Microelectronic Engineering 110 (2013) 219–223

Contents lists available at SciVerse ScienceDirect

Microelectronic Engineering

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

Fabrication of high-resolution conductive lines by combining inkjet printing with soft lithography

Jisu Sung, Byung Ju Kang, Je Hoon Oh *

Department of Mechanical Engineering, Hanyang University, 1271 Sa3-dong, Sangrok-gu, Ansan, Gyeonggi-do 426-791, Republic of Korea

ARTICLE INFO

Article history:
Available online 15 April 2013

Keywords:
Inkjet printing
Soft lithography
High-resolution printing
Surface wettability contrast
UV treatment

ABSTRACT

In this study, an effective method to fabricate well-defined conductive lines with high resolution has been proposed by combining inkjet printing with soft lithography. Soft lithography techniques such as nano-imprint lithography for negative SU-8 patterns and micro-contact printing for hydrophobic fluorocarbon layer were used to create surface wettability contrasts so that the spreading of droplets was confined on a hydrophilic region surrounded by hydrophobic regions. Surface wettability contrasts were evaluated by water contact angle measurements, and the maximum contact angle difference between hydrophobic and hydrophilic surfaces was 104°. With the help of such surface wettability contrasts and lift-off process for removing small amount of ink stains, well-defined inkjet-printed lines as narrow as 2.8 μm can be successfully generated. The sintered Ag lines also show good electrical resistivity of 7.6 μΩ · cm, 4.7 times as large as bulk Ag's resistivity. This combined approach can be used to fabricate high-quality, high-resolution electrodes in printed electronics applications.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Recently, a myriad of studies have been focusing on developing solution processes for the implementation of printed electronics because printed electronics has been expected to open new era of flexible and stretchable electronics. Inkjet printing is one of the promising solution processes to replace conventional photolithography in the field of printed electronics due to its simple, low cost and flexible characteristics [1–4]. However, inkjet printing still has several challenges, among which the limitation of resolution is probably the most serious one. Resolution is mostly determined by the initial droplet size and droplet spreading after being placed onto a substrate. The droplet size can be diminished by reducing the nozzle diameter, but this causes inks not to be ejected due to their rheological constraints. The droplet spreading is significantly influenced by surface wettability. Hydrophobic surface is preferred for producing high-resolution features; however, it causes various hydrodynamic instabilities due to high contact angles. Therefore, the resolution of conventional piezo-type inkjet printing still remains in the range of several tens of μm [5,6].

There have been some efforts to fabricate high resolution patterns by using electrohydrodynamic (EHD) jet printing [7,8] or combining inkjet printing with laser ablation [9]. However, each method has its own disadvantages: reliability issue for EHD jet printing and heat affected damage for laser ablation. Another approach is to create surface wettability patterns that confine the spreading of ink droplets on a hydrophilic region with hydrophobic regions surrounding it. For this approach, one of critical issues is how to make desired surface wettability patterns. Soft lithography techniques [10–12] such as nano-imprint lithography (NIL) and micro-contact printing (μCP) can be considered an acceptable method to fabricate such surface wettability contrasts.

In this work, we report on inkjet-printed conductive Ag lines with high resolution which are produced by combining soft lithography. In the soft lithography process, negative SU-8 patterns were fabricated on a glass substrate by placing poly(dimethylsiloxane) (PDMS) stamp onto a spin-coated SU-8 layer, followed by UV treatment to make the imprinted SU-8 surfaces hydrophilic. Hydrophobic fluorocarbon (FC) film was then transferred onto the top surface of SU-8 patterns using μCP, resulting in hydrophilic patterns surrounded by hydrophobic surfaces. After the surface wettability patterns were formed, ink droplets were placed on hydrophilic regions so that those regions can be filled with ink using capillary actions in order to minimize the interfacial energy among solid, air and liquid. Lift-off process of the FC film was performed to obtain well-defined inkjet-printed lines without any ink stains after inkjet printing process. The effects of NIL parameters such as NIL pressure and time on the morphology of imprinted SU-8 patterns were investigated using 3D non-contact surface profiler. Water contact angle (WCA) measurements for both hydrophobic and hydrophilic regions in the surface wettability patterns were conducted to evaluate the surface wettability

* Corresponding author. Tel.: +82 31 400 5252; fax: +82 31 400 4705.
E-mail address: jehoon@hanyang.ac.kr (J.H. Oh).

0167-9317/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.mee.2013.04.004

contrast. Electrical resistivity of the inkjet-printed lines was also evaluated after sintering process.

2. Experimental details

2.1. Soft lithography process

PDMS replicas have been widely used as stamps for the NIL process [13,14]. PDMS stamps are not treated by anti-sticking agents because of its inherent low surface energy [15]. The patterned Si master was spin-coated with a mixture of FC solution (EGC-1720 and FC-40, Novec™ 3M) for anti-sticking between Si master and PDMS mold. The mixture of PDMS base (Sylgad 184, Dow corning) and curing agent (Sylgad 184, Dow corning) (10:1 by volume ratio) was de-gassed in vacuum and then poured onto the patterned Si master as shown in Fig. 1a. The PDMS stamp cured at 60 °C for 4 h was then peeled off from the Si master. Thermoplastic and photosensitive epoxy based SU-8 solution (SU-8 2002, Micro Chem Co.) was selected as a NIL resin. A glass substrate was ultrasonicated in propylene glycol methyl ether acetate (PGMEA) solution for 5 min and then dried on a hot plate at 100 °C for 10 min. SU-8 solution was spin-coated on the glass substrate at 3000 rpm for 30 s to make thin and uniform SU-8 layer with 2 μm thickness and baked on a hot plate at 90 °C for 5 min to fully remove any residual solvents. As shown in Fig. 1b, the SU-8 layer was imprinted using the PDMS stamp under different pressures ranging from 0 to 15 kPa for 1, 2 and 3 min. The temperature of the SU-8 layer was kept at 100 °C to ensure viscous flow and thermal stability during initial NIL stage. The SU-8 pattern was then cooled down to room temperature, and the PDMS stamp was peeled off.

