Hybrid Stacked RFID Antenna Coil Fabricated by Ink-Jet Printing of Catalyst with Self-assembled Polyelectolytes & Electroless Plating

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Abstract

This article describes a method of forming stacked hybrid metal structure and pattern to enhance RFID antenna coil inductance. The essential strategies included the use of self-assembled polyelectolytes to modify surface property, an ink-jet printing process for catalyst, and a stacked hybrid metal layer formed by electroless plating. The minimum line width and line spacing can reach 100μm / 100μm. In addition, the characteristics of prior researches about metal antenna formed by use of ink-jet printing or other traditional methods were also compared with this case. It is verified that this process with different substrates, like PI, PET, and FR-4, could render satisfactory performance in related application. Laboratory experiments showed that the inductance of this antenna is tunable from range 300 nH up to 20 uH, depending on the resulting metal coil thickness.

Introduction

In recent years, printed organic electronics have been intensively developing because of many advantages, such as low cost, easy and flexible processes, efficient usage of material and large size manufacturing in comparison with conventional lithography and vacuum processes. These applications include polymer light-emitting diodes (PLED), organic thin-film transistors (OTFT), organic bistable memory (OBD), metal circuits and so on. According to the forecast data from marketing research institutes, printed logic integrated circuits gradually attract much attention and will dominate in the future. Among the logic ICs, radio-frequency identification (RFID) tags seem to be the most potential vehicle. These low-cost printed products can replace not only tremendous UPC barcodes but also expensive inorganic RFID with silicon chips used on supply-chain and retail automated check. Generally, a simple RFID system (Fig. 1) consists of a reader and a tag. There are many active and passive devices in a tag, including an antenna, a capacitor, a diode, a transistor and some memories at least. The system can be operated at lower than 125 kHz, 13.56 MHz, 860-930 MHz, and higher than 2.45 GHz respect to different application. Many companies have devoted to printed RFID development with organic semiconductor; however, the operation frequency of RFID is limited to the organic semiconductor with low mobility. Hence a highly conductive coil for the tag antenna is necessary. [1,2]

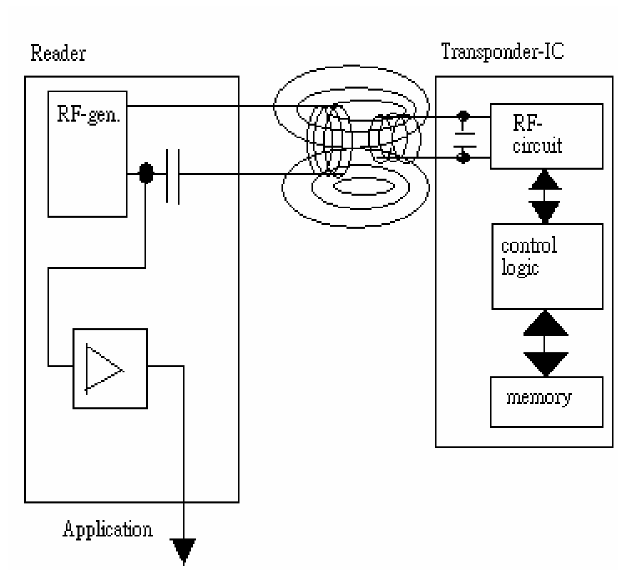

Figure1. A RFID system

At present, most tag antennas, with good conductivity, are fabricated by copper or aluminum etching. The line width is 600-800 um and line space is 200-400um in each common etching case. For metal paste, it can be used in screen printing or inkjet printing process, but suffered from low resolution, poor adhesion, and high cost. In addition, the resulting metal paste patterns always need a thermal curing process to sinter the metal particles to afford acceptable conductivity. The curing temperature will increase as the particle size increase, especially for the screen process. However, polymer type substrates often limit the usage of high temperature processes. [2, 3]

Besides conductivity issue, high Q value inductors and well behaved capacitors are required for power coupling and communication. High Q inductors can be achieved with several methods, which include increasing the circles of antenna coil, reducing the resistance of antenna coil and addition of magnetic material to the coil. Among those measures, the addition of magnetic material was best method to promote Q value. [3, 4]

Due to the high inductance value of magnetic material, we apply magnetic metal, nickel, to our inkjet printed copper RFID antenna coil in this article. By use of this method, the inductance of antenna coil can be enhanced from 300 nH to 20 uH.

