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Prototype development of a roller imprint system and its application to large area polymer replication for a microstructured optical device

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ABSTRACT

In this study, the prototype of a thermal roller imprint lithography (RIL) system was developed and applied to RIL tests to evaluate its feasibility for the large area replication of an optical micro device. The developed system adapts an automatic stamp releasing mechanism and has the capacity to replicate ultra-precision structures on an area of 100 mm × 100 mm at the scanning speed range of 0.1–10 mm/s. For RIL tests, 1 mm-thick polyethylene terephthalate (PET) plastic plates and 100 μm-thick cycloolefin resin films were used as imprint materials. All samples were 100 mm × 100 mm in size. The combination of a thin and flexible polymer film and an elastomeric adhesive sheet was effective for both rapid processing and uniform replication. For given RIL conditions (700 N press force and $T_g + 50\,^{\circ}C$ roller temperature), the complete filling for a 1 mm-thick PET sample was achieved at the roller scan speeds of 0.1 mm/s, whereas that for a 100 μm-thick cycloolefin sample could be obtained at the roller scan speeds of <2 mm/s with much better replication uniformity over a whole surface area. Finally, a light guide plate (LGP) for a back light panel was fabricated by RIL.

1. Introduction

Since the mid-1990s, imprint lithography has drawn a lot of attention as one of the most promising technologies for the definition of nano/micro-patterns due to its simplicity, low cost and high resolution (Chou et al., 1996; Gates et al., 2005; Guo, 2004; Guo et al., 2004; Heidari et al., 2000; Nakajima et al., 2006; Scheer and Schulz, 2001; Torres et al., 2003; Chang et al., 2006; Seo et al., 2007; Youn et al., 2007). One of the current key issues of this lithography technique is the size of a processing area, since it is one of the major factors that dominate the process throughput. The need for rapid and uniform patterning over a large area has lead to the development of a number of imprint-based technologies such as an imprint lithography using a flat-type stamp with a large surface area (Heidari et al., 2000; Scheer and Schulz, 2001), a step-and-stamp imprint lithography (SSIL) (Gates et al., 2005; Guo, 2004; Torres et al., 2003) roller imprint lithography (RIL) (Chang et al., 2006; Seo et al., 2007; Suh et al., 2005; Tan et al., 1998) and others. Among those technologies, traditional flat imprint lithography using a large stamp is the simplest way, but commonly requires several tons of force that increases the possibility of stamp deformation. Further, the thickness variation on a stamp or substrate can be as large as a micrometer on a large

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wafer area, and it is hard to be compensated (Heidari et al., 2000). During imprinting, non-conformal contact occurred by the local flatness distortion in the mold causes the reduction of replication uniformity and leads to a huge stress concentration, resulting in the warping or distortion of the stamp (Deguchi et al., 2002; Lazzarino et al., 2004). In the SSIL process, a stamp is pressed into a polymer film under suitable pressure and temperature conditions replicating the pattern in the stamp into the polymer, followed by stepping to the adjacent site. Thus, the SSIL is not the best choice for the replication of continuously connected and complex-shaped structures such as micro-channels for bio-devices although it can transfer nano/micro-scale patterns over large areas. The RIL, first proposed by the Chou group (Tan et al., 1998), is one of the most promising candidates for rapid patterning on a very large area substrate. As compared to other two types of large area replication methods previously described above, the RIL process provides some distinctive advantages (e.g, compact-sized system configuration, lower imprint force, better replication uniformity) because only a line area is in contact during imprinting. The line contact between the stamp and polymer surfaces during imprinting reduces the force for the complete filling, the effects of thickness unevenness and dust. Moreover, the RIL has more flexibility in the choice of replication geometry. Up to date, several kinds of RIL techniques (e.g, roll-to-roll (Seo et al., 2007; Suh et al., 2005), roll-to-plate (Chang et al., 2006) and others) have been studied by several research groups, but have been generally limited to ultra-violet (UV) -based techniques.

