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Reduction of pattern peeling in step-and-flash imprint lithography

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ABSTRACT

A strong adhesion force between resist and underlayer materials was employed to reduce resist pattern peeling generated from de-molding in step-and-flash imprint lithography (SFIL), while simultaneously minimizing the adhesion force between resist material and the template surface with fluorinated surfactants. The reduction in resist pattern peeling by the interaction between the fluorinated SiO_2 resist with epoxy groups and UV reactive underlayer materials with epoxy groups during UV irradiation was investigated. An optimized resist material formulation and high adhesion strength between resist and underlayer materials led to the well-patterned 80 nm resist lines on an underlayer for 100 imprints. The underlayer material was modified by a thermal crosslinking reaction of the aminoplast at 130 °C before nanoimprinting and, in conjunction with a cationic epoxy chemical reaction between the resist and the underlayer during UV irradiation before de-molding, proved to be quite effective for SFIL defect reduction.

1. Introduction

UV nanoimprint lithography is capable of fabricating very small structures that have features on the order of 10 μm or smaller. Encompassing a wide array of applications such as high speed single electron transistor memory, ultra high speed metal oxide semiconductor devices, high density magnetic storage devices, micro-electromechanical systems, and optical films, the processing industry continues to strive for larger production yields while increasing the number of circuits per unit volume that can be formed on a substrate.

Nanoimprint lithography (NIL) has proved itself as a simplified patterning technique which entails reduced cost of manufacturing, fast operation, and compatibility with conventional pattern transfer techniques. Vias and trenches with a minimum size of 25 nm and a depth of 100 nm were imprinted in the polymer [1]. Nanoimprint lithography was employed here to demonstrate uniform patterns over a 15 mm by 18 mm area [2]. Arrays of 10 nm diameter and 40 nm periodic holes were imprinted in poly (methylmethacrylate) on silicon and gold substrates [3].

Step and flash imprint lithography was developed at the University of Texas at Austin and Molecular Imprints, Inc., and is considered to be one of the most promising alternatives to conventional lithography. The advantages of SFIL include feature resolution that is limited only by template fabrication, a thin residual resist thickness, large patterned areas, low line width roughness, high throughput, process simplicity and robustness, ambient temperature and low pressure processing conditions, device manufacturing cost reduction, and the capability to execute over 100 imprints or pattern transfers.

Submicron patterning has been demonstrated with SFIL using patterned templates [4] and automated SFIL tools have been manufactured [5]. The fabrication of very small structures with features on the micron and nanometer scales have been demonstrated [6–8]. Nanoporous anodic aluminum oxide has been widely used for the development of various functional nanostructures in SFIL [9]. Direct patterning consisting of 100 nm gratings of TiO_2 were successively imprinted using SFIL [10].

The methodology used in our previous studies with SFIL have been useful in executing the results of this paper. In our previous studies, a fluorinated silicon-based resist material and a UV reactive underlayer were developed for defect reduction using SFIL [11]. The high adhesion between the silicon-containing underlayer and the resist material led to excellent patterning fidelity and straight 80 nm resist profiles [12]. A trehalose derivative resist with specific desired properties capable of producing 80 nm resolution was successfully developed for SFIL [13]. High quality nanoimprint patterning of dense lines and other complex structures was achieved using the proposed material design and UV imprinting conditions [14]. A methacrylate-based, UV reactive branched siloxane was directly patterned by SFIL for use as a low-k dielectric [15].

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Employing SFIL for the mass production of advanced electronic devices faces challenges because the adhesion force between the resist material and the surface of the template must be minimized with fluorinated surfactants and the adhesion force between the resist and underlayer materials must be maximized to avoid various kinds of resist pattern peeling, defects, particles, and contaminants [16–19]. Fig. 1 shows a scanning electron micrograph (SEM) images of resist pattern peeling due to the weak adhesion force between the resist and underlayer materials which present a challenge that must be resolved for SFIL. These issues during separation must be overcome before this materials stack is ready for manufacturability [11,20,21]. In addition, an improved self-assembled monolayer on the template with higher separating performance must be developed.