Experimental Section

Multilayer Assembly

Poly (allyamine hydrochloride) (PAH) (Mw=55000~65000) and Poly (acrylic acid) (PAA) (Mw = 70000, 25% aqueous solution) were purchased from Aldrich. All chemicals were used without further purification. DI water was used in all aqueous solutions and rinsing procedures. The concentration of the polyelectrolyte-dipping solutions was 10 mM based on the molecular weight of repeat unit. The pH values of the PAH solution and PAA solution were adjusted to 7.5 and 3.5 by adding 1M HCl and 1M NaOH, respectively. Layer-by-Layer assembly was carried out on an auto-dipping system.

Table 1.The process flow of self-assembled polyelectrolyte layers.

Step	Condition
Substrate Cleaning	Washing with Toluene and DI-water in sequence
Immerse into $PAH_{(aq)}$	$PAH_{(aq)}$ (10mM)
Substrate flushing	DI-water
Immerse into $PAA_{(aq)}$	$PAA_{(aq)}$ (10mM)
Repeating (PAH/PAA) Bi-layer deposition	Up to three pairs of PAH /PAA layers
Immerse into $PAH_{(aq)}$ (10mM)	$PAH_{(aq)}$ (10mM)

Ink Preparation

The ink was prepared by dissolving Pd complex compound in DI water. The ink viscosity and surface tension were controlled by addition of commercial thickener to reach about 8~20 cps and 40 dyne/cm. Before installing into the print head, the compatibility of head and ink was performed previously.

Ink-Jet Printing

The printing process was conducted on a third generation print platform, designed and integrated for 550 mm x 650 mm substrates by ITRI. Polyimide, PET, FR-4 substrates with different self-assembly layers were printed on with the catalyst solution. The printed pattern was according to the input of image data. When the solution was drying, the catalyst would be adsorbed on the substrate surface, and gradually diffusing into the beneath layer of poly (allylamine hydrochloride) (PAH) and therefore an inkjet defined area was afforded. [5, 6, 7]

Electroless Plating

Electroless Plating Nickel Process

Commercial formulation, consisting of 40 g/L nickel sulfate, 20 g/L sodium citrate, 10 g/L lactic acid, and 1 g/L DMAB in DI water, for the electroless nickel deposition was used. The nickel electroless plating solution of all components except DMAB, a reducing agent, solution was prepared in advance. DMAB aqueous solution was prepared separately. The fresh electroless plating solutions were prepared with a ratio of 4:1 (in volume) for nickel contained solution to DMAB solution before nickel plating process. Then the mixture solution was adjusted to a pH value of 6.8 by titration with 0.3 M ammonium hydroxide solution.

Before deposition of nickel metal, the substrate need to be dipped into the accelerator solution about 3 to 10 seconds and then washed with DI water then dry. In order to keep the solution uniform, an air bubble generator was used in the plating bath. [5, 6, 7]

Electroless Plating Copper Process

Because nickel and nickel electroless plating solutions would induce copper ion reduction, the substrate with nickel antenna coil, obtained from previous plating process, need to be washed with DI water for 10 min. to remove non-adsorbed nickel particles and nickel plating solution from the surface then dry, before electroless plating copper. All of the reagents for copper electroless plating were dissolved in DI water at room temperature with stirring. To keep the solution uniform, an air bubble generator air was also used in the electroless plating bath. The pH value of the bath was monitored and kept within a specific value of the bath case monitored and kept within a specific value. The copper deposition was carried out at 40℃. Immersion time and temperature are two key factors to control the wire thickness. After being removed from the electroless plating solution, the samples were rinsed with DI water to remove electroless plating solution and then set aside to dry. [6, 7]

