70 dB EMI shielding between 10 MHz and 10 GHz with Sprayed Metallization of Ag

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ABSTRACT

This paper starts with the description of a new direct chemical plating method for silver, called the JET METAL (JMT) process [1]. This technology is based on spraying separately an aqueous solution containing silver metallic ions together with a CMR free, aqueous based reducing agent. This process allows to plate chemical silver at 12 µm/hour at room temperature and at ambient pressure and is already used in industrial processes for metallizing plastics, composites and non-conductive materials in general and this in different formats (3D pieces, 2D foils like textiles …). In the second part, the EMI shielding measurement method and results obtained with a 500 nm silver coating, deposited with the JMT process are shown and discussed.

Keywords: New process, spraying metallization, EMI shielding, Silver deposition

I. INTRODUCTION

Autocatalytic or electroless metallic plating is widely used to metallize non-conducting surfaces and it is a key technology for manufacturing a.o. printed circuits boards [2]. It is also used for connector applications and to pre-plate a conductive thin film on plastics for subsequent electrochemical plating. One of its most successful applications is Electromagnetic Interference Shielding (EMI / RFI). This "wet" plating technique is a commonly used approach to obtain homogeneous and uniform metal deposits on a catalytic surface and it can be applied to any complex or intricate shape substrate [3]. In spite of all these advantages, electroless plating and electrochemical plating are still suffering from several practical problems such as:

- Bath control and limited solutions shelf life
- Toxicity (i.e.: carcinogen formaldehyde compound are commonly used) and ecological disadvantages (waste treatment, use of chromic etching…)
- Difficulty to plate parts with large dimensions
- Ag plating speed which is limited to 4 - 6 µm/hour for most of commercial available plating solutions

On top of the above mentioned problems, another very important industrial inconvenience should be taken into account which is the high number of processing steps, particularly during the activation step which is at the same moment also a very expensive step. For example, palladium, used to obtain a catalytic surface to initiate copper or nickel depositions, has a price that increased from 100 $ / oz. in 1997 up to 490 $ / oz. in 2016. The increasing demand for palladium and the rather limited sources of supply explain the high value of palladium at its price volatility.

A new "direct plating" technology has been developed which avoids the disadvantages listed above and in particularly avoiding the Pd / Sn activation step [4,5]. In few seconds, it is possible to plate a non - conducting surface (like plastics or composites) with an Ag film without the Pd catalytic activation step. For example, on ABS plastic, a 150nm Ag metallic underlayer (which gives enough electrical conductivity to start an electroplating deposition [4]), is plated in 90 seconds at room temperature and ambient pressure.

The novelty of this plating method is based on a sequentially highly controlled supply of the material (metallic ions Ag+) and the energy source (CMR and Pd free reducing agent) to the substrate. In other words it can be described as a metal plating process using continuous and simultaneously spraying of two solutions. Using compressed air and a double nozzle paint spraying gun, the reducing and oxidising agent are sprayed simultaneously onto a substrate surface (can be both a conducting or a non-conducting surface; with or without a complex geometry, big or small dimensions) forming a very thin liquid film as shown in Figure [1]

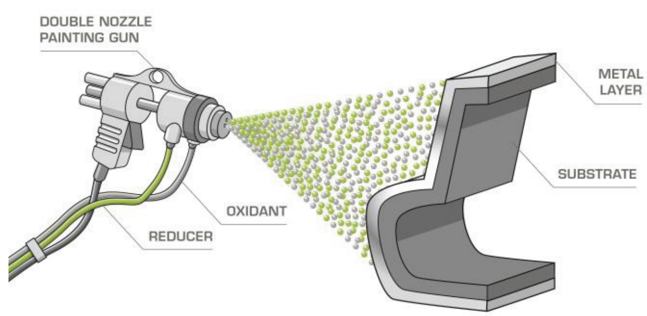

Figure [1]. Principle of the Jet Metal metallization process

This film is adsorbed on the surface and contains the active components. The film is thermodynamically unstable which means that the oxidation - reduction reaction will occur spontaneously. But under some well-defined conditions, this spontaneous reaction can be controlled to avoid coarse precipitation. These conditions are the following:

- The sprayed liquid film, which is adsorbed on the substrate, must be thin enough so the redox reaction occurs on the surface.
- The ratio of the sprayed oxidising and reducing solutions must be adapted to give an optimal stoichiometric electrochemical reaction on the surface. This corresponds to the ratio of electrons exchanged between the oxidising and the reducing agents for a fixed sprayed volume of solutions.
- The polymer substrate must have a uniform wettability and a relatively high surface energy ($\gamma > 56$ mJ / m).

