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Magnetron Sputtering Technology for Microvias Metallization

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Abstract

The increased demand of miniaturized and much more functional electronic devices inspire producers of PCBs (Printed Circuit Boards) to search the new constructions and technologies of manufacturing. Searching for new solutions due to high miniaturization of electronic components is concentrated on increasing density of electronic packaging and using multilayer PCBs. The interconnections between conductive layers are realized by holes with diameter less than 150 μm (microvias). The technologies of metallization of microvias are elaborated (e.g. electroplating), but only in case when aspect ratio is not higher than 1. In the paper we propose metallization of microvias with much more higher aspect ratio. The technological steps which enables metallization of that microvias are as follow: forming of microvias in FR-4 material by Nd:YAG laser drill machine, self-sustained sputtering process, and grown onto the sputtered copper layer. The purpose of our research is to find a combination of magnetron sputter deposition process parameters which guarantee achieving reliable microvia connections.

1. Introduction

The rapid development of electronic components integration determined the direction of PCBs evolution. The main aspect of these concerns on the miniaturization of multilayer interconnects. It needs the new generation of via, or rather microvias - blind holes with small diameter. The microvia is the hole in which diameter is about 150 μm or less. In the result, using of microvias considerably allows to minimize of PCBs dimensions and weight even about 40%. Additionally, the microvias placed in the contact lands of PCBs contribute to extremely reduce connects length between electronic components. It has direct influence on the functionality and reliability of the electronic assemblies. On the other hand, using of microvias requires high efficiency of metallization process. Microvias are recommended to have diameter 1-1.5 times grater than the thickness of the dielectric layer. This recommendation has resulted from the difficulty of metallizing microvias if the aspect ratio is higher than 1. It means that the via depth should not be higher than via diameter. However, the ascending requirements of interconnections miniaturization establish that the aspect ratio should be much more higher than 1. It excludes using of traditional metallization and determines the PCBs manufacture companies to searching of new metallization methods. In this case, the one of the alternative methods is the very high power magnetron sputtering process. Such process has been reported [1], but with the aspect ratio close to 1. In this paper the results of our investigations of microvias metallization with much higher aspect ratio by using of magnetron sputtering process are presented. The new solution in this domain is the self-sustained magnetron sputtering. The self-sustained process allows to deposit thin films in an atmosphere of sputtered particles only without any working gas in the vacuum chamber [2]. In the start of self-sustained process the labour gas is needed only to initiate of the sputtering process. After that the

labour gas is separated, and all process to the end is realized without it. That type of sputtering process permits to receive the high purity of sputtered layers, and it is especially dedicated to the filling of high-aspect-ratio sub-μm structures [2]. The Ar as the labour gas was used in our investigations.

2. Test samples

To achieve the vias with high aspect ratio the UV Nd:YAG laser drill machine from ESI (Electro Scientific Industries Inc.) model 5200 was used. The microvias in the FR-4 and in the RCC (Resin Coating Copper foil) material were formed. In case of FR-4 material, the vias in 200 μm thick laminate with 35 μm Cu layer on both sides with 50, 100 and 200 μm diameter were formed (with aspect-ratio 5.4:1, 2.7:1 and 1.3:1 respectively).

The first trials of metallization shows that the quality of via is very important. The via should be cylindrical with smooth walls. It is the precondition to obtain the uniform layer of sputtered copper on the via walls. However, the microvias formed by laser drill machine have not uniform structure of via wall (see Figure 1). It comes from that the different materials (resin and glass fiber situated in FR-4 laminate) have various level of laser beam ablation [3].

