Thin Au layers for advanced Multichip module interconnection substrates.

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Abstract

A Multichip Module (MCM) is a structure consisting of several ICs (typically bare chips) interconnected on a common supporting substrate and packaged as an interconnected group. The substrate conductors are usually formed in multiple layer structures that are separated by dielectric material. Via connect the various layers. As consequence, this type of technology integration demands a high-quality interconnection between the different circuit levels in order to establish a proper functioning of the module. Typically, in MCM, gold (Au) thin films are used as interconnection tracks terminated by wire bonding process to the chips. This bonding technology presents challenges, which include smaller and closely spaced wire bond pads. Thus, the good quality of the Au thin films for interconnects purpose is essential, what is closely linked to the deposition process used.The present work reports the analysis of wire bonding and pull-test made on Au thin films, destined essentially to interconnect the different circuit levels on a MCM. The results evidenced a high dependency between Au films thicknesses and the welding points quality, while the influence of the alumina (Al_2O_3) activation step used before the deposition process, is practically imperceptible. Au films with thickness above 3 μm obtained the best results.

Keywords: *Au electrolytic-thin-films, MCM-D, morphological characterization, wire bonding, pull-test.*

1. Introduction

Multichip Module (MCM) technology is a special packaging process where several integrated circuits are packaged as a single component (L. PRADEEP, 1993). Among the many advantages this technology presents, it can be mentioned: structures with better performance (by having shorter interconnections, lower values of parasitic inductances and capacitances, and less crosstalk effects); higher miniaturization of the module compared to others kind of integration; and wide range of applications (e.g. communications systems and radio-frequency circuits) due to its compatibility with heterogeneous technologies such as Si, GaAs, etc. (L. PRADEEP, 1993: M. BILLAH, 2015: U. W. KAWARE, 2015). Classic thin-film hybrid technology (MCM-D) is an example of integration that fall into MCM packaging and it is the kind of MCM in which attention will be focused. The die attach and bonding method mainly used in MCM-D is wire-bond, where high-density interconnects are the key to realize the electrical connectivity and ensure the patency of data exchange between inside chip and external ports (D. T. ROONEY, 2005). In the technological process of MCM-D production proposed by our research group (Electronic Packaging Research Group, Renato Archer Center for Information Technology - NEE/CTI), alumina (Al_2O_3) is used as substrate and photosensitive benzocyclobutene (p-BCB) polymer is used as insulator and dielectric of the capacitive elements. The interconnections and the passive elements will be formed by several sequences of deposited metallic thin films and defined by photolithography processes. Gold (Au) thin films are going to be use as conducting layers (C. B. ADAMO, 2015). Relatively soft Au layer ensures the surface to be bondable and solderable.

Many researchers have been discussing the feasibility of Au film thickness reduction on the interconnection points and lines due to high cost that presupposes its use (X. LI, 2005). However, defective welding points, resulting from non-adhesion of Au films, can limit this thickness reduction. Accordingly, the properties of these films are those that will determine the minimum thickness necessary to establish a good interconnection between the components inside the MCM-D (X. LI, 2005). The Au films will be deposited by electrodeposition technique. Compared with others Au deposition methods such as evaporation or sputtering, electrodeposition techniques are preferred because of their relatively low-cost and potentially higher deposition rate (T. A. GREEN, 2007). In addition, this deposition technique allow obtaining thicker films and can be performed with relatively simple and inexpensive equipment where the processes are typically operated under near-ambient conditions of pressure and temperature (T. A. GREEN, 2007).

As part of the Au deposition sequence on Al_2O_3, a Ni-P film is deposited as a bonding layer between Au and Al_2O_3. In order to ensure a better adhesion of the Ni-P film on Al_2O_3, an activation step was performed on some of the Al_2O_3 substrates prior the deposition. The present work propose to debate about the influence that this additional step of substrate activation during the samples fabrication, has in the Au films properties, specifically in roughness and thickness parameters. In addition to this, it will discuss how these parameters (roughness and thickness of Au films) affect the wire bonding quality and pull-test in these Au films with interconnection purposes.

2. Experimental Details

The samples investigated were fabricated following the sequences shown in Figure 1. Al_2O_3 (1 in. square; 96%) were used as substrates. Ni-P films with thickness between 2.1 and 2.4 µm, and roughness between 0.6 and 0.7 µm were obtained by electroless deposition, at a temperature of 60°C (± 2°C) during 10 minutes.

