Thin Solid Films 544 (2013) 64–68

Contents lists available at ScienceDirect

Thin Solid Films

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

Inkjet printing RF bandpass filters on liquid crystal polymer substrates

Hsuan-ling Kao [a,*], Cheng-Lin Cho [a], Li-Chun Chang [b,c], Chih-Sheng Yeh [a], Bo-Wen Wang [a], Hsien-Chin Chiu [a]

[a] Department of Electronic Engineering, Chang Gung University, 259 Wen-Hwa 1st Rd., Kwei-Shan Tao-Yuan 333, Taiwan
[b] Department of Materials Engineering, Ming Chi University of Technology, 84 Gongzhuan Rd., Taishan Dist., New Taipei City 24301, Taiwan
[c] Center for Thin Film Technologies and Applications, Ming Chi University of Technology, 84 Gongzhuan Rd., Taishan Dist., New Taipei City 24301, Taiwan

ARTICLE INFO

Available online 3 May 2013

Keywords:
Inkjet printing
Silver
Nanoparticle
Liquid crystal polymer (LCP)
Bandpass filter

ABSTRACT

This study investigates inkjet-printed radio frequency bandpass filters on liquid crystal polymer (LCP) substrates. Silver nanoparticle colloidal solution was used as a printing ink. A plasma polymerization technique was used to improve the LCP surface by optimizing the printing contact angle. Silver lines were then inkjet printed on the LCP substrate and cured in an oven to remove excess solvent and material impurities. The lines were printed with varied numbers of passes to study the changes in surface roughness and line width. The silver-film conductivity of the conductive ink was approximately 4×10^6 Siemens/m. The third-order dual-behavior resonators bandpass filter was simulated using software and printed with an inkjet printing system. The minimal insertion loss and maximal return loss were −2.18 and −27.8 dB at 5.4 GHz, respectively. This study describes the optimization of the inkjet printing process and discusses the surface treatment study of the inkjet-printed seed layer and process integration is presented in detail.
© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Due to the development of direct-write technology, inkjet printing has begun to emerge as a technique that can reduce manufacturing costs. Unlike the traditional etching technique, direct-write technology uses no masks, reducing material usage and waste generated from wet processes. Inkjet-printing technology is also generally faster and more economical than other additive manufacturing technologies. Some reports have investigated surface treatment [1–4] and also drying and heating treatment [5–8] by studying the morphology and electrical conductivity of inkjet printing metal films. In recent years, inkjet-printing technology has been attempted in RF (or microwave) applications, such as an ultra-high frequency antenna or filter on a paper substrate [9–13]. Although paper, as a substrate, offers low-cost, fast and simple inkjet printing, it is limited by high-frequency, absorption, and humidity issues. Substrate materials must also be developed due to the ever growing demand for low-cost, flexible and power-efficient broadband wireless electronics. Liquid crystal polymer (LCP) [12,13] is a good material with an impressive loss tangent (approximately 0.005 up to 110 GHz) for high-frequency applications. It is also suitable for reel-to-reel processing due to its good flexibility. However, only one study has examined a dual-band antenna using inkjet printing on an LCP substrate to serve as a sensor in 24/60/70 bands [13]. Conductivity uniformity and the thickness of the inkjet-printed metal line are the major concerns when it comes to insertion loss in printed circuits. Therefore, inkjet-printing conditions including surface treatment, dot size, additional thermal treatment, and multi-pass printing on the LCP substrate, should be established to improve the conductivity uniformity and printed metal line thickness. This study observes and compares the microstructure and electrical properties of inkjet-printed Ag-film on an LCP substrate. This study proposes a simple third-order DBR bandpass filter using inkjet printing using optimal inkjet-printing conditions to achieve good performance. The inkjet-printing parameters and the interaction between the ink and LCP substrate indicate the future low-cost, rapid manufacturing of RF and millimeter-wave (mm-wave) circuits.

2. Experiments

The bandpass filter was reproduced on an LCP using inkjet-printing technology. An LCP substrate, with constant relative permittivity (ε_r) at 3.2, a stable loss tangent (tan δ) below 0.005 up to 110 GHz and a substrate thickness of 100 μm, is suitable for a high-frequency design with excellent performance. Before printing, it is necessary to treat the surface by plasma polymerization with appropriate conditions. Samples were held in a vacuum at a pressure of 4 Pa. Adding oxygen to the chamber increased the working pressure of 9.33 Pa. The surface treatment processes were conducted at room temperature. The plasma was sustained between parallel-plate electrodes by an RF generator operating at 13.56 MHz at various plasma polymerization operation powers for 5 sec. The filter was printed using a Dimatix DMP 2800 printer with a DMC-11610 cartridge. The cartridge contained 16 nozzles, 20 μm in diameter and each nozzle generates 10-pL ink drops. The drops produced a 50-μm spot when printed on a surface treated with an LCP substrate. Silver

* Corresponding author. Tel.: +886 3 2118800x5951; fax: +886 3 2118507.
E-mail address: snoopy@mail.cgu.edu.tw (H. Kao).

0040-6090/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tsf.2013.04.125

nanoparticle inks are usually used in the inkjet-printing process to ensure good metal conductivity. The ink (ANP, DGP-40LT-15C) we used contained 30 to 35 wt% of spherical silver nanoparticles, dispersed in triethylene glycol monoethyl ether. Silver nanoparticle ink was printed on a substrate heated to 60 °C.

The sintering process is important because it removes excess solvent and material impurities from the deposition and increases bonding between the silver ink and substrate. After the silver ink was printed, it was sintered in an industrial oven at a low temperature (<150 °C). The low sintering temperature also enables passive microwave circuitry to be printed on an LCP substrate. The sintering process increases the conductivity of the printed structures toward the higher end of the conductivity range.

