Survey of Laboratory Scale Fabrication Techniques for Passive UHF RFID Tags

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***Abstract*—** This paper presents an overview of various RFID tag fabrication methods and briefly describes the advantages and disadvantages of each method. The purpose of this paper is to provide the reader with the fabrication techniques that can be applied for RFID fabrication purposes for laboratory scale experiments. This paper will present the performance results of laboratory made RFID tags based on two fabrication methods (etching and screen printing) on multiple substrates (paper, thin transparent film, polyethylene terephthalate (PET), and fabrics). These results will prove the effectiveness of the presented methods for RFID tag fabrication purposes.

***Index Terms* -** Radio Frequency Identification (RFID), etching, screen printing.

I. INTRODUCTION

In today's world the role of radio frequency identification (RFID) has increased considerably. RFID is a technology which uses RF signals for automatic identification of objects. RFID tags are used for many applications in various areas such as electronic toll collection, asset identification, retail item management, access tracking systems and many others. It has many advantages compared to electronic product code (EPC). For example, RFID systems can identify multiple objects simultaneously without a direct line of sight [1].

An RFID system consists of two basic components, a reader (interrogator) and a tag (transponder). An RFID tag can either be active, operated by a battery, or passive. A passive tag consists of an antenna and an application specific integrated circuit (ASIC) known as a chip. Passive ultra high frequency (UHF) RFID systems which achieve read ranges longer than 1 meter are defined as long range systems. These systems operate at the UHF center frequencies of 866MHz (Europe), 915MHz (America), and 950MHz (Asia and Australia) [1]. In this paper the fabrication techniques for passive RFID tags will be discussed. Section II will introduce the method of screen printing and etching. The parameters, characteristics, and a step-by-step laboratory procedure will be described for each fabrication method. The advantages and disadvantages of each method will be clearly presented. Section III will convey experimental data of a prototype RFID tag fabricated from the procedure proposed in this paper. Section IV will conclude the effectiveness of the presented methods for RFID tag laboratory scale prototyping.

II. FABRICATION TECHNIQUES

A. Etching Process

The process of etching has been used for hundreds of years. It originated from the custom of making etching designs on armor and was adopted by printmakers as an easy method of engraving. Since then the process of etching has evolved from artistic uses to manufacturing techniques.

The etching processes can be classified into two categories: wet and dry etching. The process of wet etching uses liquid chemicals or etchants to remove metallic substrates. The function of the photoresist mask is to prevent the removal of the desired pattern from the substrate when the etchant is applied. "The wet etching process can be presented in three steps: 1) application of the etchant to the substrate; 2) reaction between the etchant and the material being removed; and 3) diffusion of the reaction byproducts from the reacted surface. The process of dry etching does not require any liquid chemicals or etchants. Dry etching can be accomplished by any of the following methods: 1) using chemically reactive gases or plasma; 2) physical removal of the material, usually by momentum transfer; or 3) a combination of both physical removal and chemically reactive gases or plasma [2,3]."

Some etching parameters that need to be taken into account are the etch rate and the etch selectivity. The etch rate refers to the rate of material removal (μm/min). The etch selectivity refers to the ability of the reactive chemical to etch away only the material intended for removal, while leaving all other materials intact [4].

Wet and dry etchings have characteristics suitable for different applications. Wet etching is an isotropic process (uniform direction) while dry etching is anisotropic (directionally dependent). Since wet etching is isotropic, it is quick, easy, and cheap. It provides a unilateral and high etching rate and good selectivity rate for most materials. The disadvantage to wet etching is that it is inadequate for defining features smaller than 1μm and has the potential for chemical handling hazards. Dry etching allows for defining features smaller than 100nm, but it is relatively expensive, hard to implement, provides poor selectivity, and has the potential for radiation damage [5].

Etching has been the most commonly used method for fabricating RFID tags. This process can be used for fast prototyping of RFID tags. Off-the-shelf supplies and equipment may be used for inexpensive prototypes. For mass production purposes metal etching is impractical due to wasted materials and chemicals. Since etching is a subtractive process only a portion of raw materials are consumed while the rest is either recycled or thrown away. The loss of wasted materials has an effect on the overall price of production. Furthermore, because aggressive chemicals are used, maintenance fees for their removal must also be taken into consideration. This is why etching is perceived as an environmentally unfriendly method.

Although etching provides high conductivity and reliability it lacks in flexibility. Etching can only be used on substrates that can tolerate the chemical baths such as ferric chloride for copper and sodium hydroxide for aluminum. To fabricate a prototype RFID tag utilizing the wet etching method, the supplies needed include: the substrate, the acid/etchant, the solvent/development chemical, the photoresist varnish, a transparency sheet, a heating chamber, and an ultraviolet (UV) machine. The procedure below describes one method in which wet etching can be performed in laboratory settings. The procedure is conducted on an aluminum substrate.

