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Longitudinal stitching of sub-micron periodic fringes on a roller

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ABSTRACT

In this work, a servo-assisted system for fabricating sub-micron gratings on a roller-type mold is developed. The fringes are produced by optical interference lithography and have period of about 800 nm. A supporting and precision manipulating system for roller mold is established so that seamless longitudinal fringe stitching can be achieved. Analysis of the measurement system and stitching error are given. Also, beam-steering concept is introduced into this system for correction of relative motion between the roller and the optical system. Exposure experiment is initiated on a 50 mm-diameter roller. The grating structure is directly and indirectly examined by microscopic equipments.

1. Introduction

The explosive increase in demands and the growing number of micro or nano structure applications has called for the development of high-throughput defect free manufacturing technology. Among the possible solutions, the roller nano-imprint lithography (RNIL) has received great attentions due to its inherent nature of low cost, continuous production and the high achievable resolutions [1–5]. These processes, often referred to as the roll-to-roll NIL (R2RNIL) or roll-to-plate NIL (R2PNIL), all require defect-free molds.

Creating micro/nano structure is not considered very difficult with current day technologies. It is also possible to fabricate these patterns on cylindrical rollers [6,7]. However, it would be extremely difficult if one desires both nano scale patterns and seamlessly continuous structure on the roller. A few issues need to be resolved: First of all, one needs a way to create the nano patterns and a feasible way to transfer the pattern onto the curved roller surface. Secondly, for continuous patterning, one needs to determine whether to use a continuous patterning process or a step and stitch process to extend the nano pattern into large continuous areas. Thirdly, a precision rotating servo mechanism should be available to orient and position the roller into precise position for patterning. All these issues pose major obstacle in the system design. The current high precision machining technology states 1 nm command resolution for linear feed, but if one examines the spindle run out this figure becomes 0.50 nm [8]. The machining results then achieve 20–90 nm peak-to-peak value for small flat surface and 0.12 μm peak-to-peak variation for curved surface [9]. These figures are achieved by very experienced operators. Examining further into the straightness of the machine, the figure increases to 0.2 μm per 40 mm. It is fair to say that there is still great need for advancement in ultra precision large distance machining technique. Being able to fabricate continuous nano pattern on rollers is even harder for today's technology.

As mentioned in the beginning, there are already many research results in the literature on R2R or R2PNIL. Experimental and theoretical studies on pattern transfer efficiencies are also available [1,10]. Nevertheless, most of the experimental results are either restricted by micro scale patterns [1,6] or have focused on isolated patterns with nano structures [11]. Some of the few studies on patching nano patterns include the work by Cho et al. who used a step and repeat process to create large area patterns [12]. Even though they claimed large area, they have left small gaps between adjacent patterns. The work by Chen et al. [13] is one of the few results that directly addressed the continuous nano patterning. They developed an interference lithography system that steps and aligns the nano patterns into large continuous but flat wafer. Another work that address seamless roll mold is by Taniguchi and Aratani [14] who developed a rotating mechanism within an electron beam writer to seamlessly write continuous nano pattern on a roller. They also described the use of dip coating to obtain uniform layer of photo resist. This is one system that truly writes continuous nano pattern on roller; however, the e-beam writer allows a very small working space for the roller and the wobbling of the

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rotating mechanism basically prevents anyone to require very accurate system specifications.

In this study, we present a system that uses a step and align approach to patch continuous nano patterns onto a roller. The proposed system is based on interference lithography to generate nano patterns. Generally, there are two popular approaches to fabricate the molds: the direct fabrication and the flexible mold wrapping. To the authors' best knowledge the technique to seamlessly wrap the flexible mold sheet onto a bare roller still does not exist. This study adopts the direct fabrication approach to directly write onto the roller. We devised a dip coating technique to coat very thin uniform layer of photo resist on the roller and use interference laser lithography to form gratings with a few hundred nanometers line width. A special servo system is developed to achieve very accurate alignment between the roller and the lithography pattern to guarantee continuous pattern after exposure.

The paper will first describe the design principle and the system setup. Section 3 then presents the measurement design to directly detect any pitch movement of the roller. The depth of view of the interference pattern allows a less stringent bound on the yaw movements. There is also a beam stabilization system to suppress the vibration induced from the UV laser cooling system. The mathematical model for design accuracy estimation is then presented in Section 4. Section 5 presents the servo testing and experimental fabrication results. Section 6 then provides the conclusions and some suggestions for improvements.

