S-band Proximity Coupled Patch Antenna Based on TiN/Ag Multilayer Material

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Abstract— In this paper, a first patch antenna design with TiN/Ag multilayer material as antenna patch is demonstrated. The advantage of this multilayer material is its high resistance corrosion. Since the patterning of this material by photolithography is not simple, neither it cannot be soldered nor bonding wires easily, a proximity electromagnetic coupling method is employed for this design. This antenna comprises an Alumina substrate (with the grown TiN/Ag layers) on top of a baquelite substrate, where the microstrip feeding line is patterned. This antenna was measured showing a central frequency of 3.58 GHz with 196 MHz of bandwidth, and a gain of 5.7 dBi.

1. INTRODUCTION

Microstrip antennas have been extensively used in many different applications since their introduction in 1953 [1]. These antennas possess a low profile, are simple, can be easily mounted on planar surfaces, are inexpensive and of easy manufacturing [2]. However, exposure levels and resistance to the environment and corrosion must be taken into account when microstrip antenna design is performed, especially in shore or coast regions where corrosive agents such as chlorine and sulphides are found.

To overcome the effect of these substances and extend the useful life of the antenna, corrosion resistant materials have been researched. In [3], polymer materials with high electrical conductivities and corrosion resistance are used for the fabrication of a direction finding antenna. However, substituting the copper from traditional PCB with conductive polymers would increase the difficulty of fabrication and, therefore, the cost. In a research work [4], a microstrip patch antenna was given a gold coating treatment to make it more resistant to corrosion at the expense of increasing the manufacture costs. In [5], a thin coating of Sn was applied to the Cu electrodes of a PCB to form Cu/Sn intermetallic compounds to increase the corrosion resistance of the PCB.

In this work, the use of a multilayer structure composed of Titanium nitride (TiN) and silver layers grown on an Alumina substrate is proposed as an antenna patch. It is well known that Titanium nitride (TiN) has important properties as high hardness and high corrosion resistance. Nevertheless, its electrical resistance is high and not convenient for antenna use. Due to this, a multilayer material consists of TiN and silver is grown on Alumina substrate by using DC magnetron sputtering.

2. ANTENNA PATCH MATERIAL PROCESSING

Titanium nitride is a very hard material (more than 2000 HV), it is also high resistant to abrasion wear and it has an appearance similar to gold. Due to these properties, this material is used as coating for cutting tools and also in jewelry. Besides, titanium nitride is an electrical conductor material; it has much more conductivity than silicon but much less than copper.

On the other hand, silver is the metal with highest conductivity, but it is easily attacked by normal environmental atmosphere. Multilayers structure of titanium nitride and silver may result in a system with high conductivity and highly resistant to atmospheric corrosion. These properties make it a good candidate for electronic components, and for the present work, for an antenna patch.

The proposed structure for the antenna patch was built on an alumina substrate of 1 mm of thickness. Two silver layers of 200 nm of thickness were intercalated between three titanium nitride layers of 500 nm of thickness. In Figure 1(a), this structure is shown.

Titanium nitride and silver layers were produced in a vacuum chamber by using DC magnetron sputtering (see Figure 1(b)). For titanium nitride, reactive magnetron DC sputtering was employed. A titanium target of 3 inches of diameter and 99.99% purity was used, the plasma power was 150 W

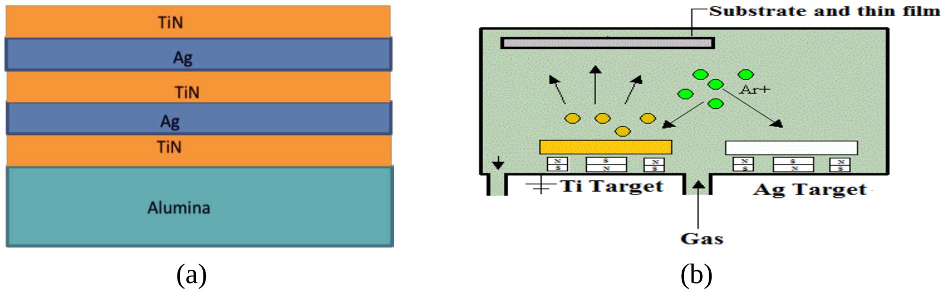

Figure 1: (a) Schematic of the structure made of intercalated titanium nitride and silver layers, (b) schematic of the sputtering process.

and the deposition time for each layer was 30 minutes. The chamber was evacuated up to 10^{-6} mbar and then argon and nitrogen were introduced. The partial pressure of nitrogen was 3.5×10^{-4} mbar and the total pressure deposition during TiN deposition was 5.5×10^{-3} mbar. The silver layer was produced during one minute with a 3 inches and 99.99% target in an atmosphere of pure argon at pressure 5×10^{-3} mbar.

