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High density phase change data on flexible substrates by thermal curing type nanoimprint lithography

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ABSTRACT

In this study, high density phase change nano-pillar device (Tera-bit per inch^2 data density) was fabricated on flexible substrates by thermal curing type nanoimprint lithography with high throughput at a relatively low temperature (120 °C). Phase change nano-pillar was formed with on flexible poly (ethylene terephthalate) (PET) film, polyimide (PI) film, and stainless steel plate (SUS) substrate without any damage of substrate. The electrical property of the fabricated phase change nano-pillar device was confirmed by electrical signal measuring of conductive atomic force microscopy.

1. Introduction

Recently, many flexible devices have attracted much attention for various applications such as flexible displays, flexible electronics, flexible solar cell, flexible light emitting diode and flexible chemical sensor and so on [1–5]. For high performance of these flexible devices, high density nano-size patterns of the flexible devices should be needed. But, it is difficult to fabricate nano-patterns on flexible substrate using conventional photolithography, because of its non-flat, flexible surface. Also, there are thermal and chemical limitations of nano-patterning process for flexible plastic substrate. Almost, printing method or soft lithography with some nanoparticles, organic materials involved ink has been used for flexible device fabrication due to its low process temperature, and chemical-free process [6–9]. However, there are some problems such as its low critical dimension resolution, low throughput.

Nanoimprint lithography (NIL) is one of the most promising next generation lithographic techniques, which is possible to fabricate nano-sized patterns on flexible substrate or curved substrate unlike conventional photolithography [10–14]. For nano-device fabrication on flexible polymer substrate, the process temperature of NIL should be lower than 150 °C. And imprint resin and underlayer for planarization or removing solvent should be not reacting with flexible substrate material. Also, it is important to fabricate nano-patterns uniformly over large area with minimized residual thickness. There are few studies about fabrication of nano-device on flexible substrate by nanoimprint lithography. We previously reported 70 nm metal patterns on poly (ethylene terephthalte) (PET) film for flexible electronics, and CdTe nano-pattern on flexible polyethylene naphthalate (PEN) film for flexible solar cell device, phase change nano-pillar device on flexible polyimide (PI) film for flexible memory device [15–17]. But, it was fabricated by UV-NIL and the electrical properties of phase change nano-pillar on flexible substrate were not reported.

In this study, high density phase change data (Tera-bit record per inch^2) on various flexible substrates was fabricated using thermal curable NIL process, at relatively low temperature (120 °C). Although, UV-NIL method has a lot of merits for nano-patterning process, in the point of productability, thermal NIL is more beneficial than UV-NIL for large area process. The 200 nm phase change nano-pillar patterns was fabricated on flexible poly (ethylene terephthalate) (PET) film, polyimide (PI) film, and stainless steel plate (SUS) substrate without any damage of substrate, and its electrical property was evaluated by conductive atomic force microscopy (c-AFM).

2. Experimental

Fig. 1a and b present the schematic diagram of the overall process of fabricating nano-size phase change nano-pillar device on flexible substrate, and the schematic diagram of high density phase change data on flexible substrate. First, a 100 nm thick TiW bottom electrode layer was deposited on the flexible PET film, PI film. In case of SUS substrate, the SUS layer was used for bottom electrode. Then, polyvinyl alcohol (PVA) layer was coated on the flexible sub-

