Electrolytic gold thin films for interconnection in Multichip Modules.

Bolsista Melissa Mederos Vidal (CTI) melissa.vidal@cti.gov.br

Abstract

A Multichip Module (MCM) is a structure consisting of several ICs (typically bare chips) interconnected on a common supporting substrate and packaged as a single device or system (SIP: System in package). The substrate conductors are usually formed in multiple layer structures that are separated by dielectric material with vias connecting the various layers. As consequence, this type of system integration demands a high-quality interconnection between the different circuit levels to establish a proper interconnected SIP. Gold (Au) thin films are usually used as MCM 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, a good quality of the Au thin films for interconnects purpose is also demanded. The present work reports the analysis of wire bonding, pull-test and sheet resistance measurements made on Au thin films, destined essentially to interconnect the different circuit levels on a MCM. The results evidenced a high dependency of the Au films thicknesses with the welding points quality, the pull-test and the sheet resistance value. Au films with thickness above 3 μm provided 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 or system (PRADEEP, 1993). Among the many advantages this system in package (SIP) 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. (PRADEEP, 1993; BILLAH, 2015 & 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 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 (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. The interconnections levels formed by several sequences of metallic thin films deposition and defined by maskless photolithography processes using a MicroWriter ML3. Gold (Au) thin films are going to be use as conducting layers (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 (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 (LI, 2005).

In this study, the Au films will be selectively deposited by electrolytic 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 (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 (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 the Al_2O_3 substrates prior the deposition. The present work proposes to discuss how morphological properties of these Au thin films (specifically roughness and thickness parameters) affect the wire bonding quality, the pull-test and the sheet resistance values.

2. Experimental Details

The samples investigated were fabricated following the sequences shown in Fig. 1. Al_2O_3 (1-inch, square, 96% and 0.6 mm thickness), with and without polished surface, were used as substrates in order to evaluated the surface roughness influence. Samples S_1 and S_2 are non-polished Al_2O_3 meanwhile S_3 is polished. The Ni-P adhesion films were obtained by electroless deposition, at a temperature of 60°C (± 2°C) during 10 minutes. 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 two different current densities (for sample S_1 was used half of the current density used for samples S_2 and S_3). This was made to obtain two different thicknesses of Au films.

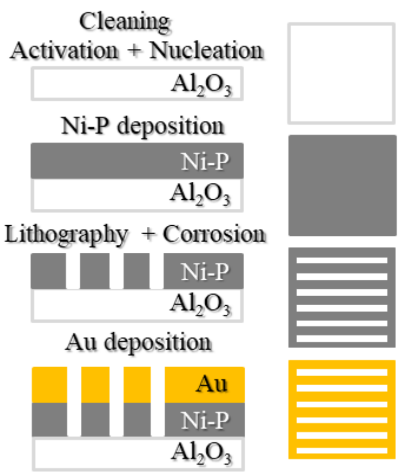


Fig.1. Schematic of the samples fabrication sequences used in this study. Left: a lateral cross section sequence. Right: top view sequence.

For morphology measurements of the films (thickness and roughness) a DekTak XT was employed. For the sheet resistance measurements was used a 4 point probe RS3000+ Jadel. 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 the Military Standard 883 version L was applied (MIL-STD-883L, 2019). Au and Al diameter wires were 17 µm and 31 µm, respectively.

3. Results and discussions

Table 1 shows thickness and roughness results obtained by scan profiling, and sheet resistance results determined for four-point probe method, for the Ni-P films. As can be observed, the values of these parameters for samples S_1 and S_2 are close to each other, indicating process reproducibility from wafer to wafer. It should be noticed that the Ni-P roughness is smaller than the alumina substrate roughness.

Samples	Al_2O_3 Roughness	Ni-P Thickness	Ni-P Roughness	Ni-P Sheet Resistance
S_1	1.09 µm	2.38 µm	0.74 µm	23.82 Ω/□
S_2	1.04 µm	2.14 µm	0.64 µm	22.30 Ω/□
S_3	0.09 µm	0.78 µm	0.12 µm	5.92 Ω/□

Table 1 – Thickness, Roughness and Sheet resistance of Ni-P films

Table 2 shows the same figures of merit for Au films deposited onto the Ni-P. The thickness values are for the Au only, i.e., excluded the Ni-P below, while the sheet resistance is for the Au/Ni-P stack. We noticed that the roughness of the Au films accompanies the roughness values of the Ni-P films. From the thickness results of Au films (see Table 2), is observed that, the thickness of S_2 and S_3 are approximately double of sample S_1. This result is expected since, as was comment on last section, it was used two different current densities during the deposition (S_2 and S_3 with the double of current of S_1).

