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Integration of rotated 3-D structures into pre-patterned PMMA substrate using step & stamp nanoimprint lithography

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ABSTRACT

In this work, we fabricated hybrid micron-scale blazed grating structures on top of linear nanoscale gratings by superimposing thermal nanoimprint process. A poly(methyl methacrylate) (PMMA) substrate was at first pre-patterned with a nanoscale binary line grating by thermal NIL. The second imprint was added into the linear surface-gratings by sequential thermal imprinting using a stamp with micron-scale blazed gratings. The rotation controlled patterning was realized by Step and Stamp Imprint Lithography (SSIL) using NPS300 nanoimprinting stepper with a rotation imprint head with ability to control X/Y positioning and angular orientation of the stamp.

In this paper, we demonstrate the potential of the hybrid imprint process for fabrication of e.g. hybrid bio devices or optical elements with arbitrary orientation.

1. Introduction

Nanoimprint lithography (NIL) is based on mechanical deformation of a polymer under pressure at elevated temperature. This technology has received interest for low cost high resolution nanolithographic techniques [1,2]. In NIL, a patterned stamp and a substrate with polymer coating are heated above the glass transition temperature of the polymer. The stamp is then pressed against the substrate. After cooling the sample the stamp and the substrate are separated and the patterns in the stamp have been replicated into the substrate forming a mask for subsequent processes. The step and repeat method or step and stamp nanoimprint lithography (SSIL) [3] offers a lithography process compatible with conventional lithography methods. The potential of the method is, for example, stamp mastering process, in which large master stamps are fabricated by sequential imprinting. It has been used to fabricate large area bendable stamps for example Roll-to-Roll process and UV-imprinting [4,5].

The present work explores a scheme for the manufacturing of three-dimensional stamps based on hybrid 3D nanofabrication processes. The target is industrial applications in the field of Nano bio technology [6] or optics for e.g. diffractive optical elements [7,8] in which high production volumes are required. In many cases hybrid approaches, i.e. process sequences obtained linking different lithographic technologies, are the only ways to realize patterns which cannot be fabricated by a single technology [9]. Here we describe how a step & repeat process is used for the local addition of blazed gratings, the latter made by state of the art Deep X-ray lithography and LIGA [10,11], onto the top surface of a polymer sheet pre-patterned with a linear grating. Adding patterns, whether 2D or 3D, in selected areas, while varying its orientation from site to site, is quite challenging and can be realized by a step and repeat nanoimprint machine equipped with a rotation head. A key advantage of this approach is that the complexity of the pattern origination is restricted to the fabrication of a master, since once a resist structure is fabricated as the result of a process chain, it can be replicated by a stamp manufacturing process using electroplating or casting and enlarged even further for large scale patterning.

The rotation controlled imprinting method introduced here, allows patterning elements with defined angular orientation at different locations of a large area substrate. It is also possible to switch between multiple stamps by pick-and-place. The rotation head integrated into the machine allows imprinting in a defined angle in the lateral direction, thus enabling to print linear gratings in different orientations with respect to the substrate outlines. This is essential for generating, for example, different optical surfaces to control light.

2. Experimental

In this work, we used a poly(methyl methacrylate) (PMMA) substrate which was at first pre-patterned with a nanoscale binary

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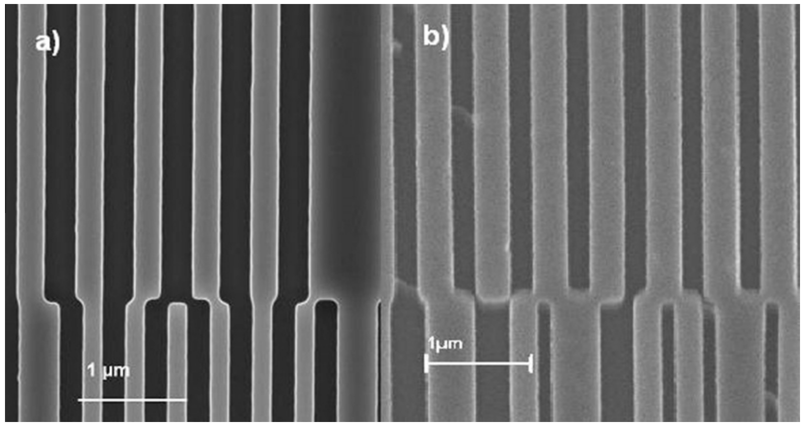

Fig. 1. SEM micrograph of the silicon master stamp patterned with a linear binary grating of line width and height around 200 nm (a). SEM micrograph of the linear grating in the PMMA substrate imprinted using the silicon master (b). The line width of the imprinted grating corresponds well to the lateral dimensions of the stamp features.

line grating by thermal NIL. A rather thick polymer slab (3 mm) ensured sufficient mechanical stability when the substrate is exposed to the heat load of a second thermal imprint step.