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When the above conditions are fulfilled, the redox reaction will be induced on the surface instead of a spontaneous precipitation of the metallic ions in the adsorbed liquid film. This will result in a compact, dense and adherent silver film on the substrate surface.
As Silver is a reference material in the radio frequency world and applications such as wave guide, RFID patches or EMI shielding applications already use it, we focused the further tests & results on the metal. Today, major players active in the above markets reach the required shielding characteristics by using metallic parts / foils or conductive painting / ink.

II. EMI SHIELDING MEASUREMENT METHOD

The evaluation of the JMT Ag coating characteristics for its EMI shielding properties were done at a COFRAC accredited institute, more particularly at EMITECH FRANCE, Lyon. The measurement tests that were done followed the GAM T20 norm, which are the shielding attenuation measurement test for high end applications like military applications.
The methodology of these tests is to use a Faraday cage to shield the environment and place the metallized sample as the “only” way to pass for the Electro Magnetic waves. The other objective of the reverberation chamber is to obtain a field which is constant on average, which has many polarization directions, and which is statistically uniform.
Electro Magnetic waves are generated by a first antenna, waves will pass through the metallized sample and the second antenna will receive the attenuated signal. A scheme of the test set – up principle of this measurement is show in Figure [2].

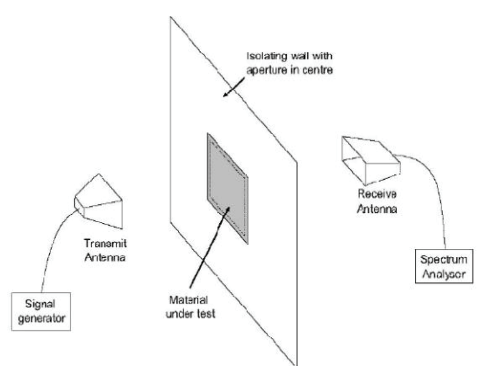

Figure [2]. Test set - up for GAM T20 test

The frequency test range is from 10 MHz to 10 GHz using the following materials:

Equipment	Brand	Type	Technical data
Synthesizer	HP	83620A	10 MHz-10 GHz
Receptor	Rohde & Schwarz	FSEA	20 Hz-3.5GHz
Pre-Amplifier	ADE	27dB	
Antenna Log Spiral	EMITECH		10 MHz-1GHz
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Cable	Cable & Connectiques	N - 4m	F < 1GHz
Cable	Cable & Connectiques	N - 3m	F < 1GHz
Cable	Cable & Connectiques	N - 2m	F < 1GHz

Table [1] Equipment used in test set-up for GAM T20 test between 10 MHz and 1 GHz

Equipment	Brand	Type	Technical data
Antenna	Schwarz beck	BBHA 9120B	1 GHz - 10 GHz
Antenna	Emco	3115	1 GHz - 10 GHz
Receptor	Rohde & Schwarz	ESIB265Rev(3-4)	20 Hz - 10 GHz
Cable	HYTEM	HY304	F < 10 GHz
Pre Amplificatory	MYTEQ		1 – 10 GHz
Synthesizer	HP	83620A	10 MHz - 18 GHz
Cable	Cable & Connectiques	N-2m	F < 10 GHz
Cable	Cable & Connectiques	N-1m	F < 10 GHz

Table [2]. Equipment used in Test Fixture for GAM T20 test conditions from 1 GHz to 10GHz

III. RESULTS AND DISCUSSION

All of the tests performed beneath were performed using a 500 nm thick Ag layer deposited with the above described JMT technology