Procedure:

- First apply the photoresist onto the substrate, as seen in Fig. 1.
- Next, place metallic substrate with the photoresist varnish into a heating chamber at 75 ^{o} C for 20 minutes. The thermal treatment will typically be completed in 20 minutes if not then repeat heating process.

Fig. 1. Application of the photoresist to the aluminum substrate via spraying.

- Next, place a transparency sheet with the printed antenna design on top of the varnished metallic substrate. Then insert both items into the UV machine. Set the UV machine to approximately 45 seconds (time may vary with different varnish thickness). If completed correctly the design will noticeably appear on the varnished metallic substrate.

Next, the chemical process requires two containers one containing the solvent and the other containing the acid. In this procedure an aluminum substrate was used, therefore, the solvent consisted of 70ml of NaOH and approximately 1.5 to 2 liters of water. The etchant solution consisted of 80ml of water, 30ml of HCl, and 30ml H_2O_2. Place the varnished metallic substrate within the container of the solvent. The solvent will remove the photoresist varnish, as seen in Fig. 2.

Fig. 2. Placement of varnished aluminum substrate within the solvent.

- Next, place the substrate into the etchant solution. Agitate the substrate within the container. This process will begin dissolve the metallic substrate. When the appearance of oxidation occurs remove the substrate from the container and rinse under cool running water. Repeat these steps until the metallic substrate around the design has been completely removed. The end product will be a transparent plastic with the metallic substrate design, as seen in Fig. 3.

Fig. 3. Placement of varnished aluminum substrate within the solution.

These etchant solutions operate by dissolving any metallic substrate uncovered by a photoresist. This process result in the formation of hydrogen gasses at the surface of the substrate, therefore removal of these bubbles is necessary because it masks the metal needing to be dissolved. Therefore rinsing the substrate resolves this problem by detaching the bubbles from the substrate [6].

B. Printing Fabrication Process

Printing is an additive process that allows designs to be selectively imprinted on to certain areas. It can be as simple as cutting out a stencil and applying a layer of conductive material to achieve the imprint. The method of printing has been used for many products such as clothing, printed circuit boards, and containers. The flexibility of printing allows it to be applied to almost any surface or material.

Printing can have a great potential for RFID antenna fabrications. With the use of RFID tags in almost every industrial sector, the need for a universal fabrication method is apparent. Printing holds the key to provide high volume and low manufacturing costs. Compared to the traditional method of fabrication (etching) screen printing is more stable, reliable, cost-effective, flexible, and has a low environmental impact compared to etching [7].

The use of printing allows for intricate and minute details to be fabricated while still maintaining conductivity throughout the entire design. Printing is an additive process which only uses the minimal amount of material needed to complete the task. Even the amount of raw materials used for printing can be reduced since the layers of conductive ink can vary in thickness. Due to the consumption of fewer raw materials, its application for mass production of a design provides the best cost per development ratio allowing a company to sell at the lowest price. Printing can be used to fabricate an RFID antenna on almost any substrate or material such as metal, paper, and plastic. With the use of flexible substrates for RFID antennas, added characteristics to the tag include the ability to bend and twist that was impossible with metal substrates. Though some environmental issues do still occur with screen printing due to the use of conductive silver or copper inks it is relatively incomparable to etching which contains far more chemical waste. The disadvantage to screen printing is its resolution which has its maximum at 50 lines per centimeter [8-10].

Compared to pure metals, such as copper or aluminum, conductive inks cause small degradation to the antenna gain, but they affect the input impedance of the tag antenna and produce high resistivity compared to pure metals. However, due to these variations their effect on the read ranges of the tag antennas are relatively small [11]. Conductive inks are composed of a polymer matrix and conductive fillers with a thermo-plastic polymer binder or resin [7]. For the conductive inks to remain imprinted onto a substrate, the conductive inks must be cured. Curing is the process of preserving the ink by heating. When the conductive ink is heated the polymers shrink and bond with nearby polymers which produce a conductive path though out the design. There are two important parameters during the curing of a substrate: the curing temperature and the curing time. These have an effect on the conductivity of the imprint and must always be taken into consideration when fabricating RFID tags [11].

There are many printing techniques that can be used to manufacture RFID tags such as screen printing, flexography, gravure, and ink jet. The speed at which tags can be produced and the cost per tag are as listed from slowest to fastest and highest to lowest in prices, respectively [12]. Different printing technologies require different ink characteristics. Some characteristics of the most typical printing processes are shown in Table 1 [11,13].

Table 1: Characteristics of the most typical printing processes.