Results and Discussion

An antenna coil pattern with line width of 75-100um and line space of 75-100um was obtained. The resulting conductance can be adjusted by controlling nickel and copper electroless plating recipes. The edge of the nickel metal line with 2 um thick was uniform as shown in Fig. 2 (a) to Fig. 2(c). The line edge after electroless plating copper was still smooth as shown in Fig. 2 (d) and Fig. 2(e), in which the copper metal thick was 5um. However, many unexpected particles were present within the line space (Fig. 2 (f)), which might come from unwanted residual nickel particles and nickel electroless solution.

The electrical measurement was performed on a RLC meter and the data was shown in Table 2 and Table 3. The inductance of hybrid RFID antenna coils (sample 1 and sample 2) was higher than that of copper antenna coil (sample 3) about 50 times, although the resistances were similar in both cases. The incorporation of magnetic metal into the coil structure can dramatically enhance the inductance, and therefore the Q factor. A maximum Q factor near 0.62 was achieved from a hybrid metal structure of 2 um thick nickel and 5 um thick copper. The conductivity of the printed antenna coil could reach about 90% of bulk copper; however, the antenna coil resistance was higher than that of etching copper antenna coil. The high resistance was due to the impurities imbedded in the antenna coil when the electroless plating process proceeded. Hence the Q factor could be further improved by reduction of antenna coil resistance.

In addition to Q factor, the impedance between antenna coil and interconnected coaxial cable should be about 50 ohm, on the basis of this layout, to get better communication response of the RFID antenna coil, as shown in Table 2, the resulting impedance of printed RFID antenna coil was 29 ohm, mismatching to that of expected value. In order to get better performance of RFID antenna coil, the impedance matching shall also be optimized in the future.