The imprinted SU-8 pattern was UV-treated for different times to convert its surface wettability from hydrophobic to hydrophilic (Fig. 1c). For UV treatment, UVO cleaner (AH-1700, AHTech LTS, Korea) which has power of 28 mW/cm^2 and two UV lamps with wavelength of 184.0 and 253.7 nm was used in the ambient condition. This UV treatment also leads to increase in the glass transient temperature of SU-8, above 200 °C, by producing photoacid that acts as a catalyst for cross-linking reaction during post exposure bake, which prevents distortion of structure in the sintering process of inkjet-printed features. Then, the μCP process was conducted using a flat PDMS substrate spin-coated with a mixture of FC solution (EGC-1700 and HFE-7100, Novec™ 3M) at 500 rpm for 20 s (Fig. 1d). The spin-coated FC film on the flat PDMS substrate was carefully contacted with the top surface of imprinted SU-8 patterns for 10 s. As a result, the top surface of SU-8 pattern became hydrophobic while the surfaces inside SU-8 pattern remained hydrophilic.

2.2. Printing process

After the soft lithography process, Ag nanoparticle ink (Harima Chemical Co.) was inkjet-printed on the imprinted SU-8 patterns using a piezoelectric single-nozzle printhead with a 30 μm nozzle diameter (MicroFab Co.). The ink contained 63.7 wt.% Ag nanoparticles in tetradecane with average particle diameter of 12 nm. Single droplet was sequentially inkjet-printed at three different positions on the imprinted SU-8 patterns to completely fill the inside of imprinted patterns (Fig. 1e). All inkjet printing processes were performed at room temperature, and all the inkjet-printed patterns were dried for 5 min under ambient condition. For the lift-off process to remove any remaining ink stains, the inkjet-printed patterns on the glass substrate were immersed into the fluorous solvent (HFE-7100, Novec™ 3M), which is a main solvent of the transferred FC film, for 30 s after drying process (Fig. 1f).

2.3. Inkjet-printed pattern evaluation

Morphology of the imprinted SU-8 patterns with different NIL pressures and times was observed using a 3D non-contact surface profiler. WCAs were measured on both the UV-treated and FC film-coated regions of the imprinted SU-8 patterns to estimate the surface wettability contrast. Optical microscopic images of

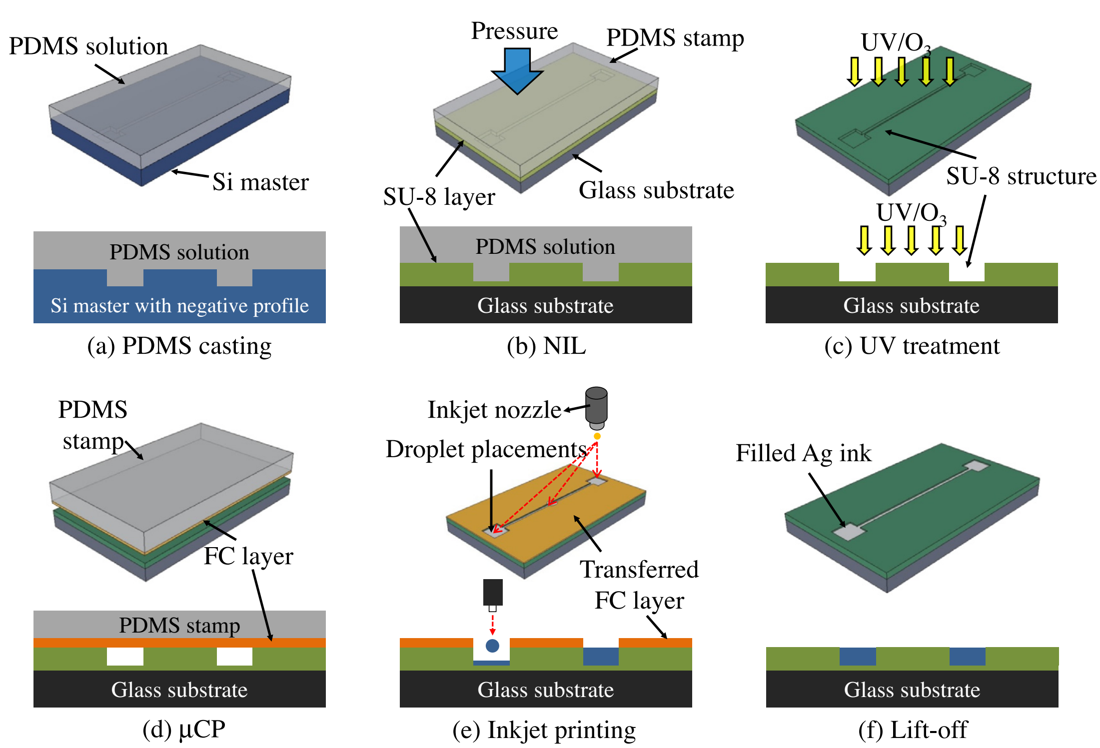

Fig. 1. Schematics of fabrication process of a high-resolution Ag line by combining soft lithography with inkjet printing.

Download English Version:

https://daneshyari.com/en/article/544264

Download Persian Version:

https://daneshyari.com/article/544264

Daneshyari.com