Process	Screen Printing	Flexography	Gravure	Ink Jet
Substrate	All	Papers, Boards, Polymers	Coated papers, Boards, Polymers	All
Ink film Thickness (µm)	0.02-100	6-8	8-12	Depends on ink
Ink Viscosity (Pa.s)	0.1-10	0.01-0.1	0.01-5	0.01
Resolution (lines/cm)	50	60	100	60(continuous) 250 (DOD)

Screen printing is a stenciling process where the ink is transferred on to the substrate through a stencil covering a fine fabric mesh, as shown in Fig. 4. The fabric mesh is stretched onto a frame, allowing pressure to be applied to the stencil by a squeegee [15]. The ink is poured on to the stencil and the squeegee is drawn across the frame, forcing the ink through the stencil (see Fig. 4) [15]. Screen printing allows versatility in its ink thicknesses from 20 nm to 100 µm. Among the limitations of screen printing, its maximum resolution remains usually under 50 lines per centimeter and its speed is slow in comparison to other conventional printing processes [13].

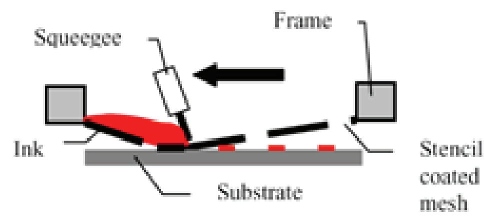

Fig. 4. Diagram of the screen printing process.

Screen printing is the cheapest method to implement for laboratory scale prototyping. To fabricate a prototype RFID tag using the screen printing the supplies needed include: a screen printing machine, conductive ink, a substrate, and a heating chamber. The machine used for the fabrication of the RFID tags in the procedure section was the Simatic Sim 20 semiautomatic screen and stencil printer.

Procedure:

- First attach stencil screen unto the frame of the screen printing machine, as seen in Fig. 5.

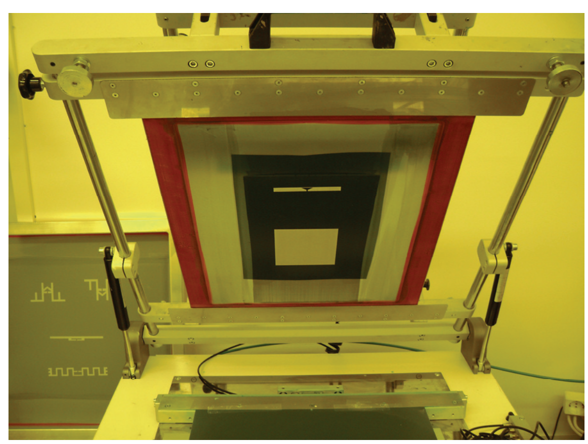

Fig. 5. Placement of the stencil screen onto the screen printing machine.

- Next, initiate air tight suction via floor pedal. Apply conductive silver ink above the screen design, as shown in Fig. 6.

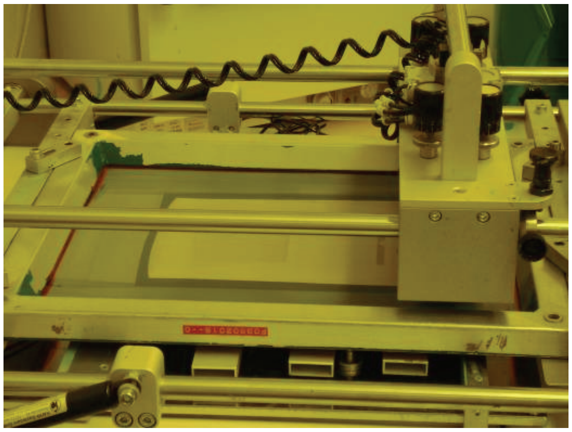

Fig. 6. Placement of the silver conductive ink onto the stencil screen.

Then, lower and initiate the front squeegee and slide it across the frame as shown in Fig. 7. Raise squeegee and allow excess ink to accumulate onto the screen.

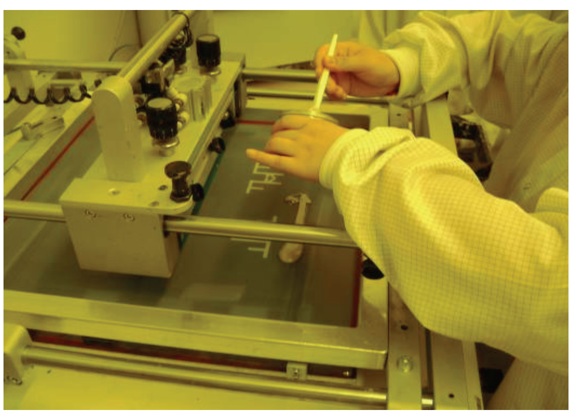

Fig. 7. Transferring the squeegee across the stencil to imprint the design on the substrate.

