Microelectronic Engineering 88 (2011) 2017–2020

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

Roller nanoimprint lithography for flexible electronic devices of a sub-micron scale

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ARTICLE INFO

Article history:
Received 8 September 2010
Received in revised form 3 January 2011
Accepted 2 February 2011
Available online 15 February 2011

Keywords:
Nanoimprint lithography (NIL)
Roller nanoimprint lithography (RNIL)
Flexible substrate

ABSTRACT

This paper proposes a new concept of a RNIL (roller nanoimprint lithography) system. The system does not require the roll stamp that is necessary in the conventional RNIL system, and it easily transfers patterns from a hard stamp to a flexible substrate. Generally, hard stamps such as Si wafers are of a circular shape. While imprinting with a hard stamp using the RNIL system, the pressing force of the press roller in the system varies as the length of the contact line between the circular-type hard stamp and the roller changes. In this study, the contact force profile is presented and is then implemented. Micro- and nano-scale patterns are transferred from Si stamps onto thin and flexible PC (polycarbonate) substrates. Then performance of the system is the evaluated by SEM images.

1. Introduction

Since the invention of NIL (nanoimprint lithography) in 1995 [1], many variations have been proposed and developed. NIL processes have been studied to implement a low-cost, high-throughput and high-resolution application. RNIL (roller NIL) is an alternative approach to flat nanoimprint lithography. The RNIL process is used to transfer patterns onto flexible substrates. Compared to flat NIL, RNIL has the advantages of better uniformity, a lower pressing force, and the ability to repeat the patterning process continuously on a large substrate. Although many researchers have studied and reported RNIL processes and systems [2–4], many remaining issues associated with this process must be addressed, such as the fabrication of the stamp rollers, the decrease of the pattern width, and the increase in the substrate size. One of the key issues for the RNIL or NIL process involves the fabrication of the master stamp. EBL (E-beam lithography) is typically used to obtain a master stamp based on a silicon wafer. Similar to the RNIL process, a continuous roll-to-roll manufacturing technology is widely used for the production of solar cells or electronic paper [5–7].

Conventional RNIL systems have a stamp roller which contacts to a counter roller. A substrate goes through it and patterns are transferred from the stamp to the substrate. This technique can realize high-throughput operation and can transfer patterns to any substrate regardless of its rigidity. However, the fabrication of the roller stamp, especially for nanometer-scale patterns, remains as a bottleneck of the RNIL system. The stamp roller and counter roller should be aligned to realize perfect line contact.

In this paper, a roller nanoimprint lithography system is proposed. For imprinting, the press roller in this system rolls on a stamp while pressing the substrate on the stamp. After the imprinting process is finished, the press roller returns to its original position. For verification of the system, micro- and nano-scale patterns are transferred from a Si stamp based on a flat hot plate onto a flexible PC substrate.

2. Roller nanoimprint lithography

2.1. System design

A conceptual drawing of the RNIL system as suggested to transfer patterns from hard Si or quartz stamps is shown in Fig. 1. A press roller rolling on the stamp presses the flexible substrate into contact with the stamp on a hot plate line by line. The proposed RNIL system can easily adopt a flat-shaped hot plate, which is one of the most important technologies in the NIL system. Guide rollers following the press roller prevent the overall substrate length from shrinking or stretching during the RNIL process if the flexible substrate between the supply/withdrawal rollers and guide rollers is parallel to the top surface of the stamp.

There are springs on top and bottom of the roller holder guided by the vertical translation stage. Lower springs and upper springs are used to support the press roller and to deliver the pressing force from the vertical stage to the press roller, respectively. The pressing force is determined by the stiffness of the springs and by the displacement of the vertical translation stage after contact.

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doi:10.1016/j.mee.2011.02.018

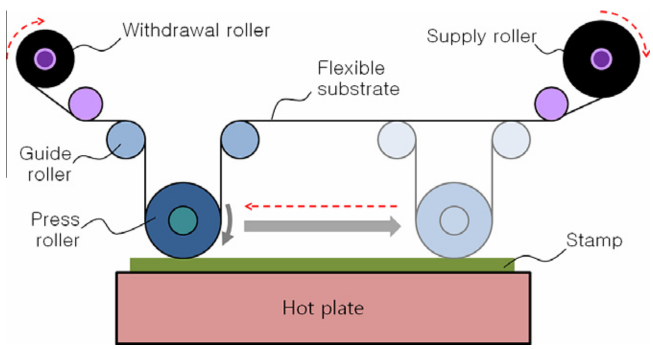

Fig. 1. Schematic drawing of the RNIL system for flexible substrates.

After the press roller with the flexible substrate moves down and comes into contact with the top of the stamp on the hot plate, the press roller rolls from the left position to the right position of the stamp, as shown in Fig. 1. When this imprint process is finished, the press roller with the substrate moves up and is thus released from the stamp. The press roller returns to its origin and the supply and withdrawal rollers rotate to feed the substrate for the next pattern transfer. This is one cycle of the pattern transfer, which can be repeated. The conceptual drawing in Fig. 1 shows only the case when the hot plate is used in thermal RNIL. However, the UV RNIL system can easily adopt a transparent window and a line-shaped UV source which follows the press roller to cure the resin on the substrate when only the substrate comes into contact with the stamp.

