LOW-COST FLEXIBLE ALL-INKJET-PRINTED MICROFLUIDIC SENSOR

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ABSTRACT

This paper demonstrates a novel and low-cost additive manufacturing process for flexible and disposable microfluidics on virtually any substrate, with which the first "all-inkjet-printed" microfluidic microwave sensor is prototyped. A 30-µm-high 600-µm-wide SU-8 (polymer) 3-D microfluidic channel and an electromagnetic sensing setting are fabricated with sole reliance on multilayer inkjet-printing technique. This flexible and deposable sensor can be used in detecting and calibrating various fluids.
KEYWORDS: Microwave Sensor, Inkjet-printing, Additive Manufacture

INTRODUCTION

Microfluidics devices are traditionally fabricated with photolithography and associated technologies, as these technologies are relatively mature given the development of microelectronics and microelectromechanical systems (MEMS). However, these processes are generally expensive and environmental unfriendly [1]. Recent years witnessed an increasing number of novel and low-cost microfluidics fabrication approaches being proposed. Inkjet-printing, a low-cost rapid additive manufacturing technique, is a promising candidate which is recently involved in microfluidics fabrication process. By inkjet-printing barriers of channels on filter paper, plenty of paper microfluidics are prototyped [2,3], yet this method has only seen applications in filter papers and 2D structures. Another approach is inkjet-printing polymer as a sealing method [5,6], but it still needs cooperation from other subtractive manufacturing techniques such as laser etching. In this paper, a disposable and flexible microfluidics sensor is presented, which can be additively manufactured on virtually any substrate with sole reliance on multilayer inkjet-printing technique.

THEORY

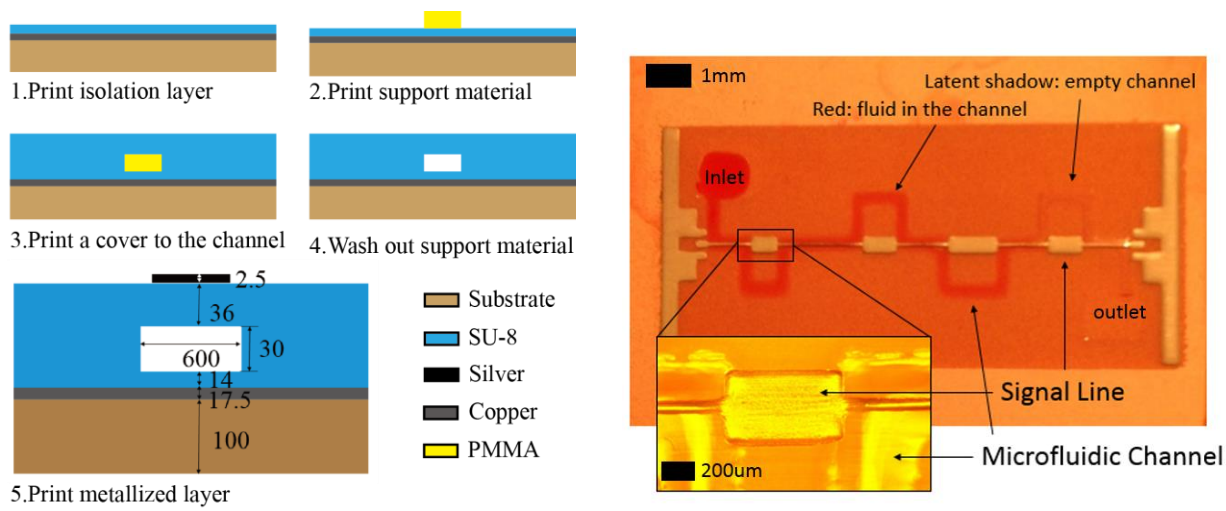
In our nature environment, fluids have a wide permittivity distribution at microwave frequency and a lot of potential information, such as concentration or mixing ratio about the fluids can be learned by sensing the permittivity changes. Most microfluidics microwave sensors observe frequency shift to detect permittivity changes [5,6], which requires a microwave detector with a wide frequency spectrum and largely increases the burden. This paper takes another approach, reading permittivity difference from attenuation variation, which only needs response at one or two frequency points. A stepped impedance low-pass filter is used which allows signal under 13GHz to pass and weaken the signal above 13GHz. The stepped impedance low-pass filter is optimized and has dimensions in Table 1. By placing the microfluidic channel right under the narrow segments and 2.5 mm away from the wide segment (figure 1(b)), the attenuation and cutoff frequency of the filter would change with the fluids in the channel.