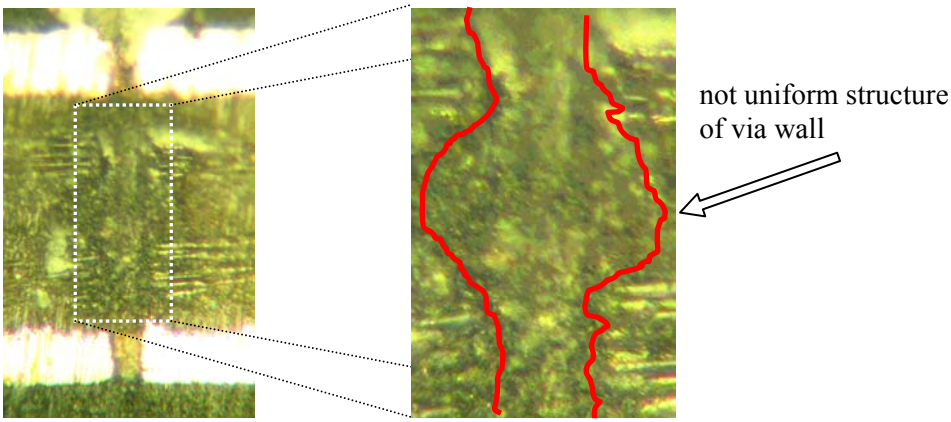


Fig. 1. The first trials of magnetron sputtering metallization of laser drilled microvias in FR-4 material (50 μm diameter on the top of via)

In the result, to obtain the smooth walls, the vias in FR-4 material were formed by mechanical Excellon model EX200 drill machine. In this case the test samples were made in 1 mm double sided (18 μm Cu) laminate with 0.4, 0.6, 0.8 and 1.0 mm holes diameter. It means that the drilled holes have 2.6:1, 1.7:1, 1.3:1 and 1:1 aspect-ratio respectively.

In case of RCC material, the test samples were made with another construction. According the SBU (Sequential Build-Up) technology the outer dielectric material and copper foil (RCC) were pressed on the core (FR-4 laminate with thickness 0.5 mm) in the standard lamination process. In this case the FR-4 laminate was used as a mechanical construction. After press process the thickness of RCC material is about 12 μm Cu layer and 55-65 μm dielectric layer. Directly in RCC layer the microvias with 70, 50 and 30 μm diameter were formed.

The each of the samples contained the holes with the same diameter. The test samples prepared as mentioned above were put to the trials of metallization by magnetron sputtering deposition process.

3. Magnetron sputtering deposition process

In the experiments the WMK-100 magnetron type was used. The magnetrons of WMK type were designed and manufactured by Faculty of Microsystem Electronics and Photonics of Wroclaw University of Technology. The WMK-100 has the target with 100 mm diameter and 11 mm thickness. Despite the small dimensions of target it is very high power magnetron because it has very effective cooling system.

Magnetron sputtering during both standard (with Ar) and self-sustained (without Ar) modes was investigated. The tests of metallization were realized in two steps, separately for through holes drilled by mechanical drill machine in FR-4 material and for blind microvia drilled by laser drill machine in RCC material. The samples with through holes were used as base point of our investigations.

On the beginning the samples with through holes were investigated. In this part of experiment 8 samples were used. The four samples for standard mode and four for self-sustained mode of magnetron sputtering were investigated.

Similarly, the samples with blind microvias were investigated. The three samples for standard and the three for self-sustained method of magnetron sputtering were investigated. In all cases the magnetron sputtering process was realized in the same way.

Additionally, the half of trials was realized by static and half by dynamic method. In the static method the distance between test samples and target was about 175 mm. However, in the dynamic method test samples were in the movement towards target during the process. It is shown in figure 2.

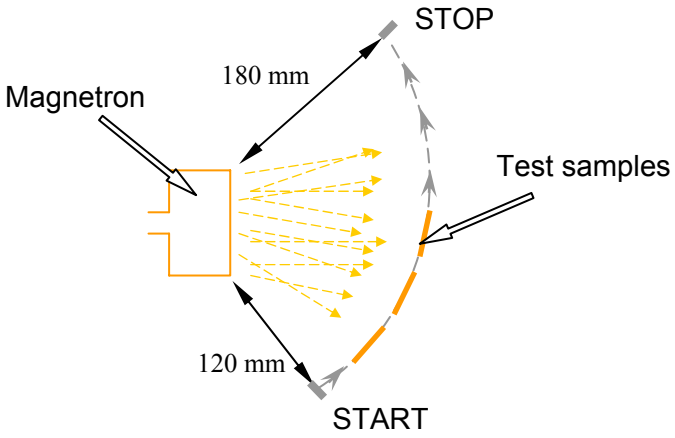


Fig. 2. The movement of test samples during the magnetron sputtering process

The thickness of sputtered copper on the surface of each trials was the same and it was about ~ 6,0 μm. Because the sputtered copper was deposit on the copper surface of samples it was impossible to precise measuring of deposited copper thickness. It was made by using of the glass plate which was placed with samples in sputtering chamber.