For the first imprint layer, a large area binary line grating was generated by electron-beam lithography and subsequent pattern transfer into a silicon substrate using dry etching technique (area: 50×45 mm^2; depth and min. lateral feature sizes: 200 nm). Following the surface passivation of the silicon master by a silane-based anti-sticking layer (ASL), a working stamp was generated by replicating the silicon master into a 30 µm thick OrmoStamp® layer on a transparent borofloat substrate using UV NIL. This allowed reversing the pattern polarity into protrusions more favorable for imprinting purposes. The linear grating was replicated onto the PMMA slab at 165 °C. A reduced pressure of 0.25 MPa enabled the generation of a surface patterning without reducing the slab thickness, which was previously observed for increased temperatures and imprint pressure.

For the second imprint layer, a blazed grating stamp with micron scale structures was fabricated in two steps. A first generation nickel master was fabricated by the LIGA process and electroplating. The patterned area is only 80 µm by 40 µm which requires up-scaling of the nickel master. The blazed grating master was scaled up by replicating 16 times (4 by 4 matrix) by thermal sequential imprinting into the polymer substrate to fabricate a larger stamp. The imprinted polymer mold was used for preparing a new, second generation nickel stamp with 16 blazed grating elements with a distance of 200 µm in the center of a 10 mm by 10 mm chip.

The second imprint was added into the linear surface-gratings by thermal step and stamp imprinting using the second generation nickel stamp with micron scale blaze gratings. The rotation controlled patterning was realized by SSIL using a NPS300 nanoimprinting stepper [12] with a rotation imprint head. The rotating head introduces the ability to control X/Y positioning and angular orientation of the stamp. The nominal overlay accuracy of the alignment system is 0.25 µm. Though, here were no alignment marks in the samples used, so only rough accuracy of placement was achieved. The imprinting head can be rotated between −90° and +90° with an angular accuracy of 0.1° [13].

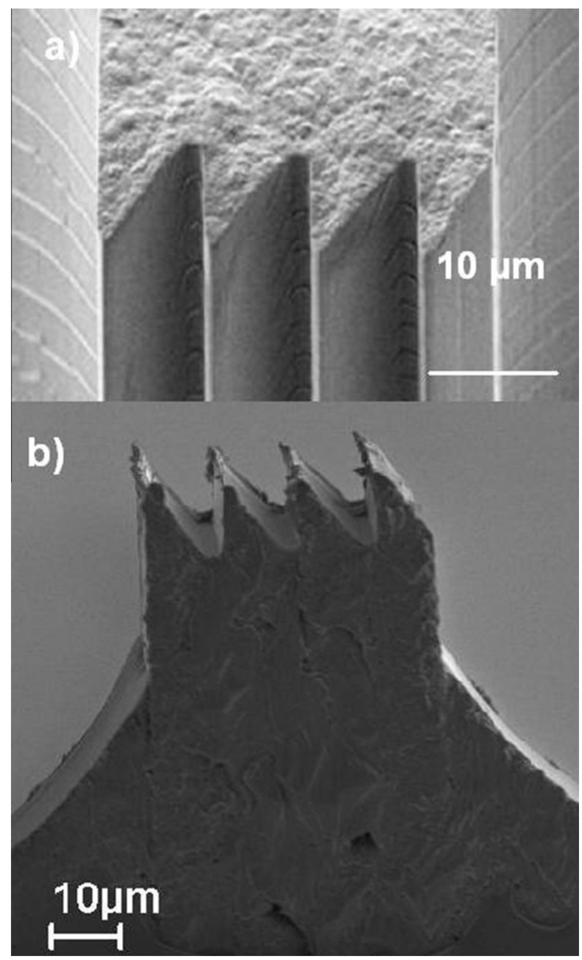

Fig. 2. SEM micrograph of the high quality blazed gratings made of Nickel fabricated by a novel process based on deep X-ray lithography. The radius of curvature of the ridges along the teeth is around 200 nm all along their length (a). SEM micrograph of the blazed structures replicated by NIL and electroplating process (b). The slope and height of the replicated teeth correspond to the original master, though some residual of the seed metal from galvanic process can be seen on top of nickel surface.

3. Results

In Fig. 1(a) is a SEM micrograph of the linear grating in the silicon master stamp replicated into the PMMA substrate slab at 165 °C and at the pressure of 0.25 MPa. The features formed into the PMMA substrate by imprint are shown in Fig. 1(b). Comparison between the silicon master and the PMMA replica shows good replication fidelity of the lateral dimensions.

For the second step we scaled up the blazed grating tool into 4 by 4 matrix by step and repeat imprinting into polymer mold for