The aims of this study are to develop the prototype of a roll-to-plate type thermal-RIL system and to evaluate its feasibility for the large area replication of an optical micro device, such as a light guide plate (LGP) for a back light panel. The back light panels with a LGP provide features of high brightness, high uniformity, thin and lightweight, and are widely used on various applications for monochrome and color displays. Series of RIL tests were conducted to investigate the effects of process conditions (e.g, scan speed of roller, vertical press force and temperature) on the formability of polymer materials including a polyethylene terephthalate (PET) and a cycloolefin resin. For comparison, flat imprint tests were also performed. Polyethylene terephthalate (PET) plastic and two types of polyolefin resins were used as imprint materials. Finally, LGPs were replicated under the achieved process conditions by the RIL.

2. Experimental procedure

Commercially available thermoplastic polymers, including polyethylene terephthalate (PET $T_g = 81.5\,^{\circ}$C) plastic and two types of polyolefin resins (product name of "Zeonoa ZF14-100" and "Zeonex"), were used as imprint materials. Zeonoa and Zeonex are new thermoplastic polyolefin resins (cycloolefin polymers) developed by Zeon Corporation and have almost the same glass transition temperature of about 138 °C. Series of RIL tests were conducted on a 1 mm-thick PET plastic plate and a 100 um-thick Zeonoa resin film using the prototype of a RIL system that was developed in this study. The details regarding the development of RIL system are described in the next section. All samples used for RIL tests were 100 mm × 100 mm in size. To fix the sample film (or plate) on the sample platform in the RIL system (refer Fig. 2 (a)), a heat-resistant silicone rubber adhesive sheet (product name of "Hi Performance Stickiness Plate (HSP)", Shin-Etsu Polymer Co. Ltd., Japan) film was used. Flat imprint tests on 1 mm-thick PET and 2 mm-thick Zeonex plates were also performed in hot-press equipment, which is designed to imprint 3 cm × 3 cm samples (the maximum heating temperature: 700 °C and the maximum press force: 2 kN). A pumping system allows embossing samples under vacuum, with the pressure of 1 Pa inside the chamber. Prior to imprint tests, local flatness distortions in the mold were evaluated using a pressure-sensitive film (Prescale film, Fuji-Film Co., Japan), and compensated. No mold release agent was used. For roller and conventional imprint tests, three types of nickel micro-molds were prepared. The fabrication process of a nickel mold began with silicon micromachining process, such as deep reactive ion etching (RIE) using standard Bosch process. After sputtering seed and barrier metallic layers on the silicon master, nickel was electroplated to sufficient thickness. In the final step, the silicon master was etched away using KOH-based solution after chemical mechanical planarization (CMP) of the backside of the electroplated nickel. An optical microscope and a conforcal microscope were used to obtain the local morphological data of the processed samples. The commercial macro observation system for micro-scale defect detection (Geoscan, Japan minicomputer systems Co. Ltd., Japan) was also utilized to evaluate the replication uniformity over a whole sample surface area. This system enables to visualize the micro-scale defects over the whole surface area of a wafer by detecting the change of a specular reflection.

3. Results and discussion

3.1. *Development of roller imprint lithography (RIL) system*

Fig. 1 shows the photograph of the developed RIL system hardware. The system is made up of the major components such

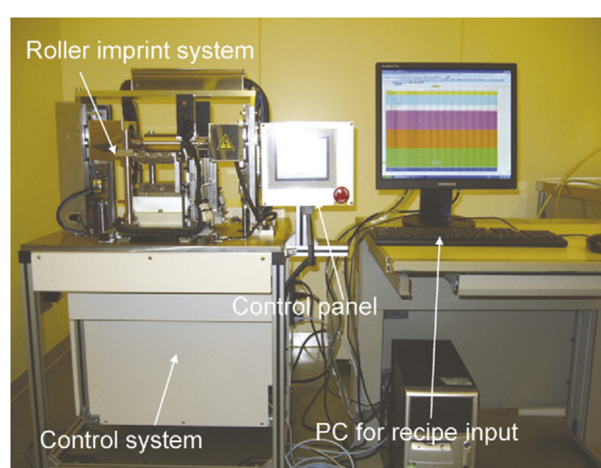

Fig. 1 – An overview of the system hardware.