- Then, lower and initiate the back squeegee and return to starting position. Release the vacuum suction via floor pedal. Raise the frame and remove the substrate from the platform.
- Finally, place the substrate into an oven preheated to 120 degrees Celsius. After approximately 20 minutes, the silver conductive ink will cure. Repeat thermal treatment if necessary.

III. PROTOTYPE RFID TAG FABRICATION EXAMPLE

Two RFID antenna designs corresponding to the operating frequencies of 886 MHz and 915 MHz were developed using high frequency **s**tructural **s**imulator (HFSS). The details of the design's characteristics and procedure can be found in [19]. Both designs were fabricated by the process techniques described in this paper. Each design was fabricated on multiple substrates (paper, thin transparent film, polyethylene terephtalate (PET), and fabric).

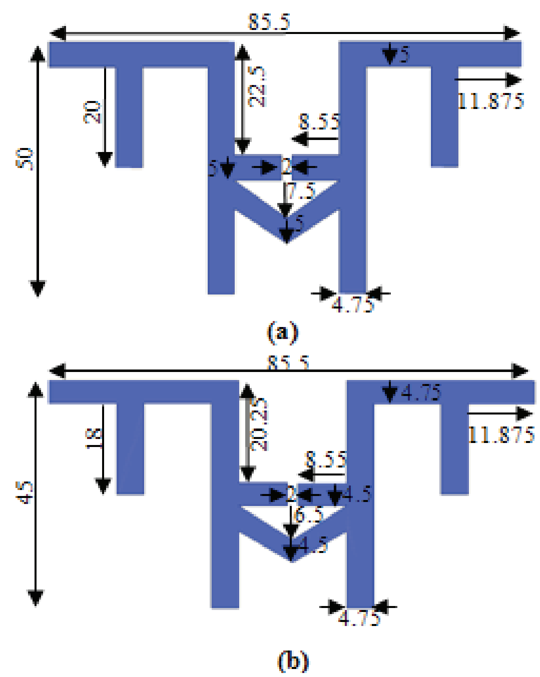

Fig. 8. The design layout of a Logo RFID tag (a) 866MHz and (b) 915MHz, (all dimensions are in mm).

The measurements of operational characteristics of these two tags were conducted using the Voyantic Tagformance reader [16]. The read ranges measurements were based on the electromagnetic threshold measurements technique, in which the frequency was changed from 830 MHz to 990 MHz by increments of 1 MHz. At each frequency the transmitted power was increased by 0.1dB until the tag responded and the minimum transmitted power to activate the tag at that frequency was measured. The device calculated the read range by using free space Friis formula [17] and taking into account the path and cable losses and the antenna gain. The read range was calculated using the following equation:

$$r_{\max}(f) = \sqrt{\frac{EIRP}{P_{t\min} L G_t}} \quad (1)$$

where $EIRP$ is the effective isotropic radiated power, $P_{t\min}$ is the minimum transmitted power to activate the tag, L is the factor considering the cable and path loss, and G_t is the transmitting antenna gain [18]. The material composition of the fabricated tags are shown in Table 2.

Table 2: The material composition of the RFID tags and their fabrication method.

Tag No.	Substrate	Conductive Material	Fabrication process	Read Range [m]	Frequency of Operation [MHz]
1	PET	Copper	Etching	12.5	866
2	Thin film	Sliver Ink	Screen Printing	9.5	866
3	Thin film	Sliver Ink	Screen Printing	6	915
4	Thin film	Aluminum	Etching	9	866
5	Paper	Sliver Ink	Screen Printing	9	866
6	Fabric	Sliver Ink	Screen Printing	11.2	866
7	Fabric	Sliver Ink	Screen Printing	7	915

Table 2 presents the results of fabricated tags categorized by their substrate, conductive material, and fabrication process. The simulated and measured antenna parameters and design processes can be referred to in [19]. Table 2 portrays the effectiveness of the step-by-step fabrication procedure in developing RFID tags with multiple substrates and conductive materials. From this step-by-step procedure laboratory scale fabrication of RFID tags can be developed with a relatively simple and cost effective method.

IV. CONCLUSION

In this paper two fabricating techniques (etching and screen printing) were described. The advantages and disadvantages of each method were discussed and a step by step procedure was conveyed. Two prototype RFID tags were designed using numerical simulations and fabricated using the discussed techniques and procedure. Their read ranges were measured to demonstrate the feasibility of the fabrication methods.

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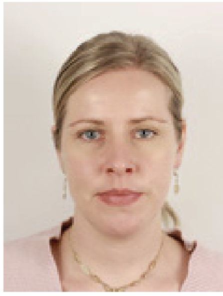

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