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Direct fabrication of microstructures on metal roller using stepped rotating lithography and electroless nickel plating

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A B S T R A C T

Roller embossing has attracted more attention in recent years due to its rapid and continuous process for mass production. The fabrication of roller is a challenge due to microstructures on the curved surface. This paper proposes a method of fabricating roller mold with microstructures on the surface using novel stepped rotating lithography and electroless nickel plating. The results prove that the microstructures can be successfully fabricated onto the metal roller using the proposed procedure. In this study, the roller with micro-grooves whose average height is 1.1 μm and widths are 23 and 45 μm have been successfully fabricated.

1. Introduction

Many kinds of microstructures replication techniques have recently been proposed for the fabrication of electro-optical elements, such as injection molding, hot embossing and roller embossing [1–5]. Among those manufacture processes, the importance of roller embossing for mass production is increasing because of its rapid, continuous production. However, the fabrication method of the roller molds with microstructures is the key technology. Many kinds of microstructure fabrication methods on roller surfaces have been reported, such as a modified LIGA process [6], thin mold wrapping [7], soft mold casting [8,9] and dry film photolithography process [10]. Most of the fabrication methods of microstructured rollers are very complicated and costly, needing high-end facilities. During the modified LIGA process method, it is hard to obtain a uniform photoresist on a roller surface before non-planar lithography because the liquid photoresist is difficult to be coated uniformly on the roller surface. The thin mold wrapping method is the most used one. However, mold sliding and warping problems are frequently encountered because of a weak adhesion between molds and rollers. The soft mold casting method can fabricate uniform polymeric microstructure soft molds, which have an excellent adhesion to the roller. However, the soft rollers with microstructures suffer from poor strength durability and temperature endurance. However, the dry film is limited by resolution, the minimum size of microstructure is up to 40 μm only, and unable to wrap the roller perfectly resulting in gap production.

In this paper, we present a novel method to fabricate the microstructured roller for UV roller imprinting technology. The method is to combine the stepped rotating lithography and electroless nickel plating to fabricate a roller with microstructures. The roller mold is fabricated by using photolithography with liquid photoresist. First, photoresist is coated on the roller surface using dip coating with rotation, then the patterns of microstructures are defined via photolithography. Subsequently, the microstructures are generated directly on the metallic roller surface via electroless nickel plating. To deposit metal microstructures or nanostructures on roller by electroless plating is not only a low-cost and easy operation method but also a useful process for microelectronic fabrication. After that, this fabricated roller mold is employed in UV roller imprint process. During the UV roller imprint process, stamping pressure and rolling speed are investigated. In the final part of the paper, the microstructured roller fabricated by the proposed method is employed in UV roller imprint, and the practicability is to be verified through optic microscope and surface profiler measurement.

2. Fabrication procedure

The procedure used in this roller fabrication is illustrated in Fig. 1. First, a thin nickel layer is electroplated on the surface of aluminum roller (the diameter is 80 mm, and length is 120 mm) and the photoresist is coated onto the roller surface using dip coating. Then the photoresist on the roller surface can be patterned using

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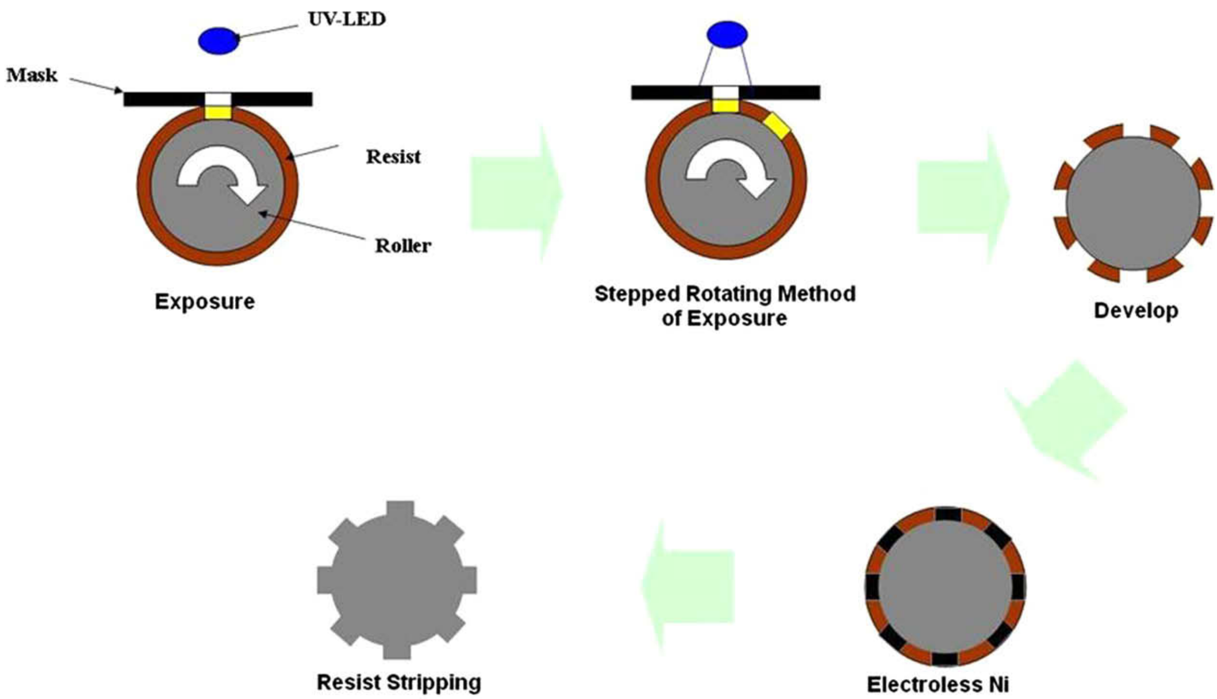

