Thin Solid Films 546 (2013) 162–166

Contents lists available at ScienceDirect

Thin Solid Films

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

Control of surface wettability for inkjet printing by combining hydrophobic coating and plasma treatment

Heung Yeol Park, Byung Ju Kang, Dohyung Lee, Je Hoon Oh *

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

ARTICLE INFO

Available online 3 April 2013

Keywords:
Inkjet printing
Surface wettability
Hydrophobic coating
Plasma treatment
Surface characterization
Printed electronics

ABSTRACT

We have obtained a wide range of surface wettabilities of PI substrate for inkjet printing by combining hydrophobic solution coating and O_2 or Ar plasma treatments. Experiments were conducted to investigate the variation in inkjet-printed dot diameters with different surface treatments. The change in chemical and physical characteristics of treated surfaces was evaluated using static contact angle measurements, field emission scanning electron microscopy, atomic force microscopy, and X-ray photoelectron spectroscopy. Only hydrophobic coated surface produces the smallest dot diameter and the largest contact angle. Dot diameter increases and contact angle decreases as the plasma treatment time increases. Since the removal of hydrophobic layer from the surface occurs due to the etching effect of O_2 and Ar plasma during the plasma treatments, F/C ratio decreases with increasing the plasma treatment time. Surface roughness variations are also observed after plasma treatments. The ranges of printed dot sizes for O_2 and Ar plasma treatments are 38 μm–70 μm and 38 μm–92 μm, respectively. Ar plasma treatment shows a wider range of surface wettability because of higher removal rate of the hydrophobic layer. This combination of hydrophobic coating and plasma treatment can offer an effective way to obtain a wide range of surface wettabilities for high quality inkjet-printed patterns.

1. Introduction

Recently, inkjet printing has been attracting significant interest in the field of printed flexible electronics as a promising alternative to conventional photolithography due to its simple, flexible and environmental friendly natures as well as its compatibility with plastic substrates. Inkjet printing is conducted by placing ink droplets, which are ejected from a nozzle, at desired locations onto a substrate [1–8]. Behavior of printed droplets on a substrate is associated with the wetting characteristics between droplets and substrate. Generally, larger droplets with lower contact angles are produced on the hydrophilic surface, while the hydrophobic surface is more preferred to generate smaller droplets with higher contact angles. Even though the same printing condition is used to fabricate patterns, final shape and morphology of the printed patterns would vary with different surface wettabilities. Therefore, controlling the surface wettability plays an important role in producing inkjet-printed, well-defined features with desired resolution [9–12].

There have been many studies on controlling surface wettability using various surface treatment methods. Hydrophobic surfaces can be created by dip or spin coatings of fluorocarbon (FC) solutions [13,14], while UV irradiation is used to obtain hydrophilic surfaces [15–17]. In addition, substrates can be rendered hydrophilic or hydrophobic by plasma treatment with different precursors [18–21]. However, hydrophilic or hydrophobic surface characteristics produced by each surface treatment process are not enough for inkjet printing applications. Hydrophilic surface leads to wide pattern widths and hence low resolution; hydrophobic surface causes hydrodynamic instabilities such as droplet merge and line bulge. Therefore, an effective and reliable way of achieving variable surface wettability suited for inkjet printing application is necessary in order to improve the quality of inkjet-printed patterns.

In this work, a wide range of surface wettabilities of a flexible polyimide (PI) substrate were obtained using the combination of two different surface treatment methods: spin coating of hydrophobic film and plasma treatment with O_2 or Ar precursor. First, the effects of surface treatments on inkjet-printed dot diameters were investigated. Then, surface characteristics were examined by static contact angle measurement, field emission scanning electron microscopy (FE-SEM), atomic force microscopy (AFM), and X-ray photoelectron spectroscopy (XPS). Correlations between surface treatment and change in chemical and physical properties of the surface were finally discussed.

2. Experimental details

2.1. Surface treatment

Fig. 1 demonstrates the process of surface treatments to modify the surface wettability. PI substrate with a 25 μm thickness was first

