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Differential deposition for producing microstructure

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ABSTRACT

A local processing method based on sputtering deposition for fabricating microstructure is described. Pinholes (φ50, 100, and 200 μm) are used as a shadow mask to narrow the deposition area. The processing properties can be predicted by a simple numerical simulation. Using this method, the fabrication of an arbitrarily curved surface was demonstrated by controlling the position of the deposition area. The spatial frequency of the figured surface was evaluated to be 100 μm with nanometer-level thickness controllability. In this paper, we introduce the configuration of the apparatus, experimental results, and a numerical simulation of this method.

1. Introduction

Over the decades, various local processing methods have been proposed and developed for the fabrication of microstructures as functional surfaces. The approach to micro-fabrication depends on the principle of processing. In the case of laser machining and focused ion beam figuring, the focusing performance is an important factor, which is characterized by the focal size and intensity uniformity [1,2]. On the other hand, many types of additive manufacturing for micro-fabrication have been developed [3–5].

Sputtering deposition is a commonly used method to coat a metal on the broad surface of a substrate. For this process, a shadow mask patterning was developed as a microfabrication technique. In this method, a shadow mask with a binary micropattern is attached to a substrate with a clearance of 10 μm order. A micropattern is printed on the substrate by deposition through the shadow mask. The deposition-based patterning of a circular or slit pattern with a size of less than 10 μm has been reported [6].

However, shadow mask patterning generates a fixed and binary micropattern which are designed and manufactured on a shadow mask. To make a different pattern, a different shadow mask must be prepared.

Here, we propose a new microfabrication scheme based on sputtering deposition using a pinhole mask. Unlike conventional shadow mask patterning, the substrate is translated along and close to the pinhole mask using motorized xy-stages. A similar method with a mm-sized slit, called "differential deposition" or "profile coating", has been widely applied to produce aspheric surfaces [7,8]. Our aim is to generate a structure with a higher spatial frequency by differential deposition combined with a pinhole shadow mask.

In this paper, we introduce the configuration of the proposed sputtering deposition apparatus and experimental results. The fabrication properties were investigated by performing a simple numerical simulation.

2. Apparatus

We adopted an ion beam gun to sputter a metal target. The ion beam gun consists of a discharge chamber, a radio frequency (RF) coil, and three acceleration carbon grids (Omegatron Co.). Inside the discharge chamber, an RF electric field ionizes the Ar to Ar^+. The produced Ar^+ is accelerated to a sputtering target by a high DC voltage, which is applied to the carbon grids. Fig. 1(a) shows a schematic view of the apparatus. The ion beam is equipped on the left side and the sputtering target is placed at the center of the chamber. We selected a pure nickel plate as the sputtering target. The deposition substrate is placed so that its surface is parallel to the surface of the nickel target. The substrate is fixed to a motorized xy-stage. The pinholes are fixed just in front of the substrate with a clearance of 100 μm orders. The pinholes are made on a stainless-steel (SUS) plate with a thickness of 100 μm. To compare the effect of the pinhole diameter, three pinholes with diameters of 50, 100, and 200 μm were made on a single SUS plate, as shown in Fig. 1(b), using a micro electro discharge machine (Sodick AE-05).

3. Spot deposition marks

We first made spot deposition marks and measured their diameter. The whole surface of the glass substrate was coated with nickel in advance to avoid a defective measurement of white-light interferometer caused by a difference of refractive index. We made six deposition marks for each of the three pinhole sizes, giving a total of 18 spot

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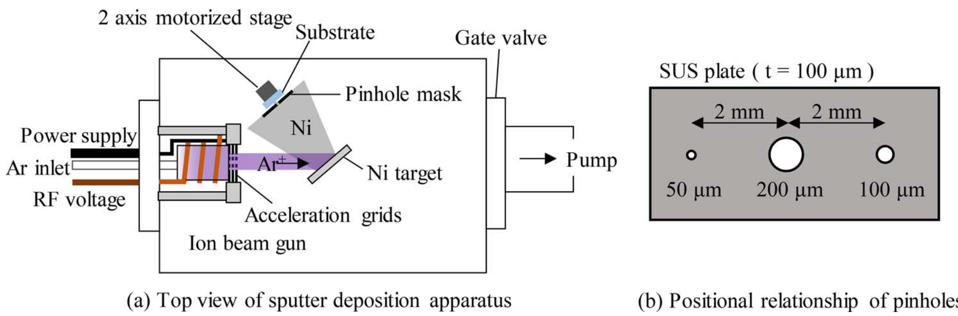

Fig. 1. Schematic view of pinhole deposition apparatus. (a) Overview of apparatus. The ion beam, equipped on the left side of the chamber emits an Ar^+ beam to a Ni target, which is set at the center. Pinholes are used as a shadow mask. The substrate can be translated in two directions by a motorized stage. The ion beam is irradiated on to the sputter target with an incident angle of about 45°. (b) Pinhole mask, which has three pinholes with diameters of 50, 100, and 200 μm.