2. System description

This section explains the design considerations for the roller exposure system. Interference lithography adopted in this system is the most efficient way available to generate periodic gratings in large area. Fig. 1 shows the system layout. The interference optics in our design resides on a moving stage. It brings together two coherent laser beams to form the interference fringes. The laser source is a 363.8 nm ultraviolet Ar^+ laser mounted on a separate table from the main system to prevent vibration propagation from the circulating coolant. Consequently, the main optics setup and the aligning servo systems are mounted on another air-bearing isolation table. The period of the fringes is designed to be 800 nm. Accordingly, the corresponding half-angle between the two inter-

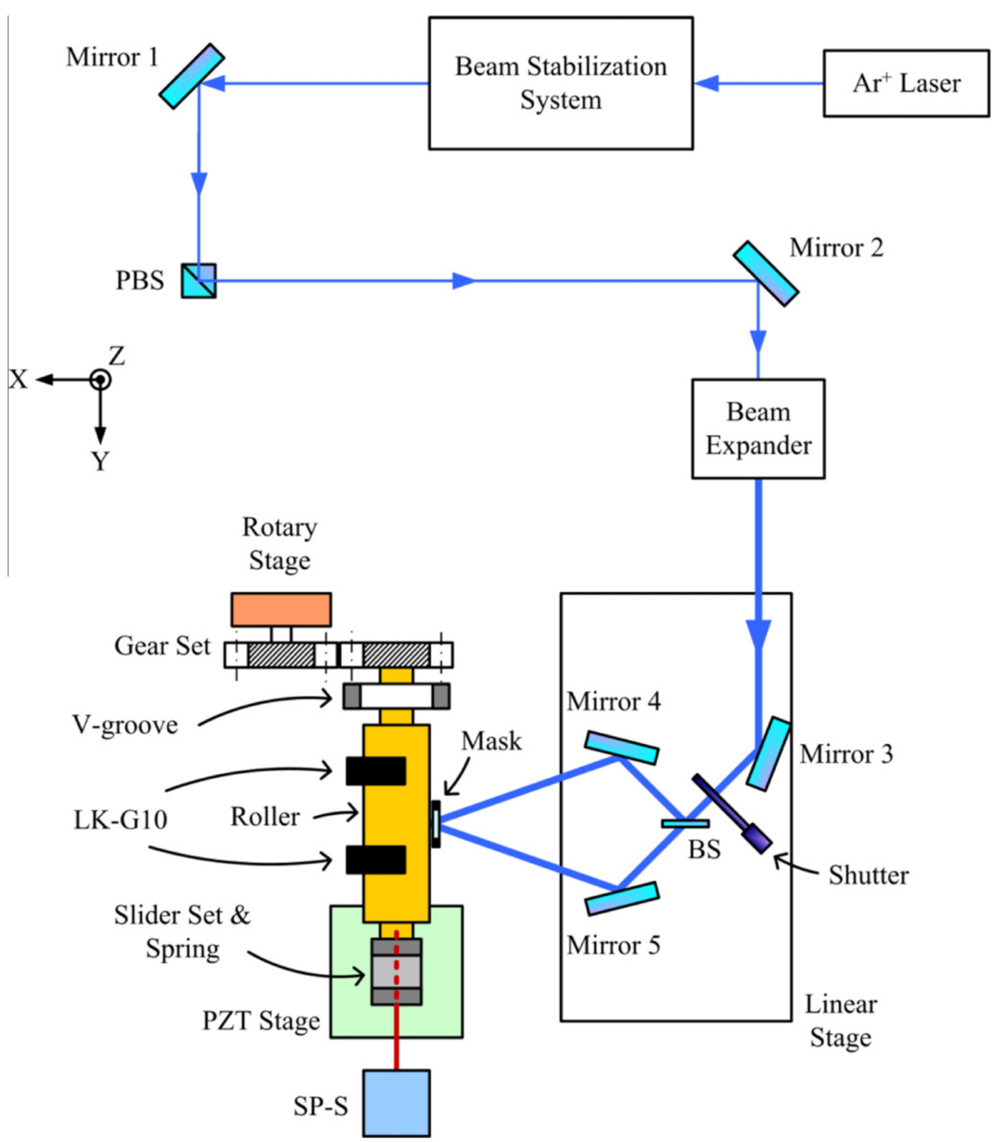

Fig. 1. The schematic diagram of the full system.