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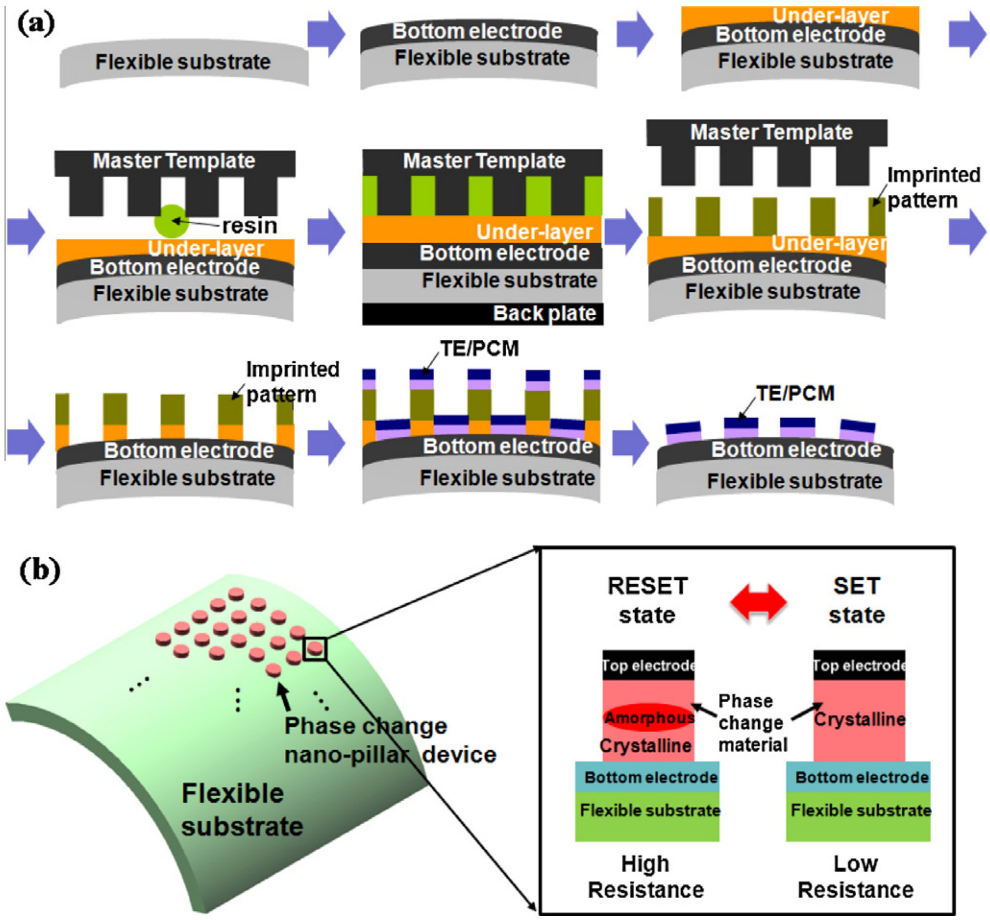

Fig. 1. (a) The overall process of fabricating nano-size phase change nano-pillar device on flexible substrate, (b) the schematic diagram of high density phase change data on flexible substrate.

strates to a thickness of 300 nm by spin-coating at 3000 rpm for 30 s, as a bi-layer. On the PVA layer coated flexible substrate, 0.3 μl of thermal curable resin, which contained 30 wt.% M-PDMS monomer based thermal curable resin, was dispensed by drop method using micropipette. Then, the master template, which has 250 nm in diameter and 450 nm in height, was set on it, and the stack of master template and the substrate was uniformly pressed by silicone rubber on vacuum condition. The imprint resin was filled to the pattern between master template and substrate for 10 min by the isotropic pressure of 20 atm, then, the resin was polymerized and solidified through thermal curing at 120 °C. Then, the master template was separated from the flexible substrates. After NIL process, the PVA under-layer was etched through oxygen reactive ion etching (RIE) process using imprint pattern on it as an etch mask. Then, $Ge_2Sb_2Te_5$ (GST), which is one of phase change materials, and Cr were deposited as a phase change material (PCM) and top electrode (TE), sequentially. Finally, the phase change nano-pillar pattern was fabricated using the lift-off process by sonication in DI water.

3. Results and discussion

Thermal curable NIL process has several merits for flexible device fabrication, such as high throughput, low process temperature and pressure. Fig. 2 shows the patterning results on the flexible PET substrate using thermal curable NIL process. The 250 nm in diameter hole array patterns were clearly fabricated on the flexible PET substrate, as shown in Fig. 2a and b.

After NIL process, any degradation of polymer substrate was not observed due to its low process temperature. The PVA layer was used for lift-off process. PVA layer helps to be flattening the flexible substrate, and undercut shaped PVA pattern is easily fabricated due to its low etch resistance as shown in Fig. 2c. The PVA layer was easily removed just sonication in DI water for 10 min. Any organic solvent was not need for lift-off process.

Fig. 3 shows fabricated phase change nano-pillar device on flexible PET, PI and SUS substrate. The nano-pillar patterns were located in the glittering area. As shown in Fig. 3a–c, 200 nm nano-pillar patterns are clearly fabricated on flexible PET and PI substrate, but in case of relatively less flexible SUS substrate, there are some defect areas with non-uniform residual layer in imprinted pattern on SUS substrate. Also, it was observed that the size of nano-pillar on SUS substrate was decreased compared with its master template. It was because the coated PVA thickness was increased due to the hydrophobic property of SUS substrate.

The electrical properties of the flexible nano-pillar device were evaluated using c-AFM instrument with pulse generator and voltage source as shown in Fig. 4a. The measurement system consists of a voltage source (Keithely 2612), pulse generator (HP 81150A) and conducting AFM (Park Scientific Instrument, XE-100) system [18]. First of all, the image of the phase change nano-pillar device was achieved from the AFM image in Fig. 4b, and the AFM tip was addressed to the nano-pillar device. The AFM system was set to the contact mode, and the set point was set to 0.15–0.3 nN. The resistance of the as-fabricated GST nano-pillar device was about 10^7 Ω. Fig. 4c shows the I–V switching characteristics of nano-pillar device on flexible PET substrate. The resistance of GST nano-pillar de-