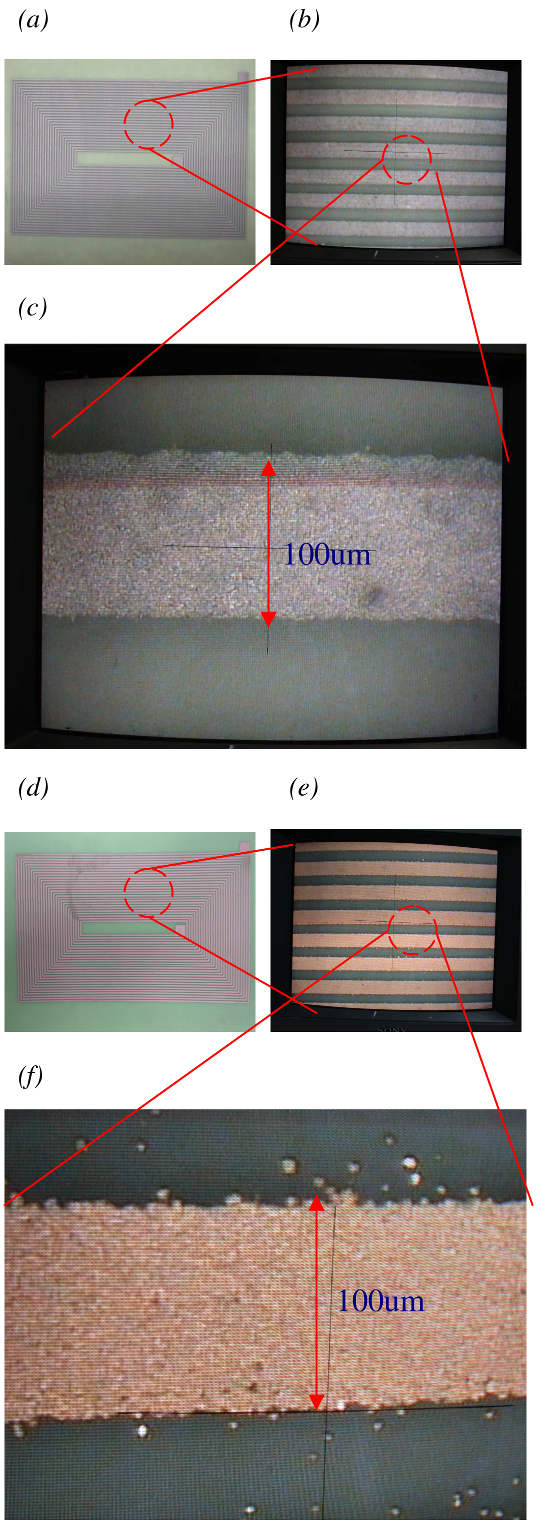

Figure2. (a) And (d) were 100um wide printed antenna coil structure. (27circles layout), (b), (c), (d), and (f) were optical micrographs of printed inductor formed on commercial flexible PI substrates.

Table2. Data of the printed antenna coil.

	L (uH)	R_{ac}(ohm)	Q
Sample 1	16	21.1081	0.62
Sample 2	17	25.8908	0.54
Sample 3	0.3	23.3501	0.0093

Table3. Measured and calculated data of the printed hybrid antenna coil.

	Sample 1	Sample 2	Avg.
Impedance (ohm)	24.5845	29.2636	27.0313
Impedance phase(Deg)	32.2368	27.3605	29.9337
R_{dc} (ohm)	20.45	24.33	22.39
Conductivity (s/m) Cu	0.904	0.767	0.836

Sample Adhesion Verification

3M TM-650 tape was used to verify the adhesion property of this printed flexible RFID hybrid antenna coil. No observed peelings on the tape prove excellent adhesion between antenna coil and flexible substrate as shown in Fig. 2. [5]

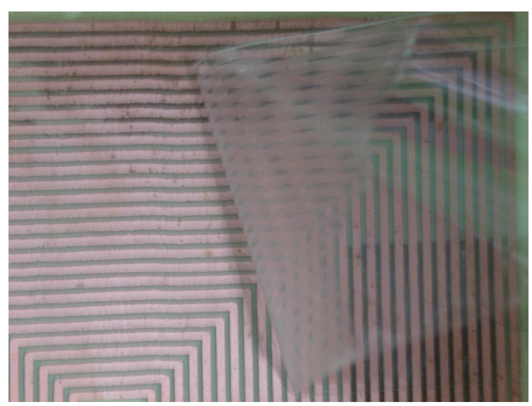

Figure2. 3M tape Peeling test with 3M TM-650 tape.

Conclusions

We have successfully demonstrated that RFID antenna coil can be manufactured by use of SAMs, inkjet printing, and electroless plating processes. Incorporation of magnetic metal, nickel could dramatically enhance the inductance value and therefore the Q value. The resulting antenna coil is flexible and can pass 3M-tape peeling test. In order to pursue a low-cost fully printed RFID antenna coil, high inductance and high Q value printed antenna is very important and necessary.

Compared with etching copper antenna coil, the higher resistance of the printed antenna coil, by this method, may be attributed to the impurity contamination in the electroless plating process of nickel and copper. Besides resistance issue, impedance matching also should be taken into account. In order to solve this problem, we will further study various antenna coil structure to improve the inductance value and select better recipes to copper electroless plating processes for decreasing resistance.

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Biography

Chung-Wei Wang received his Master degree in Institute of Organic and Polymeric Materials form National Taipei University of Technology in 2004. He is now a Printable Science Department, Display Process Integration Technology Division, Display Technology Center/Industrial Technology Research Institute at Taiwan. His work has primarily focused on the industrial Ink-Jet printing processes development, especially in PCB, LCD, and RFID fabrication by Ink-Jet printing Technology.

