not been reported.

The purpose of this study is to develop a differential deposition method with high spatial resolution on the order of 100 μm. Whereas a millimeter-sized slit is used for conventional differential deposition, we adopt a 50 μm diameter pinhole as a spatial slit to improve the spatial

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resolution to sub-100 μm. This enables the fabrication of a freeform X-ray mirror that is desirable for advanced X-ray optics. In this article, we report the details of our deposition experiments. We produce deposition spots using three pinholes and evaluate the spot size, deposition rate, and micro roughness of the surfaces produced.

2. Deposition apparatus

Figure 1(a) shows a schematic view of our deposition apparatus. During the deposition process, a plate of pure nickel, the surface material of X-ray mirrors, is placed at the center of a vacuum chamber. An ion beam gun at the left side of the chamber is used to sputter the Ni target. Inside the gun, Ar is ionized to Ar^+ and accelerated toward the Ni target. The Ar^+ beam bombards the Ni target and physically removes Ni atoms. Sputtered Ni atoms with high kinetic energy adhere firmly to the substrate.

As shown in Fig. 1(b), a pinhole mask and a substrate are mounted and placed inside the chamber facing the Ni target. The substrate is mounted on a translation stage, which can be driven vertically. The pinhole mask is fixed such that it is separated from the substrate surface by a gap of 100 μm.

The pinhole is made on a SUS plate with a thickness of 100 μm via electrical discharge machining (AE05, Sodick Co., Ltd.). As shown in Fig. 2, three pinholes with diameters of 50 μm, 100 μm, and 200 μm are arranged at 2 mm pitch in the horizontal direction. Three deposition spots are formed under three differently sized pinholes, simultaneously.

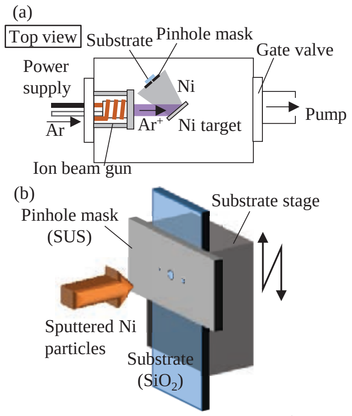

Figure 1. Schematic representation of the deposition apparatus. (a) Top view of the entire apparatus. (b) Enlarged view around the pinhole mask and substrate.

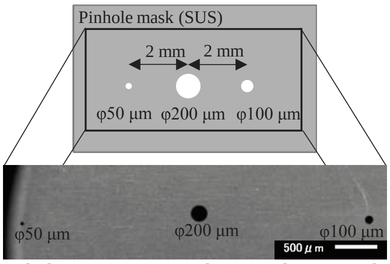

Figure 2. Pinhole arrangement on the SUS plate. From left to right, the diameters of the pinholes are 50 μm, 200 μm, and 100 μm..

3. Experiments

In this study, because the sputtering rate depends on both the Ar flow rate and the acceleration voltage applied to Ar^+, these are the main parameters that need to be controlled. Specifically, the plasma density inside the ion beam gun and the kinetic energy of the ion beam depend on the Ar flow rate and acceleration voltage, respectively. The deposition experiments were carried out under a flow rate of 2 sccm and an acceleration voltage of 1.2 kV. As a preliminary study, we fabricated coatings without the use of a pinhole and confirmed that the AFM roughness (RMS value) of the produced surfaces was a few angstroms.

The purpose of this experiment was to evaluate the figure, deposition rate, and micro-roughness of the deposition spot. The experimental procedure was as follows. First, by changing the position of the substrate stage in 500 μm steps every 30 minutes during the deposition process, three deposition marks were made for every pinhole; we refer to this as Process I. Subsequently, the ion beam gun was shut down and cooled completely. During cooling, the substrate was moved 750 μm, after which the same process (i.e., Process I) was repeated, but in this case is termed Process II. The total number of deposition marks produced on the substrate during Process I and Process II is 18. It should be noted that the difference in the results obtained before and after cooling the ion gun is quite important. The reason is that during the actual figuring process, iteration of the figuring and the measurement is required. In other words, to measure the substrate, the ion beam should be turned off to remove the substrate from the apparatus. Therefore, the data obtained in Process I and Process II should be analyzed together.

We measured the deposition mark using an interferometer. Before the deposition experiment, the substrate surface was coated with Ni to prevent the errors in the interferometry measurement caused by a difference in the refractive indices. The microroughness of the preliminary coated surface was 0.28 nm (RMS).

4. Results and discussion

Figure 3 shows an overview of the interferometry data. The values 50, 100, and 200 μm correspond to the pinhole diameters used to form each deposition spot, which were all formed at their expected positions. In the following discussion, we focus on the deposition shape, deposition rate, and microroughness of the spots.

Cross-sectional profiles of each deposition spot are shown in Fig. 4. The solid and dotted lines correspond to the shapes of the deposition spots formed during Process I and Process II, respectively. In both processes, the full width at half maximum of the deposition spots is 70, 100, and 200 μm (Figs. 4(a)-(c), respectively). We therefore achieved our primary goal of improving the spatial resolution of the differential deposition method to sub-100 μm. The spatial extent of the deposition spots increased with the pinhole diameter.