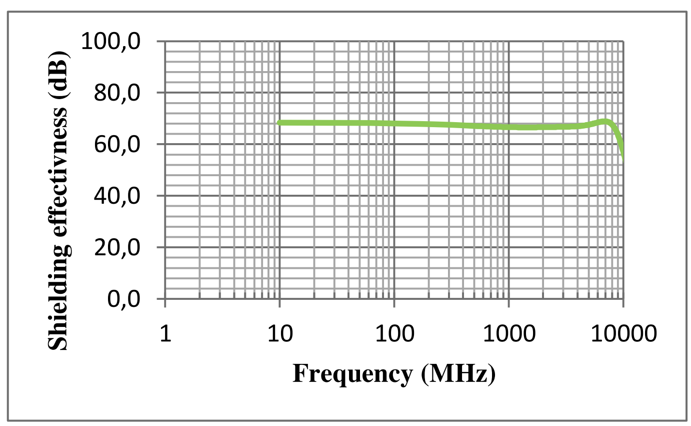

Figure [3]. Shielding Effectiveness for GAM T20 test conditions for a 500 nm thick Jet Metal Ag layer

The first observation that we can made is about the average shielding value. Indeed, a JMT Ag coating gives between 60 to 75 dB (in the frequency range of 10 MHz to10 GHz) for a layer thickness of 500nm. These results are good enough for several markets as RF / GSM, medical devices and military applications. We can better understand JMT Ag performances having a look through EMI shielding theory of a finite thin metallic layer / slab.

When an electromagnetic wave propagates in one material and encounters another material with different electrical properties, some of the energy in the wave is reflected and the rest is transmitted into the new material. A scheme to show what happens when an EM wave strikes a conductive finite layer is shown on Figure [4].

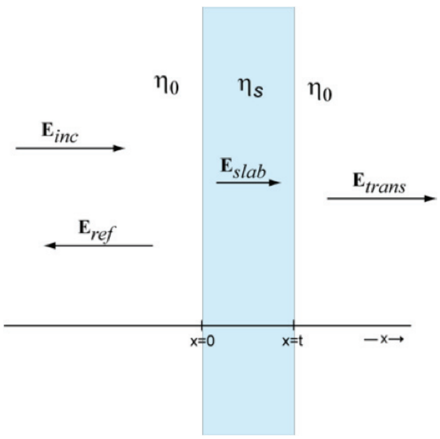

Figure [4]. Plain wave incident on a finite thickness shielding material

An incident field, Einc, strikes the surface of the shielding material. Some of the power in the field is reflected and some continues into the material.

If we define the shielding effectiveness of a finite conductive layer it will be:

$$S.E. = 20\log\frac{E_{inc}}{E_{trans}}$$

$$S.E. = 20\log\frac{\eta_0}{4\eta_s} + 20\log e^{t/\delta} = R(dB) + A(dB)$$

Where the total shielding effectiveness observed is consist of two terms. The reflection loss, R (dB), is the attenuation due to the reflection of power at the interfaces. The absorption loss, A(dB), is the attenuation due to power converted to heat as the wave propagates through the material [6].

The absorption loss is directly proportional to the thickness of the shield expressed in skin depths (δ):

$$A(dB) = 20\log e^{-t/\delta} \approx 8.7\left(\frac{t}{\delta}\right)$$

The reflection loss is independent of the thickness of the shield and depends entirely on the mismatch between the shield's intrinsic impedance ns and the intrinsic impedance of free space no.

$$R(dB) = 20\log\frac{\eta_0}{4\eta_s}$$

Based on these good results, we can match with the EMI theory assuming that our main mechanism to shield is wave reflection R(dB). As it's well known, silver is the best conductive metal which exists. From this point of view, we can assume that the high reflectivity for an EM wave coming from the air with a 377 Ω impedance field to a highly conductive silver layer is justified.

