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Hybrid Inkjet Printing Technology for Self-sustainable Wireless Sensors

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Abstract

In this paper, the far-field energy harvesting-enabled self-sustainable antenna-based sensor technology utilizing the hybrid printing technology is introduced. The hybrid printed electronics take advantages of the additive fabrication process like the printing technology and the highly advanced solid-state surface mounting integrated circuits (ICs). For the circuit metallization techniques, direct printing of silver nanoparticle ink and indirect printing of a thin copper film using $PdCl_2$ catalyst ink are discussed.

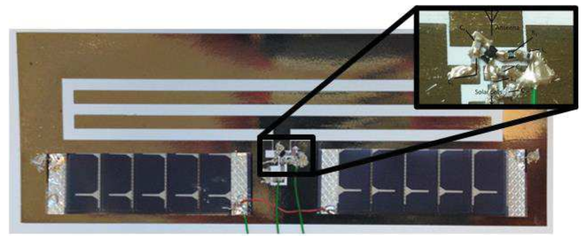
1. Introduction

Self-sustainable wireless sensor platform is one of the essential technology for the Internet of Things (IoT) and wireless sensor network applications. To make the self-sustainable senor/IoT platform real, there are numerous research efforts were reported and rigorously experimented [1][2]. Among the many promising technologies, printing technology have received huge attention due to its inherent flexibility and compatible with other technologies such as solid-state integrated circuits (ICs). It is called the hybrid printing technology integrating the high-performance conventional silicon-based ICs and low-cost printing technology. In this paper, the hybrid printed electronics which is suitable for the energy harvesting capability-enabled self-sustainable sensor platform technology is discussed with numerous design examples [2-5].

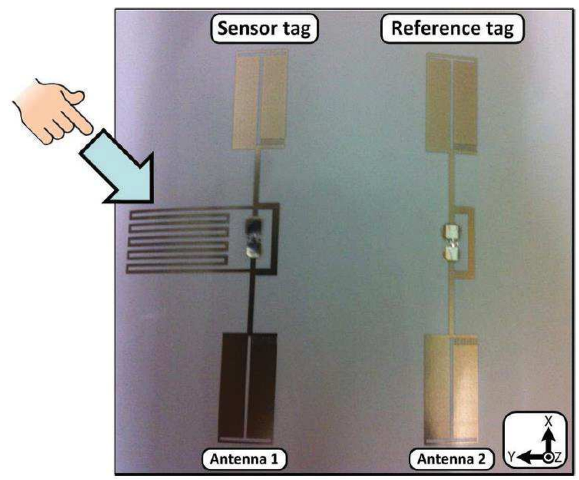
2. Hybrid Printing Technology

2.1 Direct Printing of Silver Nano-particle Ink

One of the most popular method for printing a conductive layer is to print silver nano-particle ink [2]. The silver nanoparticles ink consists of silver nano-particles in size of 10 ~ 50 nm and chemical dispersant such as polymers. A sintering process is necessary to make the printed silver nano-particles conductive by evaporating melting the solvent. The heat sintering is most popular process compared to other methods like UV flash light and laser sintering processes due to its simplicity. There are few critical parameters to achieve highly conductive silver layer. Those are number of printed ink layers, surface roughness of the substrate, sintering temperature and nanoparticle concentration of the ink. Usually, not more than 5 layers of silver nano-particle ink are printed, and the printed pattern is sintered in a convection oven lower than 200 °C at atmospheric pressure. The thickness of the printed metal film was increased by 500 nm per number of printed layers, and 5-time printed silver nano-particle layer had a conductivity value of about 1.2×10^7 S/m when it was sintered at 200 °C for 10 mins.



(a)



(b)

Figure 1. (a) Solar-to-RF energy converter for far-field wireless energy transfer and (b) RFID-based dual-tag haptic sensor.