2.2. Contact pressure and force conditions

Si wafer stamps usually have a circular shape. Therefore, the pressing force should be changed to produce a constant pressure profile while the press roller rolls on the stamp. The top view of the RNIL system is shown in Fig. 2. For a constant pressure with maximum pressing force F_{max}, the force profile can be obtained by

$$F = F_{max}\sqrt{1 - \frac{4(C-x)^2}{D^2}} \tag{1}$$

where D is the diameter of the stamp, C is the position of the center of the stamp, and x is the horizontal position of the center of the press roller. The equation can be simply derived by calculating the length of the contact line for each position; it is only valid for the range of

$$C - \frac{D}{2} \leqslant x \leqslant C + \frac{D}{2} \tag{2}$$

The pressing force is measured by load cells installed between the press roller and its holder, and the position of the vertical stage is controlled for the load cell signal to follow the desired force profile. For multi-stamps, the force profile should be summed.

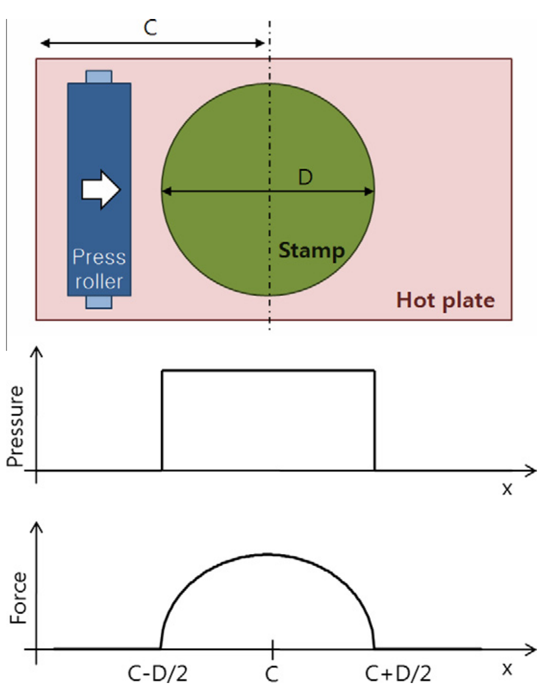

Fig. 2. Imprint pressure and force profiles for a circular stamp.

3. System implementation

3.1. System specification

The proposed RNIL system is shown in Fig. 3. The table-top sized system has a width of 1200 mm. The hot plate of the system is installed by modifying that of a UV/thermal nanoimprint lithography tool [8]. The press roller can move in the vertical direction to press the stamp and substrate, and it can move in the horizontal direction maintain contact in a line-by-line manner. The system feeds the flexible substrate from the supply roller to the withdrawal roller and maintains constant tension using a tension roller. While the imprinting process is ongoing, the hot plate applies heat to the stamp. The heat is transferred to the substrate when the roller makes contact with the stamp. Subsequently, the substrate is cooled by compressed air. A programmable PLC-based controller controls all of the components. The important variables for the imprint process are the pressing force of the press roller, the horizontal speed of the press roller under the press condition, the temperature of the hot plate, the cooling condition of the substrate,

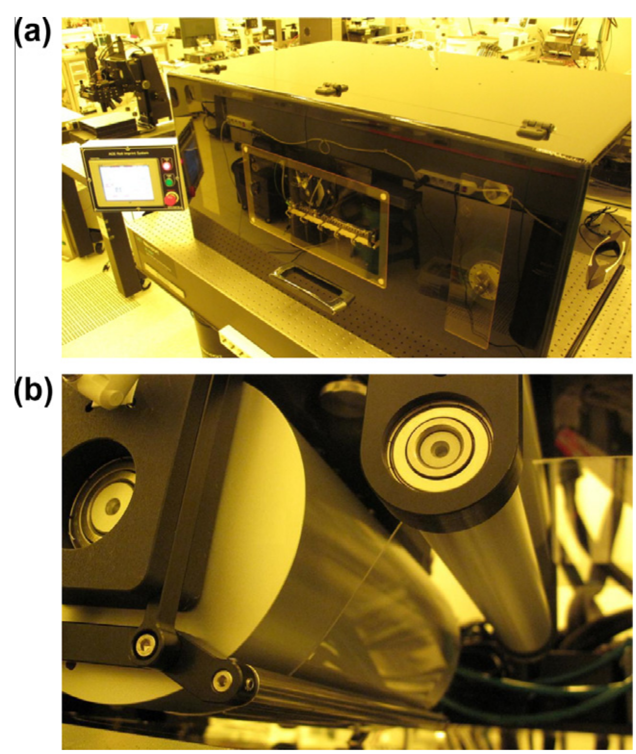

Fig. 3. Picture of (a) the RNIL system and (b) its roller mechanism.