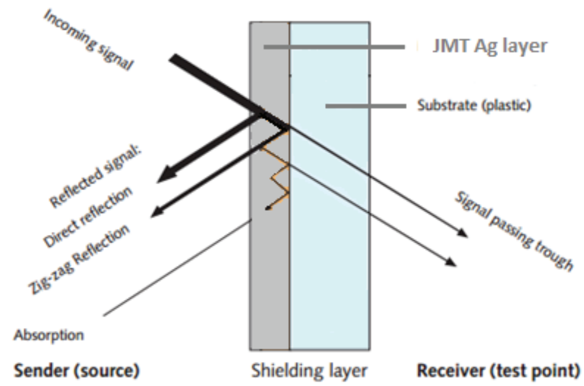

Figure [5] Shielding mechanisms of Ag JMT layer

Obviously, using a 500 nm thick layer, the absorption impact is not the main mechanism to shield for HF, VHF and UHF but Ag reflectivity is so high that a high level of shielding can be reached. Also if the market required it we can imagine to combine both phenomena with a thicker JMT Ag coating or to add an electroplating process once non-conductive parts are metallized with a 150 nm Ag JMT layer.

As reflectivity is the main JMT Ag shielding mechanism and it is based on conductivity of the Ag layer, a study on the JMT Ag electrical resistivity was made in order to define it and better understand the evolution in function of the thickness. It's well known that electrical properties as resistivity is directly linked to the thickness of the metal layer in the nanometre scale. The measurements were made using a 4 point electrical probe in order to define R□ called also RSheet (mΩ□) and following the Van der Pauw method.

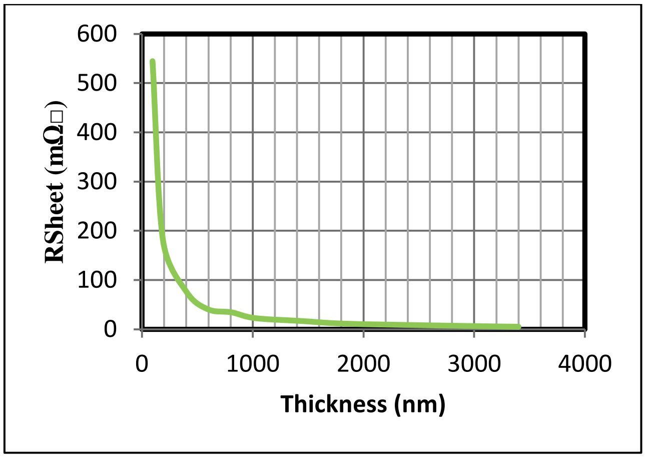

Figure [6] RSheet vs thickness of JMT Ag layers

We can observe that the measured RSheet values for a 500 nm thick JMT layer is 50 mΩ□.

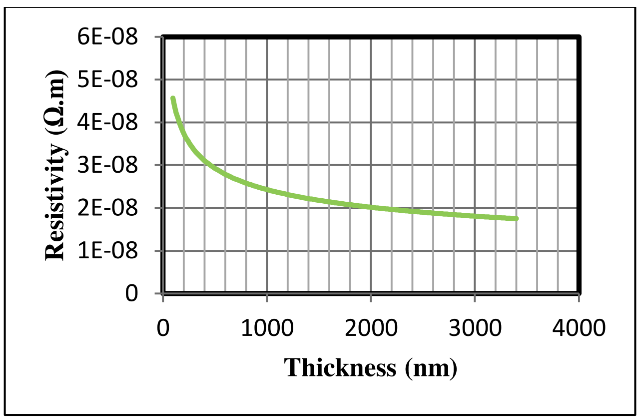

Figure [7] Resistivity vs thickness of JMT Ag layers

We can observe that the resistivity decreases with the increase of the thickness. Indeed, a JMT Ag layer approaches the standard value of silver resistivity which is around $1{,}59.10^{-8}$ Ω.m or conductivity which is $6{,}3.10^{7}$ $S.m^{-1}$ when the JMT Ag layer is 3 µm thick.

IV. CONCLUSIONS

In this abstract we showed that the JET METAL TECHNOLOGIES metallization technology is a new, green and effective metallization process for non – conductive substrates like plastics and composites with possibly complex geometries. The EMI shielding effectiveness of a 500 nm JMT silver coating reach high performances up to 70 dB for frequencies between 10 MHz to 10 GHz. Based on these results and in combination with a proven industrial track record, the JMT metallization technology is a viable alternative for existing metallization processes like PVD, plating, evaporation…

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