Multi-pass printing of the devices is required to achieve conductor thickness and thereby improve maximal conductivity and circuit efficiency. The conductivity of the printed metal lines, depending on the type of nanoparticle, printed thickness and sintering temperature, was measured using the four-probe method. Printed thickness relies on the wetting characteristics of the substrate surface, dot size, heating temperature, and viscosity, and was measured by scanning electron microscope (SEM) photo. The surface morphologies of the films were examined by field emission scanning electron microscopy (JSM7000F, JEOL, Japan) under a 3-kV accelerating voltage. The cross-sectional images of the films were evaluated by using a SEM (S3400N, Hitachi, Japan) under a 15-kV accelerating voltage. The cross-sectional SEM samples were prepared by cold mounting. Printed bandpass filter characteristics at optimized printing conditions were measured using an HP8510C network analyzer for S-parameter measurements.

3. Results and discussion

3.1. Surface treatment using plasma polymerization

The interaction between the ink and substrate is vital for high-resolution patterning in inkjet printing. Capillary forces and surface wetting determine how the inke drop spreads on the substrate. Studies have used surface treatments with argon and oxygen plasma [1], UV-ozone [4] or wet bath treatments [7] to increase substrate surface energy. [13] used an ethyl-alcohol solution as an LCP substrate and heated it to 120 °C 10 min. However, wet bath treatments are complex and tedious. Therefore, in this study, the plasma polymerization surface treatment on an LCP substrate renders it hydrophilic, producing correct printing conditions. The one-step plasma polymerization treatment is rapid and easy. Plasma treatment enhances the substrate surface energy. The contact angle monitors the surface tensions of the corresponding interfaces that intersect at the three-phase contact line. An optimal contact angle is required for uniform distribution of silver nanoparticles. Fig. 1 shows the Ag ink droplet contact angle and single-pass printing silver thickness measurement at different plasma polymerization operation powers for 5 sec. Without any plasma treatment, the contact angle is 110°. Since that angle means the LCP substrate is too hydrophobic, plasma polymerization treatment is required. Increasing the plasma operation power decreases the contact angle and silver thickness. An operating power of 10 W saturated the contact angle and silver thickness. A larger contact angle indicates a thicker silver. The initial contact angle was 111° and the silver-film thickness was 3.5 μm. The saturation contact angle and silver thickness were 48.6° and 1.96 μm, respectively. Fig. 1 also shows optical microscopy photographs for a 1 × 1 mm^2 Ag pattern. A larger contact angle produces silver nanoparticle focus on the pattern center and the pattern edge is sawtooth. With a smaller contact angle, the ink spreads and the pattern is distorted. Therefore, because of weak resolution and conductor thickness, the surface treatment was applied at 3 W power for 5 sec durations. This produced a contact angle and silver thickness of 79.44° and 2.8 μm, respectively. This setting was used in subsequent experiments.

3.2. Droplet spacing

Inkjet printing forms liquid beads by overlaping of adjacent spread drops. A liquid bead forms when a line of spread droplets coalesces. Spacing is a function of the print head traverse speed relative to the substrate. When droplet spacing is too large, no overlap of the spread drop is observed. With slightly smaller spacing, droplets coalesce, but the two sides of the line are scalloped. With proper droplet spacing, a stable liquid bead forms with smooth parallel sides. When droplet

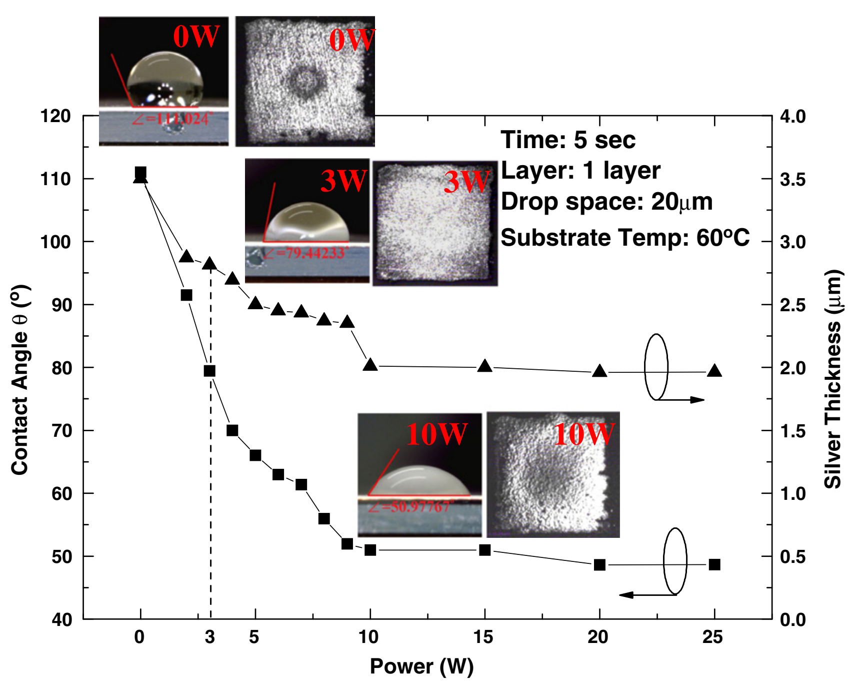

Fig. 1. Contact angle and silver thickness versus operation power of plasma polymerization for surface treatment.

Download English Version:

https://daneshyari.com/en/article/1665953

Download Persian Version:

https://daneshyari.com/article/1665953

Daneshyari.com