Samples	Au Thickness	Au/NiP Roughness	Au/NiP Sheet Resistance
S_1	1.41 µm	0.70 µm	33.13 mΩ/□
S_2	3.63 µm	0.68 µm	17.29 mΩ/□
S_3	3.25 µm	0.12 µm	31.24 mΩ/□

Table 2 – Thickness, Roughness and Sheet resistance of Au films

In addition, the sheet resistance of the Au films increases with the reduction of their thicknesses (see Table 2), what is in correspondence with the fact of the sheet resistance being inversely proportional to the thickness (KE, 2009 & LEE, 2012). That is, S_1 with the lowest thickness (1.41µm) shows the highest sheet resistance (33.13 mΩ/□) while S_2 with the highest thickness (3.63µm) has the lowest sheet resistance (17.29 mΩ/□).

As for sample S_3, in which was used a polished alumina as a substrate, very different results were found. First, Ni-P film (see Table 1) shows roughness similar of the substrate, and their thickness and sheet resistance are quite different from S_1 and S_2, even when it was deposited at the same conditions than these ones. These results show the high dependence of both process and material on the substrate. That is, not only the polished surface reduces the Ni-P deposition rate but also changed intrinsic characteristics of the alloy, by greatly reducing its sheet resistance.

A similar conclusion can be deduced from the Au film results. Au deposition conditions are the same for S_3 and S_2, leading to samples with similar thickness (3.25 and 3.63 µm, respectively). However, the sheet resistance of S_3 is the same of S_1, with half the thickness. This means that the low roughness surface does not affect the deposition process itself (i.e. deposition rate), but the Au deposited is quite different for a polished surface from a rough surface (sheet resistance).

Fig. 2 shows some results of Tables 1 and 2 for sample S_3, which will be studied in more detail to better understand these differences.

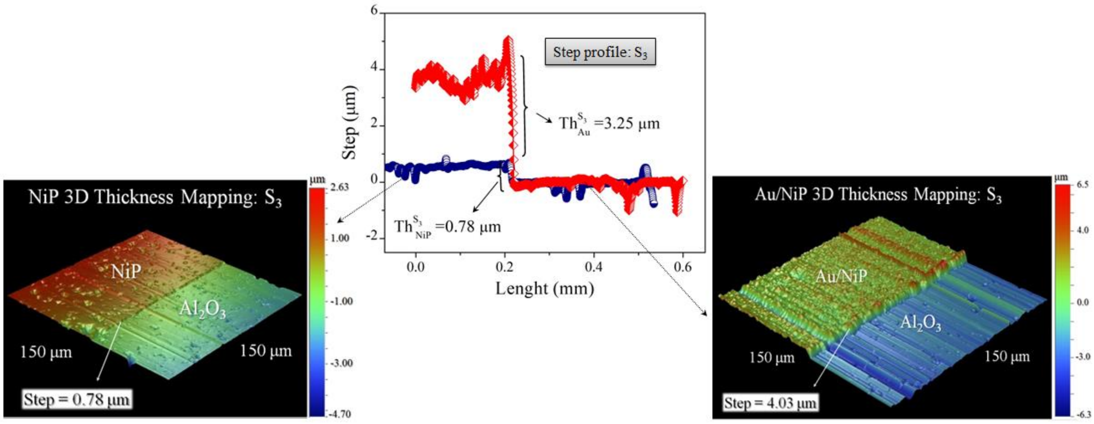


Fig. 2: Step profile 3D image for sample S_3. Test of thickness results.

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 with lower thickness (see Table 2), 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_3 with greater thicknesses (see Table 2) reported no adhesion issues of the welding points for both the Au wires and the Al wires. Fig. 3 shows the results of the latter's (S_2 and S_3).