Figure 1 shows examples of hybrid printed electronics for self-sustainable wireless sensors [3]. Figure 1(a) shows active antenna converting solar power to RF power at 860 MHz. It increases electromagnetic power density near the solar-to-RF power converting active antenna to power up the near located RF energy harvesting capability-enabled

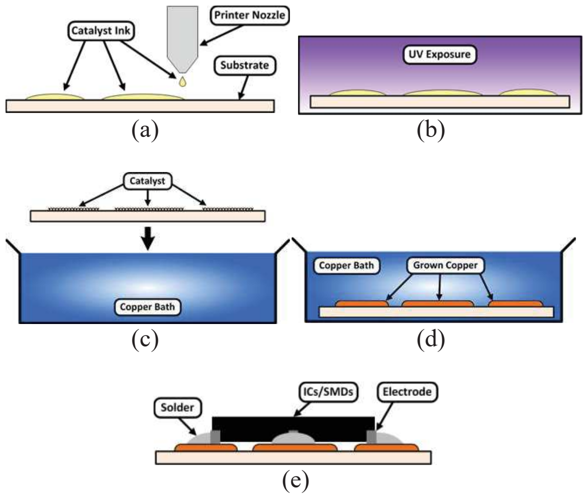


Figure 2. Indirect thin copper film printing process for the hybrid printed electronics: (a) printing of $PdCl_2$ ink, (b) UV exposure, (c) copper bath, (d) copper growing and (e) soldered ICs on the thin copper film.

sensors. The harvested solar power is connected to a voltage regulator which supplies power to the oscillator. The oscillator feeds a single tone signal at 858 MHz to antenna. Figure 1(b) shows dual-tag haptic RFID-enabled sensor [4]. A capacitive sensor was integrated with a sensor tag to detect capacitance variation. The input impedance of the sensing component (meandered line) is working as a load to the sensor tag. When the load impedance changes, matching between the RFID chip and the antenna also varies resulting in variation of the required minimum power to excite the sensor tag. However, the reference tag is independent from the input impedance of the sensing component. Therefore, it is possible to detect event (haptic touch) by comparing the read range of the two tags without any calibration.

2.2 Indirect Printing of Catalyst Ink

In this section, indirect printing technique of a thin copper film is presented. A seed layer was formed by printing palladium catalyst ($PdCl_2$) ink on flexible polymer substrate, and the printed catalyst ink was exposed to UV light to improve bonding on the substrate. The thin conductive copper layer was grown in a copper bath. The fabrication process it depicted in Figure 2. The grown conductive copper film is compatible with low-temperature soldering process which enables high performance flexible hybrid printed electronics. As shown in Figure 2(e), it is novel manufacturing process integrating printing and surface mounting technologies. The thickness of the copper film was about 3.87 µm and its conductivity is about 3.4×10^6 S/m.

As a proof-of-concept, a loop antenna and RF-DC converter with DC-DC voltage booster were designed and fabricated using off-the-shelf components as shown in Figure 3 [5]. It harvests far-field electromagnetic energy at

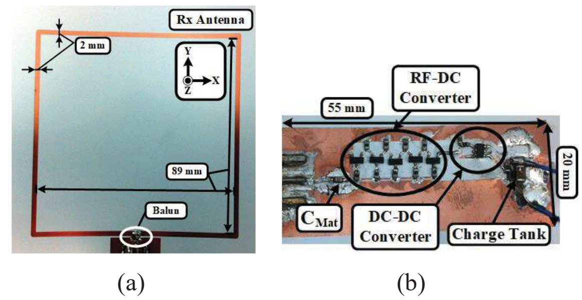


Figure 3. Indirectly printed hybrid electronics: (a) a loop antenna and (b) RF-DC converter with DC-DC voltage booster.

UHF RFID frequency band (840 ~ 940 MHz). The harvested or scavenged wireless power is rectified and boosted by the charge pump circuit. The DC-DC voltage booster supplies regulated voltage 3.0 V to a load. The load can be any types of applications such as a microcontroller-based sensor circuit. It is clearly shown that all the off-the-shelf components are soldered on the printed circuit.

3. Acknowledgements

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4. References

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