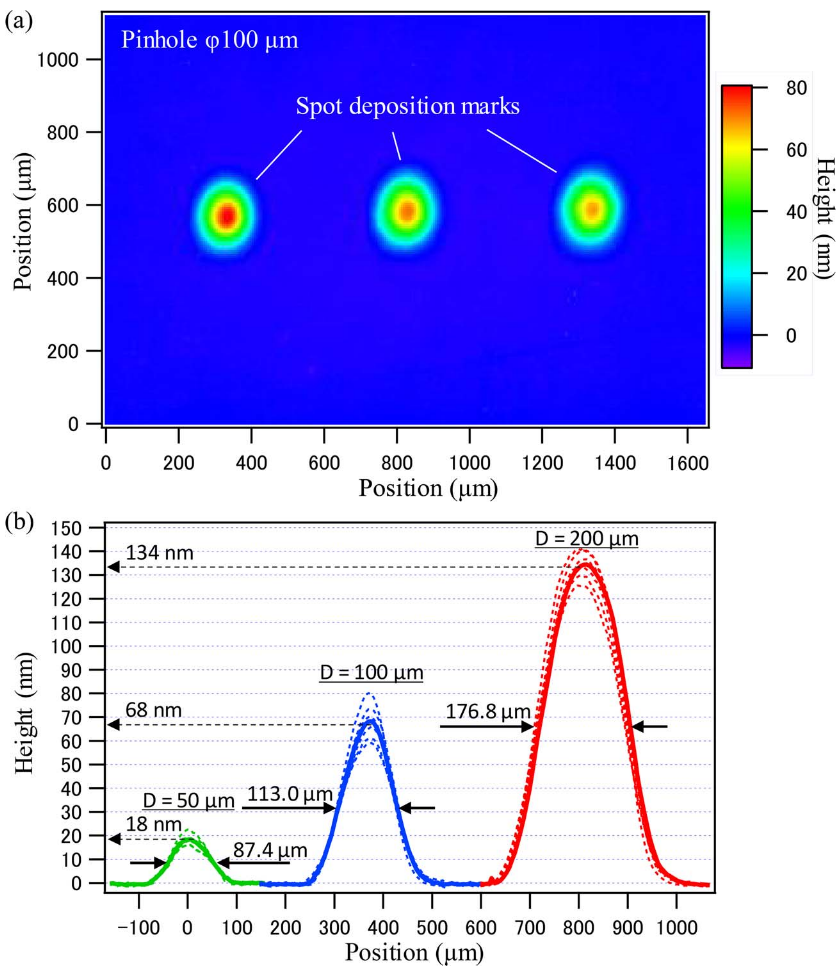

Fig. 2. (a) Measurement of spot deposition marks using white-light interferometer. The red curve is the cross-section profile. (b) Summary of cross-section profiles of spot deposition marks. Each dashed line is a profile of each spot deposition mark, and the solid line indicates the average of the six profiles for each pinhole. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

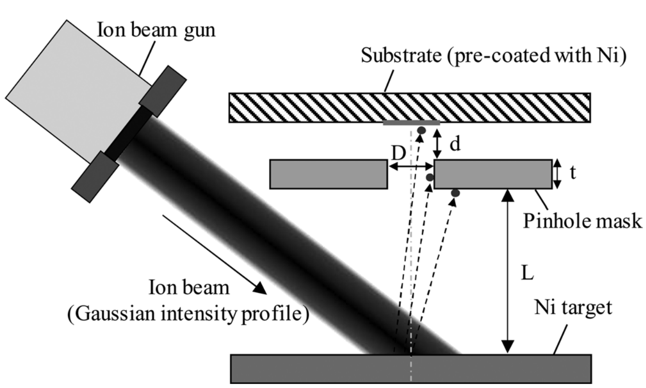

Fig. 3. Geometrical arrangement used for numerical simulation of spot deposition mark.

deposition marks on a single substrate. The shapes of the marks were measured using a white-light interferometer (NewView 700, Zygo). Fig. 2(a) shows measured spot deposition marks made by a φ100 μm pinhole. Fig. 2(b) shows a cross-section profiles of the spot deposition marks. Each dashed line shows a profiles of each deposition mark, and the solid line is the averaged profile. The diameter, defined as the full width at half maximum (FWHM), was 87.4, 113.0, and 176.8 μm when the pinhole size was 50, 100, and 200 μm, respectively. The size of the spot deposition marks clearly depends on the pinhole size. This result indicates that it is possible to generate a surface with a spatial wavelength of 100 μm.

4. Simulation study

The difference in the deposition rates among pinholes originates from the geometrical relationship among the pinholes, the sputtering target, and the substrate. The deposition rates can be calculated on the