3. ANTENNA DESIGN

Following the method described in Section 2, an antenna patch made of a TiN/Ag multilayer grown on Alumina substrate with 21.1 mm length $\times$20.9 mm width and 1 mm of thickness was fabricated. This would be the resonant element of the antenna patch. Then the feeding technique had to be defined. There are mainly four types of feeding an antenna patch: microstrip line, coaxial probe, aperture coupling, and proximity coupling [2]. The first two feeding techniques suffers of having a narrow bandwidth, typically around 2–5%, while the last two present larger bandwidths, around 10–15%, however their implementation are more complex. Furthermore, the patterning of the antenna patch by photolithography is not simple, neither it cannot be soldered to coaxial connectors nor bonding wires easily, then the two first methods were not appropriated for this design. Between the last two techniques, the proximity coupling technique was chosen in this work because of its high bandwidth, and comparing with the aperture coupling, it is easier to built.

In order to design this antenna, Keysight EMPro program was used for the simulation of this antenna, which structure is shown in Figure 2(a). This antenna comprises the Alumina substrate (with the grown TiN/Ag layers) on top of a baquelite substrate, where the microstrip feeding line is patterned. The baquelite substrate has dimensions of 32.9 mm length $\times$31.5 mm width and 1.5 mm of thickness. The initial setting of the microstrip width was defined in 4.3 mm based on 50 ohms characteristic impedance on a baquelite substrate. However, in the simulator, the length and width of this microstrip line had to be tuned in order to obtain a proper matching of the feeding line with

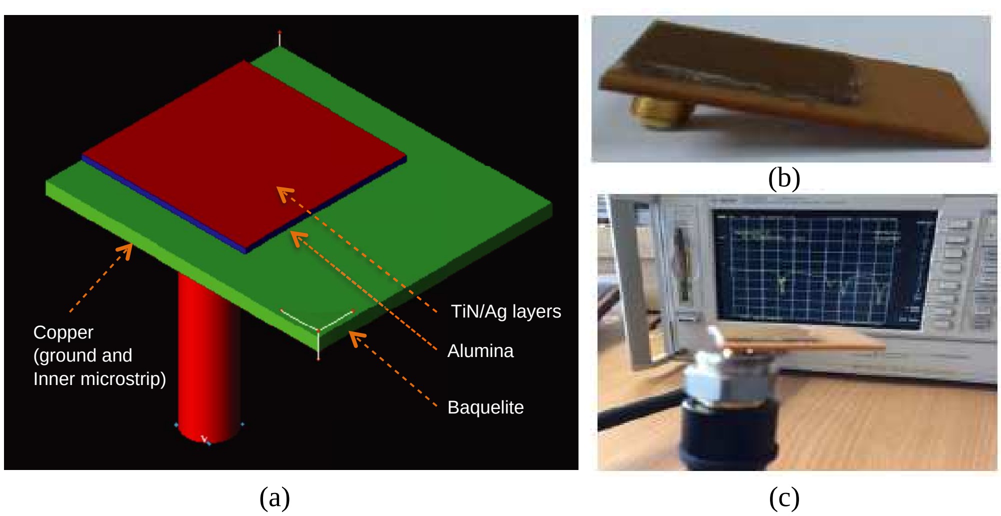

Figure 2: (a) Model of proximity coupled patch antenna, (b) its construction, and (c) reflection measurement.

the antenna patch, resulting in a line of 3.42 mm width ×13 mm length.

4. MEASUREMENT RESULTS

The corrosion test of the TiN/Ag layers on top of Alumina substrate is described.

4.1. Electrochemical Measurements

An Gamry-Reference 600 computer-controlled potentiostat/galvanostat/ZRA connected to a three-electrode cell was used for the electrochemical measurements. The working electrode was the test material with an immersed area of 1.327 cm^2, and platinum and silver/silver chloride (Ag/AgCl) electrodes were used as the counter and reference electrodes, respectively. The solution concentration inside the reference electrode compartment was 3 M potassium chloride (KCl), The test solution was naturally aerated 0.10 M Na_2SO_4-0.01 M NaCl solution at room temperature (26°C).

Potentiodynamic polarization curves were obtained after immersion in 0.10 M Na_2SO_4-0.01 M NaCl solution for one hour using a scan rate of 0.166 mV/s, from −250 mV until +250 mV with respect to the open-circuit potential (OCP).

4.2. Electrochemical Results

Potentiodynamic Polarization — Figure 3 shows the polarization curves of antenna TiN-Ag thin film after immersion in 0.10 M Na_2SO_4-0.01M NaCl solution for one and five days with corrosion current density (i_{corr}) of 2.84 and $4.19 \cdot 10^{-7}$ mA/cm^2 respectively. Compared to the test of TiN Ag thin film of one day, the corrosion current density is not increased significantly with the time of exposition (five days).

