Fabrication of high aspect ratio structures by soft UV nanoimprint lithography

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We report on results of the fabrication of high aspect ratio structures by soft UV assisted nanoimprint lithography. In particular, we describe a tri-layer process which allows us to obtain a high process latitude with a good compatibility to the commonly used pattern transfer techniques such as lift-off. We show the fabrication of arrays of different geometries (pillars, stripes) over large areas with a maximum resolution of about 100 nm and an aspect ratio of about 8, obtained by reactive ion etching with a nickel mask.

1. INTRODUCTION

One of the most important issues for the development of photonic nanostructures is the fabrication of high resolution and high aspect ratio nanostructures over a large area with high throughput and at low cost. Conventional methods such as electron beam lithography and focused ion beam lithography are time consuming and will not be suitable for mass production. The so-called next generation lithography techniques developed by semiconductor industries such as extreme UV lithography are expensive for low volume production. Alternatively, non conventional techniques such as nanoimprint lithography are low cost and high throughput. Alternatively, non conventional lithography techniques are very attractive with a simple, fast, cheap process and have often a better process compatibility for bio and biochemical applications[1–3]. Thermal nanoimprint lithography has been proposed for the first time in 1996[1] and is based on the deformation of a thermoplastic resist coated on the substrate by using a rigid mold. Replication of patterns of feature sizes as small as 6 nm[4] has been reported. The disadvantages of this technic is to work at high temperatures and high pressures. In parallel, the most promising technics of UV enhanced nanoimprint lithography (UV-NIL) has been developed[5,6]. UV-NIL consists of imprinting a photo-curable polymer in a liquid state with a transparent mold (quartz) and then curing it with UV light. This nanofabrication method is actively studied in academic and industrial laboratories on the world due to an imprinting at ambient temperature, low pressure and offers the possibility of fine alignment. However, few applications have been demonstrated as comparison with the thermal nanoimprint lithography techniques, principally because of the difficulties in pattern transfer. In order to make it more reliable, the critical aspects such as process latitude, process compatibility and CD control have to be addressed.

In the present work, we present a full of promise method based on the soft UV-NIL where the quartz mold is replaced by a soft stamp, associated with an original tri-layer process. We report homogeneous nanopatterning over a large area with a large process latitude and high pattern transfer performances.

2. EXPERIMENTAL

The soft UV nanoimprint lithography method we developed is schematically shown in Figure 1. A flexible mold of high resolution is pressed on a liquid photo-resist layer which is then cured through UV exposure. After removing of the mold, patterns are transfered in the substrate by selective etching.

The fabrication method of the soft stamps used in this work is described in our previous work[7]. The master patterns are defined in a resist layer by electron beam lithography and transferred into a silicon by reactive ion etching (RIE) with SF6 gas, resulting in 100 nm resolution with an etch depth of 150 nm. The surface of the master molds is then treated with trichloromethylsiloxane (TMCS) by vapor deposition which forms a self-assembling mono-layer for as release agent. Two kinds of soft stamps are used. Soft molds made of poly-dimethylsiloxane (PDMS) are most convenient for the pattern replication of features of sizes in the range between 100 nm to a few microns. For both smaller and larger feature sizes, tri-layer soft stamps made of structured top layer (PMMA), a PDMS buffer and a quartz carrier, are used. The PMMA layer pattern of the tri-layer stamp is obtained by either nano-compression[8] or spin coating techniques[9] and is then detached and mounted on a PDMS buffer and quartz carrier, followed by the surface treatment with TMCS molecules.

On the basis of our previous tri-layer processing of thermal nanoimprint lithography[10,11], we have developed a novel tri-layer system which consists of a bottom layer of polymer, a middle layer of 10 nm thick germanium and a top layer for photo curing, as shown in Figure 1. The substrates are either silicon wafers or thin glass slides deposited with dioxide silicon. A thermo stable copolymer MMA-MAA EL7 was firstly spin coated with thickness between 150-300 nm and pre-baked at 150 ° C for 1 min. The intermediate 10 nm thin layer of germanium (Ge) was deposited by sputtering. The photo resist Laromer used is a mixture of a monomer (Laromer 8765) and photosensitive cross-link agent (Irgacure 369), diluted by 2-isopropoxyethanol. The thickness of the top layer is controlled in the range of 120 - 200 nm. After UV-imprinting, the residual layer of Laromer and germanium are etched by RIE with SF6 gas and the