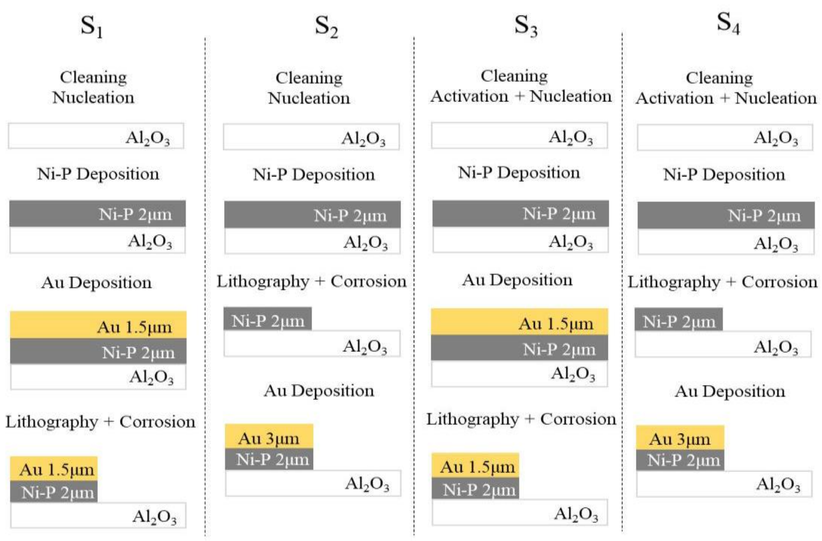


Figure 1- Schematic of the samples fabrication sequences used in this study. S_1: sample 1, S_2: sample 2, S_3: sample 3 and S_4: sample 4

For the Au films, an electrolytic commercial solution (Auruna 553-Umicore) was used. Electrolytic depositions were carried out at 60°C (± 2°C) during one hour (60 min) and using a current density of 0.1 A/dm^2 for S_2 and S_4; and 0.05 A/dm^2 for S_1 and S_3. This was made to obtain two different thicknesses of Au films. Figure 2 illustrates the electrodeposition process.

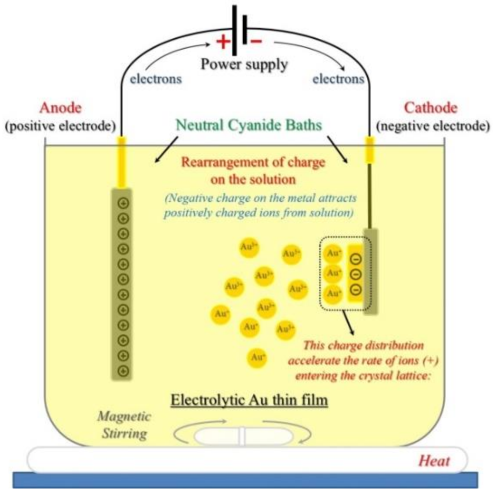


Figure 2- Theoretically diagram for Au films electrodeposition process.

Samples S_1 and S_2 (see Figure 1) were made using conventional deposition of electrolytic Au, meanwhile samples S_3 and S_4 (see Figure 1) were manufactured using an extra activation step (HF/NH_4F) before the NiP/Au deposition. Once the samples were obtained, it was made the study of the influence that the extra activation step used during the samples fabrication have in the morphology and thickness of Au thin films; and consequently, in the quality of the welding points intended for interconnections. For this, thickness and roughness measurements performed employing a DekTak XT.

For pull-test a TPTHB16 wire bonder was used to solder Aluminum (Al) (ultrasonic) and Au (thermossonic) wires on the Au films. To evaluate the bond quality and strength of this Au and Al bond on the Au thin films, method 2011.8 from MIL-STD-883H was applied (MIL-STD-883H, 2010). Au and Al diameter wires were 17 µm and 31 µm, respectively.

3. Results and discussions

Table I shows thickness and roughness results of Ni-P films determined by scan profiling using a Dektak XT. As can be observed, the values of these parameters are very close to each other regardless of the use of the activation step.