Additionally, the measurements results of the reflection coefficient, radiation pattern is presented. In Figure 4, the measured reflection coefficient is shown (measurements were performed with a VNA Agilent 8722ET).

Simulations show that the proximity coupled patch antenna has a resonance frequency at 3.33 GHz while measurements reveal that the antenna resonates at 3.58 GHz. In addition, the bandwidth of the antenna in simulations is 100 MHz in contrast to measurements in which bandwidth is 196 MHz. The variations of the results from the simulations and measurements are mainly due to a small air gap between the alumina and baquelite which was later filled with a glue film. Since the permittivity of this glue film has not been characterized, this influences the final measured results of the proximity coupled patch antenna.

In addition to the measurement of the S parameters of the antenna, the radiation pattern at the first resonant frequency was measured following the free space measurement method. Steps of 2 degrees were used to obtain good resolution of the radiation pattern. Figure 5 shows the measured radiation pattern at 3.58 GHz.

A gain of 5.7 dB was measured, which is consistent with the simulations.

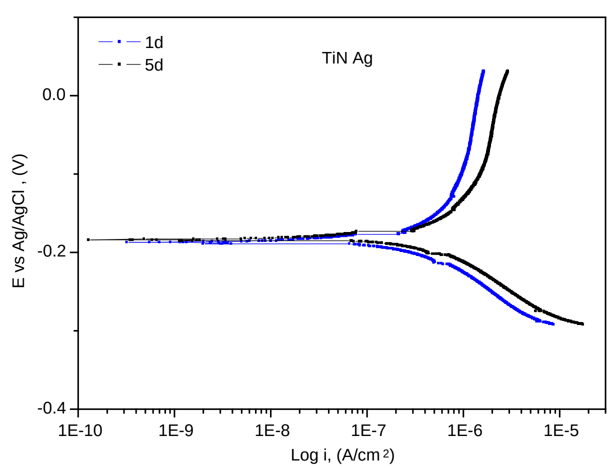

Figure 3: Polarization curves of antenna patch with TiN-Ag thin film after immersion in 0.10 M Na_2SO_4-0.01 M NaCl solution for one and five days.

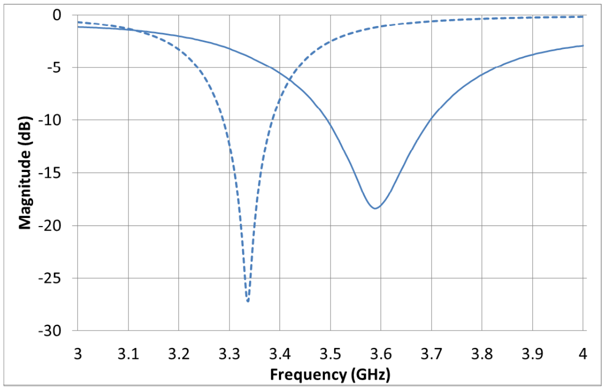

Figure 4: Reflection coefficient of the proximity coupled patch antenna (simulation results with dashed line and measurement results with solid line).

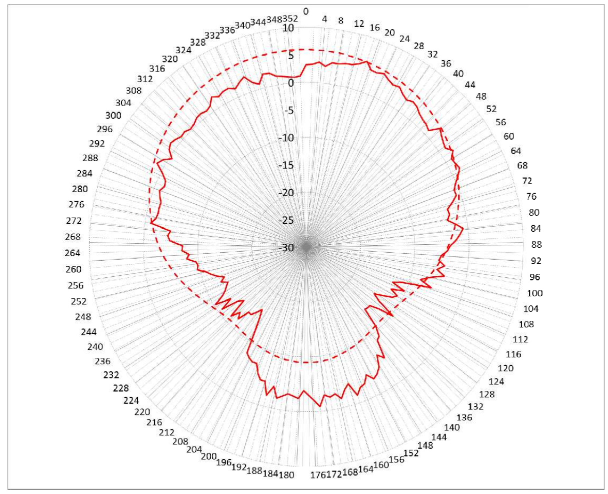

Figure 5: Radiation patterns of the proximity coupled patch antenna at 3.58 GHz (simulation results with dashed line and measurement results with solid line).

5. CONCLUSIONS

In this paper, a S-band proximity coupled patch antenna based on TiN/Ag multilayer material is demonstrated. Simulated and measured results show a slight variation due to a possible small air gap between substrates or to the unknown permittivity of the glue film used to join the substrates. The proximity coupled patch antenna resonates at 3.58 GHz with a bandwidth of 196 MHz. Measured radiation patterns using the open space measurement technique reveal a directive pattern with a gain of 5.7 dB that correlates well with the simulations.

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