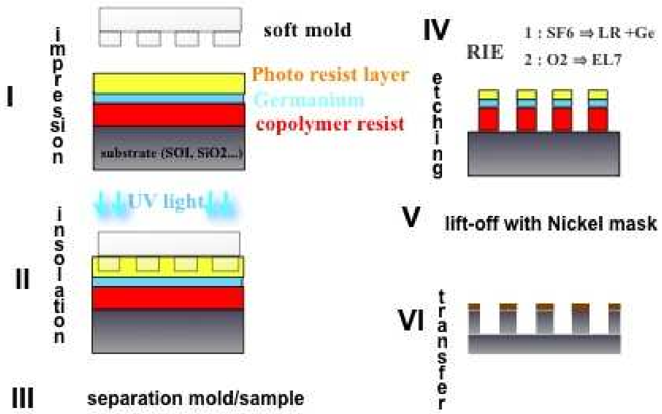

FIG. 1: Schematic representation of the soft UV-NIL with a tri-layer resist system

bottom copolymer resist layer is etched with oxygen plasma. Afterward, 20-40 nm Ni is deposited by sputtering and lift-off in an acetone bath. Finally, patterns are transferred into SiO_2 by RIE with a CHF3-SF6 gas mixture and Ni as mask and Ni is removed by HNO3 solution.

3. RESULTS AND DISCUSSION

Examples of 1D photonic crystal on silicon-on-insulator (SOI) substrates patterned by e-Beam lithography and its replication by soft UV-NIL are displayed in Figure 2. As comparison with classical bi-layer resist processing (without Ge layer), our tri-layer technique gives a lot of advantages. Firstly, because the large etch resistance of Germanium in O_2 plasma, it can be used as good etch mask to obtain polymer features of high aspect ratio. Consequently, the lift-off technique is easier which is compatible to the most commonly used pattern transfer techniques. Besides the good conductivity of the Ge layer samples can be analyzed by scanning electron microscope without metalization. Finally, the whole process latitude is largely enhanced and a better pattern homogeneity can be achieved. To illustrate these points, we report in Figure 3 SEM pictures of a dot array of 200 nm diameter before (a) and after (b) lift off of 20 nm thick Nickel.

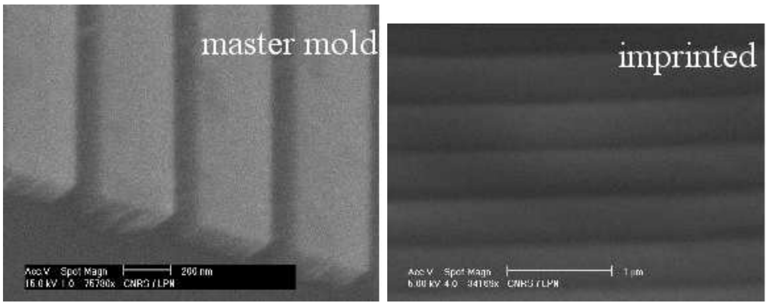

FIG. 2: Scanning Electron Micrograph (SEM) pictures of a stripes lattice of 430 nm width and 100 nm spacing on SOI substrate as master mold and after UV-imprinting

Our tri-layer processing shows that soft UV-NIL method is useful to replicate pattern of various geometries with a high resolution (> 100 nm), high aspect ratio and good homogeneity over a large area. Dense nano-pillars lattices of $200 \times 200 \mu m^2$ with a high ratio of about 8 (200 nm feature size and 1.6 μm depth) have been prepared in SiO_2 on a glass slide (see Figure 4). We would like also mention that at the present time high quality commercial resist we used (from Nanonex) for our bi-layer UV-NIL is expensive[7], the herein described tri-layer system can be a good alternative for routine operations.

4. CONCLUSION

We have reported an original tri-layer soft UV imprint lithography process to prepare nanostructures with resolution of about 100 nm over large areas. An intermediate Germanium layer is added to increase etching selectivity and allows

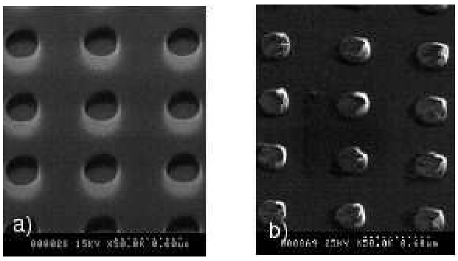

FIG. 3: Dot array with 200 nm diameter before (a) and after (b) lift-off of 20 nm thick Nickel

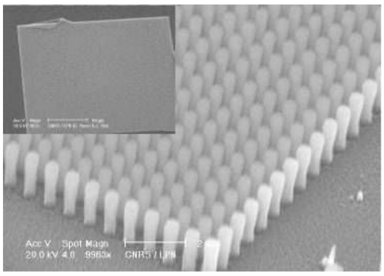

FIG. 4: SiO_2 nano-pillars lattice with 200 nm diameter and 1.6 μm depth over a 200×200 μm^2

to obtain features with very high aspect ratio and compatible to the most commonly used pattern transfer techniques. As example, we show the fabrication of high density pillars over 200×200 μm^2 area and which can be integrated in microfluidic channels to develop bio-sensors. These results confirm the high attractivity for the soft UV-NIL at low-cost and high flexibility. Future extensions of this technology on different substrates and geometries are in progress in collaboration with other partners (Univ. Pavia, Univ. Montpellier, NILPRP-Bucarest) in the framework of the Phoremost network.

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