Samples	Ni-P films thickness	Ni-P Roughness
S_1	2.14 µm	0.72 µm
S_2	2.21 µm	0.70 µm
S_3	2.38 µm	0.74 µm
S_4	2.14 µm	0.64 µm

Table 1 – Ni-P films thickness made by scan profile used a Dektak XT.

Figure 3 shows the roughness mapping of Au films for all the samples. Here it is observed that the roughness values for the samples, as it happens with Ni-P films, are very close to each other regardless the use of the activation step. Figure 4 shows the thicknesses mapping of Au films for each one of the samples. Here it is observed two Au thickness groups, one approximately double the other. These results are expected since it was used two different current densities during the deposition (S_1 and S_3 with 0.1 A/dm^2 and S_2 and S_4 with 0.05 A/dm^2). This happens again regardless the use of the activation step. These findings lead to the conclusion that the HF/NH_4F activation before the NiP/Au deposition does not lead to changes in Au films properties.

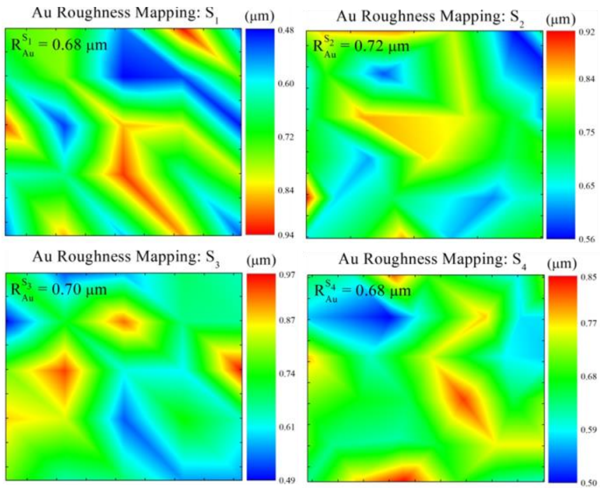


Figure 3- Roughness mapping of Au thin films for all the samples. R^s_{Au}: Mean Roughness Value.

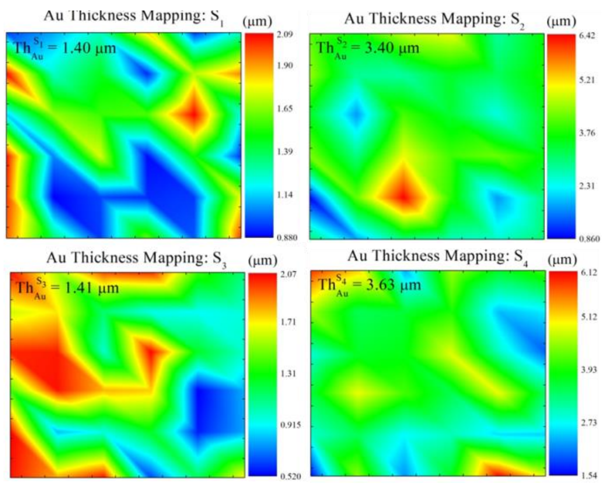


Figure 4- Thickness mapping of Au thin films for all the samples. Th^s_{Au}: Mean Thickness Value.

To evaluate the adherence quality of the Au films, wire bonding and pull-test were carried out in each one of the samples. From these tests it is observed that samples S_1 and S_3 (with lower thicknesses) did not supported the wire bonding process; due to detachment of the Au film, whereas the Ni-P underlayer remains intact. On the other hand, the samples S_2 and S_4 (with greater thicknesses) reported no adhesion issues of the welding points for both the Au wires and the Al wires. Figure 5 shows the results of the latter's (S_2 and S_4). Destructive pull-test evaluation, according the rules presented on the method 2011.8 from MIL-STD-883H, was performed on the wires bonded onto samples S_2 and S_4 that were the only ones that withstood the welding. Results are presented on Figure 6 (left). As expected for a good wire bonding, most of the breakages happened on the border of the bonding (COD = C or U), with no detachment observed from the pull (COD = A or B) (MIL-STD-883H, 2010).