Fig. 1. Schematic diagram showing the fabrication procedure of microstructure on the surface of metal roller using stepped rotating lithography and electroless nickel plating.

stepped rotating lithography, followed by PR developing. Subsequently, the roller is treated with electroless nickel plating. Finally, the residual PR is removed by acetone. After that, a roller with rigid nickel microstructures can be obtained.

2.1. Preparation of roller material

In this study, an aluminum roller with a thin nickel layer on the roller surface is used (the diameter is 80 mm, and length is 120 mm). The surface roughness (Ra) of the aluminum roller is 10 nm by diamond turning. In fact, the nickel layer can not be deposited directly onto the surface of aluminum roller by electroless plating. To meet this problem, a zincate process is necessary and of a key step during the whole process. Before starting the zincate process, the aluminum roller must be treated with soak cleaner. After that, the aluminum roller is immersed into the solution containing zinc and other metal ions for a specific while. Consequently, the zincating process is completed and a very thin zinc layer on the surface of the aluminum roller is obtained. Aluminum is catalytic for electroless nickel plating. However, aluminum rapidly oxidizes during rinsing or when exposed to air, and the surface oxide layer produced will completely prevent the formation of aluminum–nickel intermetallic bonds, resulting in adhesion failure. Consequently, zincate treatment of aluminum bond film is a important process step in electroless nickel plating to activate the film for subsequent electroless nickel plating. But the process of zincate is alkaline that would brings photoresist layer to stripping. The process of platting thin nickel layer on the roller surface is carried out previous of the photoresist coating and stepped rotating lithography processes.

2.2. PR coating on the roller

The photoresist (EPG510, Everlight Chemical Industrial Corp.) is coated onto the roller surface using dip coating with rotation. Dip coating refers to the immersing of a roller into a tank containing photoresist, then removing the roller from the tank and allowing it to drain. The coated roller can be dried by force-drying using vacuum or baking and then can be fast dried by roller rotating. It is a popular way of creating thin film coated materials along with the spin coating procedure. In the dip coating process, relative velocity (mm/min) and solvent diluting percentage (wt%) of PR are significant factors of dip coating (200 rpm of roller rotation). The relative velocity is the sum of speed of liquid surface (Vw) and roller (Uw). Maximum thickness of the photoresist coated onto the roller surface is 1100 nm with 75 mm/min of relative velocity and 50 wt% of solvent diluting percentage. The photoresist dip coating on roller surface and the response model graphs are shown in Fig. 2a. The thickness of PR coating with factors of relative velocity and percentage of solvent by response surface method is shown in Fig. 2b. The region of the thickness of PR dip coating is between 250 and 1100 nm for controlling the relative velocity and the percentage of solvent.

2.3. An apparatus of stepped rotating lithography

In this work, the microstructures with various pitches can be fabricated by adjusting the stepped rotating degree in the exposing process. The stepped rotating lithography is controlled by a rotation stage. With 1 min of each rotating degree, the microstructures with a pitch of 11.3 μm are fabricated. Fig. 3a shows the apparatus of stepped rotating lithography.

The mask is aligned with the roller using a CCD and X–Y stage. Fig. 3b shows the roller and mask. UV-LED light source is used for exposing, the wavelength of light is 365–425 nm, and the intensity of light is 9.6 mW/cm^2 at 4 cm under roller surface. To get the appropriate exposure energy, an exposure energy test is first carried out. The reasons for using UV-LED in this study are to eliminate the hold time of on/off and to avoid the rising temperature of roller and PR. Fig. 3c shows the UV-LED used in the process.

2.4. An apparatus of UV rolling imprint system

In this work, the UV rolling imprint system is employed [11]. The system is composed of a UV-lamp (97 mW/cm^2 of power and