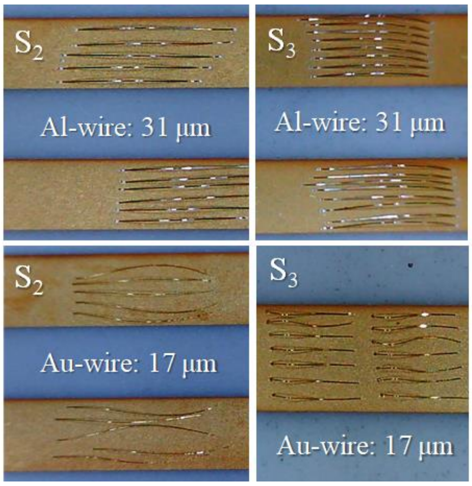
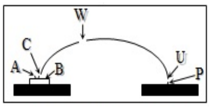


Fig. 3: Wire bonding tests results in samples S_2 (left) and S_3 (right) for wires Al (31 µm diameter) and Au (17 µm diameter). Au lines are 2 mm wide.

Destructive pull-test evaluation, according the rules presented on the method 2011.8 from MIL-STD-883L, was performed on the wires bonded onto samples S_2 and S_3 that were the only ones that withstood the welding. Results are presented on Table 3. 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-883L, 2019). This demonstrates that the Au films deposited have enough adherence to receive and maintain both Al and Au wire bond interconnections, even when they are deposited over Ni-P films with different thicknesses.

Quantitatively, it is observed that the force required for breaking the wire (see line AVE on Table 3) is above the specifications established according to the MIL-STD-883L 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-883L, 2019). Fig. 4 shows some results of Table 3 for S_2.

Wires No.	**Pull-Test Results**							
	Al wire				**Au wire**			
	S_2		**S_3**		**S_2**		**S_3**	
	GR	**COD**	**GR**	**COD**	**GR**	**COD**	**GR**	**COD**
1	6	C	8	U	2.5	C	3.2	A
2	7.2	U	7.2	C	2.5	C	3.2	A
3	7	U	6	U	2.5	C	2.5	C
4	7	C	5.5	U	2.5	C	2.5	A
5	6.2	C	6	U	2	C	1.8	A
6	6.5	C	7.5	U	3	C	2	A
7	8	C	6.5	U	2	C	1.5	A
8	7	C	7	U	2.5	C	4	C
9	5.5	C	7	U	2	C	2	C
10	7	U	6.5	U	2	C	3	A
11	8	C	7.5	U	3	C	2	A
12	6.8	C	8	U	2	C	1.5	C
13	7	C	7	U	3	C	3	A
14	8	C	7	U	2	C	1.5	C
15			7.5	U			2.5	C
SUM	97.2		104.2		33.5		36.2	
HV	8		8		3		4	
LV	5.5		5.5		2		1.5	
AVE	**6.9**		**7.0**		**2.4**		**3.3**	



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

Table 3: Pull-test results for Al (31 µm) and Au (17 µm) wires for samples S_2 and S_4.

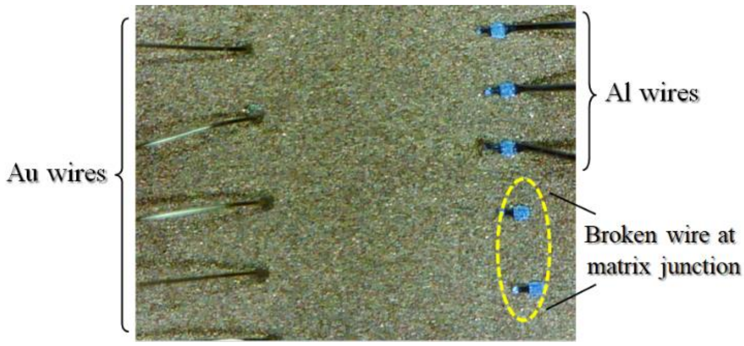


Fig. 4: Pull-test image for sample S_2.

4. Conclusions

From the morphological study, it was observed that the thickness of the Au films only depends of the deposition conditions. However their intrinsic behaviors (as for example the sheet resistance) are closely correlated not only with the deposition conditions, but also with the topographic characteristics of the substrate. That is, the roughness of the Al_2O_3 substrates, play a fundamental role in the deposition rate of the Ni-P films, and on the sheet resistance of both Ni-P and Au films.

From the wire bonding and pull-test results, it could be concluded that the thickness of Au films is again, the greatest influence parameter. That is, good adhesion was only obtained in films with thicknesses of ~ 3 μm.

The best result was obtained for sample S_3 with Au thickness of 3.25 μm. For this sample, the values reported by pull-test were 7.0 grams-force for Al wire (31 μm of diameter) and 3.3 for Au wire (17 μm of diameter). These values are above the specs established in the MIL-STD-883L standard. Those are 3.0 grams-force for Al wire and 2.0 grams-force for Au wire.

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