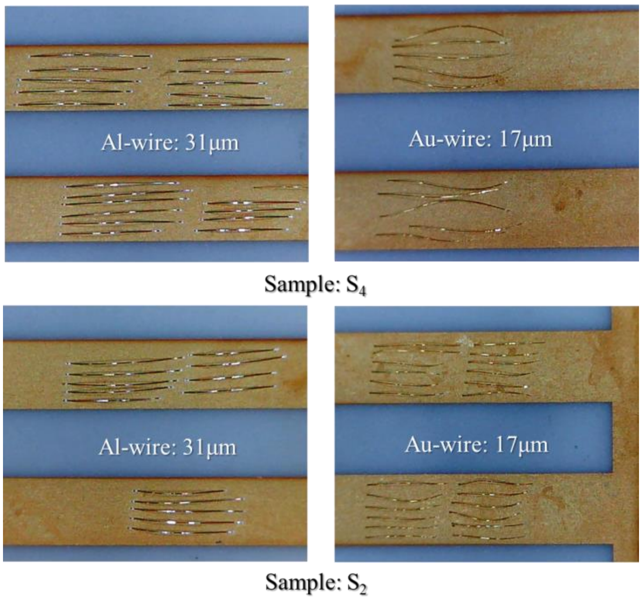
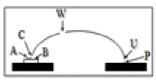


Figure 5- Theoretically diagram for Au films electrodeposition process.

This demonstrates that the Au films deposited have enough adherence to receive and maintain both Al and Au wire bond interconnections. Quantitatively, it is observed that the force required for breaking the wire (see line AVE on Table 2 in Figure 6) is above the specifications established according to the MIL-STD-883H standard. These values are 2.0 grams-force for Au wire (17 µm diameter) and 3.0 grams-force for Al wire (31 µm diameter) (MIL-STD-883H, 2010). Figure 6 (right) also illustrates some results of this Table for sample S_2.

Wires No.	Pull-Test Results							
	Al wire				Au wire			
	S_2		S_4		S_2		S_4	
	GR	COD	GR	COD	GR	COD	GR	COD
1	7	C	6	C	2	U	2.5	C
2	8	U	7.2	U	2.5	C	2.5	C
3	8	C	7	U	2	C	2.5	C
4	8.2	C	7	C	3	C	2.5	C
5	6	C	6.2	C	2	C	2	C
6	5.5	U	6.5	C	2	C	3	C
7	6.2	C	8	C	2	C	2	C
8	7	C	7	C	2	C	2.5	C
9	6	C	5.5	C	2.5	C	2	C
10	8	C	7	U	3	C	2	C
11	5.5	C	8	C	2.2	C	3	C
12	5.5	C	6.8	C	2	C	2	C
13	7	U	7	C	2	C	3	C
14	6.5	C	8	C	2	C	2	C
15	6.5	C			3	C		
SUM	100.9		97.2		34.2		33.5	
HV	8.2		8		3		3	
LV	5.7		5.5		2		2	
AVE	**6.7**		**6.9**		**2.3**		**2.4**	



HV: Higher value
LV: Low value
AVE: Average
GR: Grams

Code (COD)

A: Raised matrix terminal
B: Raised matrix solder
C: Broken wire at matrix junction
U: Broken wire at box junction
P: Raised box solder
W: Broken wire on the meb

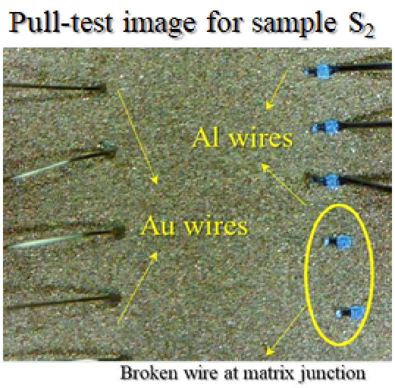


Figure 6- Pull-test results for Al (31 µm) and Au (17 µm) wires for samples S_2 and S_4 (left side) and Pull-test image for sample S_2 (right side).

4. Conclusions

From the morphological study, it was observed that the influence of the use of an extra activation step before the deposition sequences of the films is practically imperceptible over the Au film morphology, namely roughness and thickness of the Au films.

From the pull-test results it could be conclude that, in the evaluation of the quality of adherence and mechanical resistance of the welding points, the parameter that has the greatest influence is the thickness of the Au films. The best results were observed for the samples S_2 and S_4 with Au thickness of 3.40 µm and 3.63 µm respectively. Both minimum values reported by pull-test for these samples (S_2 and S_4), are above the specs established in the MIL-STD-883H standard.

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