A strong adhesion force generated by the chemical reaction between the resist and underlayer materials under UV irradiation

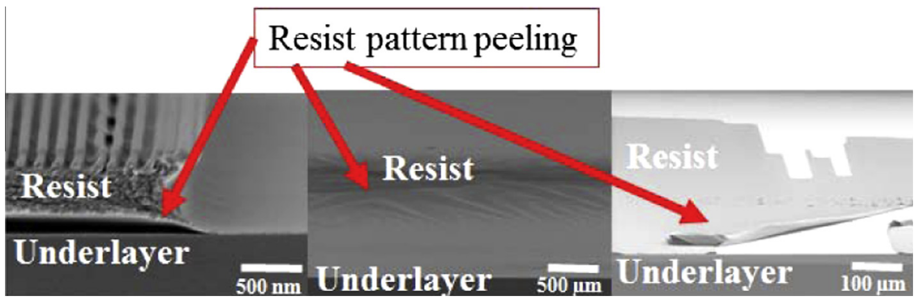

Fig. 1. SEM images of resist pattern peeling based on the weak adhesion force between the resist and underlayer materials.

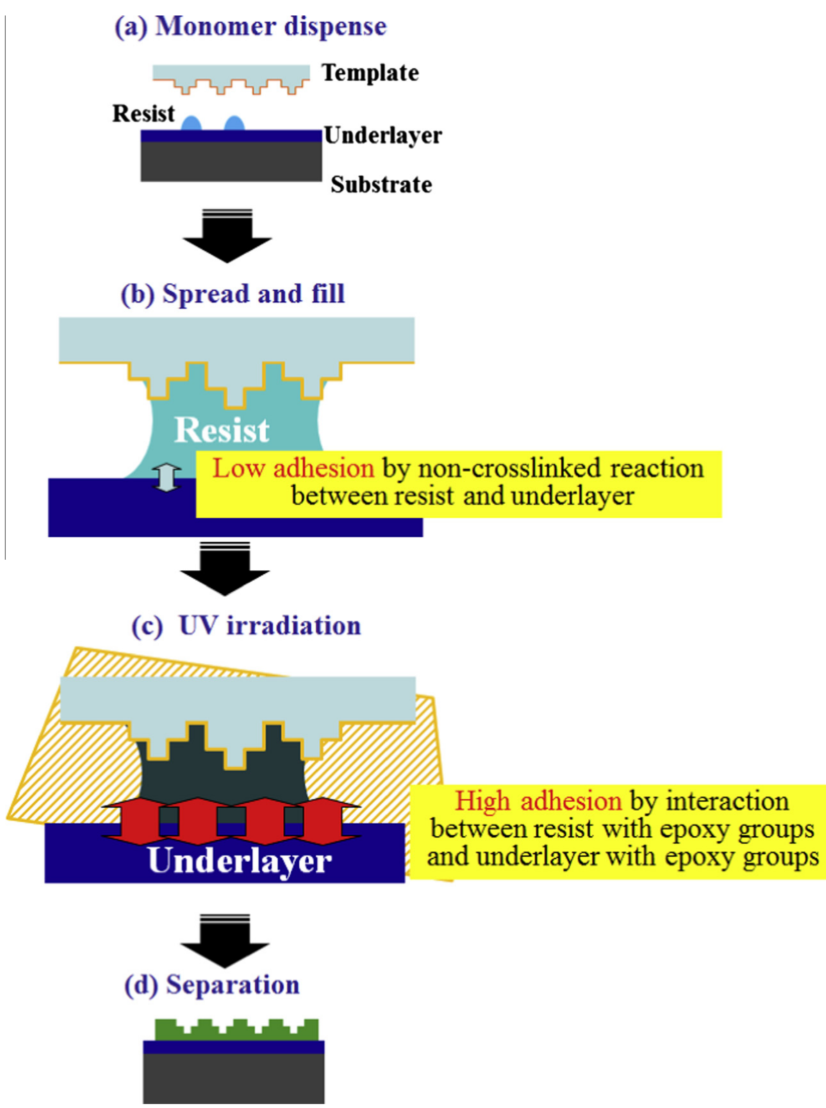

Fig. 2. SFIL process flow: (a) deposition of resist droplets, (b) spreading of the resist by imprinting, (c) UV irradiation, and (d) template release.