Table 1. Dimensions of the stepped impedance low-pass filter (metal pattern)

Name	Value (mm)				
Line width	0.12(Narrow)	0.55 (Wide)			
Segment length	1.95(Narrow)	3.79(Narrow)	2.29(Narrow)	2.22(Narrow)	2.11(Narrow)
(Left to right)	1.08(Wide)	2.04(Wide)	1.41(Wide)	1.38(Wide)	

EXPERIMENTAL

The proposed fabrication process, due to its additive mechanism, is applicable to build 3D structure on various substrates including wafer, glass, paper, metal and plastic. As a proof of concept and without loss of generality, the substrate used in preliminary prototype is liquid crystal polymer (LCP) coated with copper. The fabrication method (Figure 1(a)), involves 3 different inks, SunTronic Silver nanoparticle ink, SU-8 ink and Poly(methyl methacrylate) (PMMA) ink, and utilizes the Dimatix DMP-2831 printer. First, 14-µm-thick SU-8 was printed on the copper to isolate the metal from the tested fluids in microfluidic channel. After cross-linking the SU-8 with UV light and heat, a 30-µm-high 600-µm-wide PMMA trace was deposited as a placeholder for the channel and dried at 120 ℃ for 1 hour. After dehydration and surface energy adjustments, another 66-µm-thick SU-8 was deposited on the top. After cross-linking the SU-8, removal of PMMA was carried out by ultrasonic bath in anisole solution for 2 hours. Finally, the metallization pattern was printed with silver ink and cured at 150 ℃ for 1 hour. A fabricated prototype can be found in Figure 1(b). As LCP is a flexible substrate and printed microfluidics is extremely thin, the fabricated prototype is flexible and can easily achieve a 7-mm-radius bending.



(a) *(b)*

Figure 1: (a)Cross-section view of fabrication process(Unit: µm). (b)Top view of fabricated prototype.

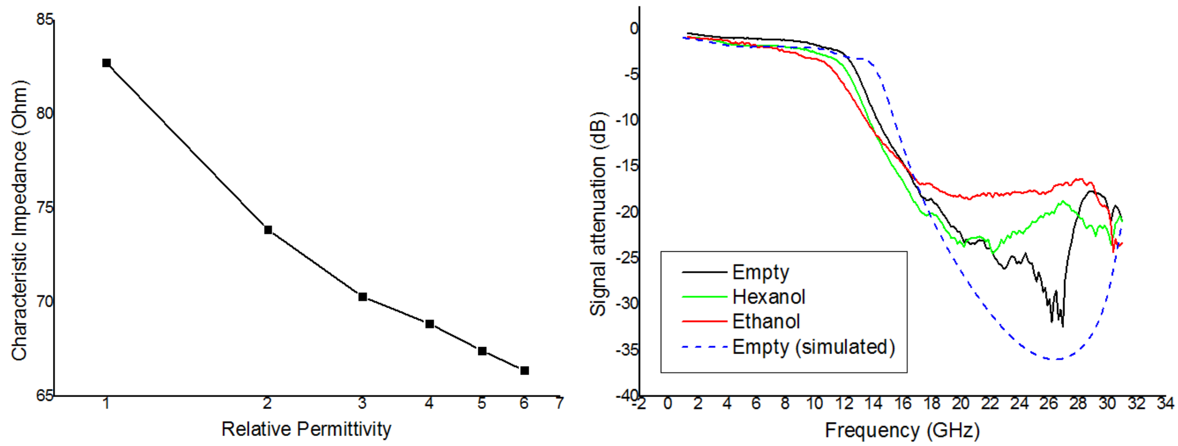
RESULTS AND DISCUSSION

In order to test the functionality of the fabricated device, a Rhode and Schwartz ZVA-8 Vector Network Analyzer is connected to the sensor to measure the S-parameters of the device under various fluids. A drop of tested fluid is drip into the inlet and capillary force lead the fluid to fill the channel. Empty (air-filled), ethanol-filled and Hexanol-filled channel, with their relative permittivity in Table 2, are used to test the fabricated prototype.

Table 2. Relative permittivity of air and measured fluids.

Materials	Relative permittivity[7]
Air	1
Hexanol	2.8
Ethanol	5

By changing the relative permittivity in the microfluidic channel, the impedance of the narrow line is tuned, as shown in Figure 2(a), which leads to attenuation change. The measured signal attenuation (insertion loss, S21) (Figure 2(b)), matches the electromagnetic simulation and demonstrates an excellent sensitivity of maximum 4 dB/εr. The signal attenuations of the sensor when hexanol and ethanol with only 2.2 relative permittivity difference fill the channel respectively, can be easily distinguished.



(a) *(b)*

Figure 2. (a) Simulated characteristic impedance varying with fluids of different relative permittivity in the channel. (b)Measured and simulated responses of the sensor with different fluids in the channel.

CONCLUSION

This paper shows a "all-inkjet-printed" microfluidics fabrication process which can be applied on virtually any substrate. As a proof of concept and without loss of generality, a 30-µm-high 600-µm-wide 3D microfluidics channel is fabricated on copper with SU-8. This paper also presents a disposable and flexible microfluidics microwave sensor which can be used to detecting permittivity difference of the fluids and has a sensitivity of maximum 4 dB/εr.

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