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

0040-6090/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tsf.2013.03.067

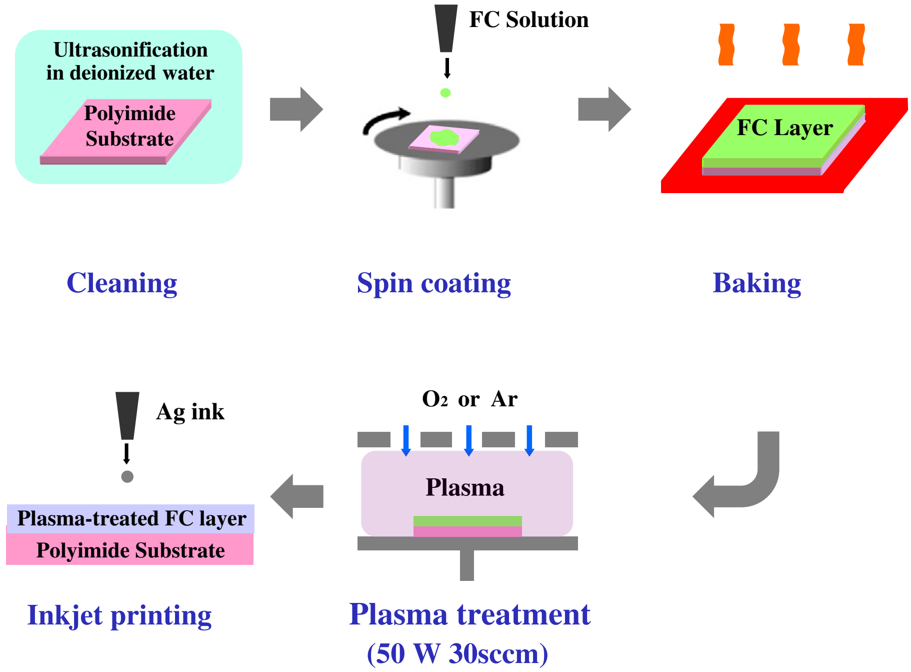

Fig. 1. Schematics of the surface treatment process.

ultrasonificated in deionized (DI) water for 5 min to remove surface contamination. The PI substrate was spin-coated with a mixture of FC solution (EGC-1720 and FC-40, 3 M, Korea) and then baked on a hot plate at 110 °C for 10 min to evaporate solvent from the FC film. After baking, the FC film-coated PI substrate was plasma-treated with O_2 or Ar precursor (Daesung Industrial Gases Co., Korea) for different treatment times. During the plasma surface treatment, the FC film-coated substrates were placed on the bottom electrode which was water-cooled to 18 °C. The process gases were introduced into the chamber through a showerhead in the top electrode at a flow rate of 30 sccm. After stabilization of the chamber pressure, 13.56 MHz RF power of 50 W was supplied to the top electrode to ignite the plasma for 10, 30, 50, 70 and 90 s.

2.2. Printing process

After plasma surface treatment, Ag nanoparticle ink (NPS-J, Harima Chemical Co., Japan), which contains 57.3 wt% Ag nanoparticles in tetradecane with average particle sizes smaller than 10 nm, was printed onto the surface-treated substrates to fabricate a 10 × 10 dot array pattern with a 200 μm dot spacing at three different positions on the substrate. The ink was ejected from a single piezoelectric printhead with a 30 μm nozzle diameter (MicroFab Co.) installed in an in-house inkjet printing system. After drying the inkjet-printed patterns, five dots were randomly chosen from each array, and their diameters were measured using an optical microscope. The average diameter of a total of 15 dots was used to evaluate surface wettability of each surface-treated substrate.

2.3. Surface characterization

We measured the static contact angle using a contact angle analyzer (Phoenix 300, SEO, Korea). Three contact angle measurements were performed at different positions on each surface-treated substrate. The surface chemical properties were examined by XPS. In order to recognize elements and chemical bonding present on the surfaces, both wide range survey spectra (0–1100 eV) and high resolution spectra of C1s (278–296 eV) were obtained from ESCA 2000 system (VG Microtech, UK) with a monochromatic Al Kα X-ray source (1486.6 eV) at pressures below 10^{-9} Torr. The aluminum X-ray source was operated at 13 kV and 15 mA current. XPS survey spectrum scans were run at a pass energy of 50 eV, and high resolution spectrum was taken at 20 eV pass energy. The C1s line of 284.6 eV (C–C) or 291.2 eV (CF_2) binding energy was used as a reference to correct the binding energies for the charge shift. FE-SEM (JSM-6700 F, JEOL, Japan) was utilized to investigate the physical change in surface morphology of the surface-treated substrates. All SEM images were taken at 10 kV. A root-mean-square (RMS) roughness of each surface was also evaluated using an AFM (My-scope, NanoFocus Inc., Korea) in tapping mode with a diamond-coated silicon tip (DT-NCHR, NanoWorld, Switzerland). The force constant and resonance frequency of the tapping mode were 42 N/m and 320 kHz, respectively.

3. Results and discussion

3.1. Inkjet-printed dot sizes

Fig. 2 shows the influence of O_2 or Ar plasma treatments on inkjet-printed dot diameters. The plasma treatment time of 0 s in all figures hereafter indicates that the substrate is only spin-coated with FC solution. The dots on only FC–coated surface show the smallest diameter of 38 μm due to a strong hydrophobicity of the FC film. As the plasma treatment time increases, printed dot diameters tend to increase for both O_2 and Ar plasma treatments. This tendency is due to the change in surface wettability with respect to the plasma treatment time. The FC–coated layer seems to be etched away during the O_2 or Ar plasma treatment process, resulting in the decrease in surface hydrophobicity (or the increase in surface hydrophilicity). Fig. 2 also demonstrates that Ar plasma treatment is more effective in increasing dot diameters than O_2 plasma treatment. Ar plasma treatment produces larger dot diameters under the same treatment time when compared to O_2 plasma treatment. When the treatment time is 90 s, the dots on the Ar plasma-treated surface have approximately the same diameter as those on the bare substrate only after ultrasonification; this indicates that the hydrophobicity of surface almost disappears after 90 s Ar plasma treatment.