In all trials the magnetron sputtering process parameters were the same. The used parameters are shown in table 1.

Table 1. The parameters of realized magnetron sputtering processes

	Unit	Standard mode	Self-sustained mode
Pressure at the end of process	[Tr]	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$
Pressure of Ar	[Tr]	$3 \cdot 10^{-3}$	~ 0
Target current	[A]	12	12
Voltage	[V]	600	600
Density of target power	[W/cm^2]	~ 93	~ 93
Time of process	[min.]	10	10

4. Test results and discussion

In our investigations the quality of magnetron sputtering process was defined as the resistance value of connections (metallized vias) between conductive layers. The final results of resistance measurements are shown in table below. All results represent the average resistance of single connection.

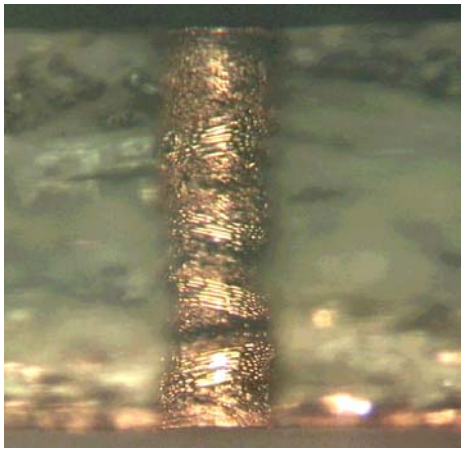
Table 2. The results of resistance measurements

	Microvias			Through holes			
Diameter	70 μm	50 μm	30 μm	1.0 mm	0.8 mm	0.6 mm	0.4 mm
Aspect ratio	1 : 1	1.4 : 1	2.3 : 1	1 : 1	1.3 : 1	1.7 : 1	2.6 : 1
Standard mode	2 mΩ	6 mΩ	157 mΩ	30 mΩ	44 mΩ	458 mΩ	1 044 mΩ
Self-sustained mode	4 mΩ	11 mΩ	43 mΩ	109 mΩ	60 mΩ	774 mΩ	1 744 mΩ

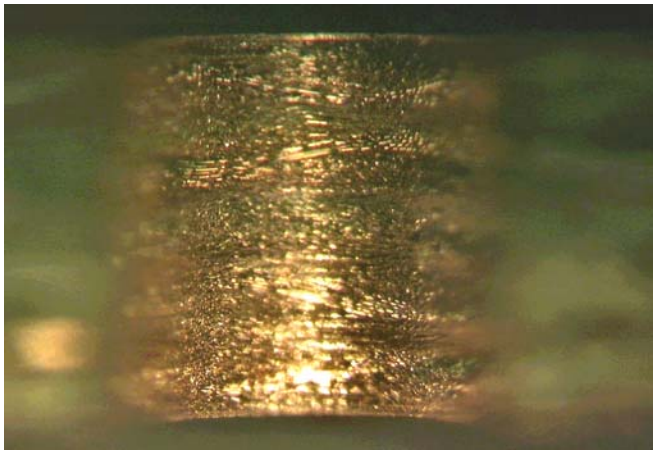
The test results which are shown above refers to the experiments which were realized with dynamic method only (Figure 2). In case of static method many vias were not conductive, and the final results were strongly diverse. The movement of samples allows to depositing on the walls of tight vias the thicker layers of sputtered material.

As it can be seen in table 2, the standard mode of magnetron sputtering allows to obtaining smaller resistance of interconnections than self-sustained mode. It comes from smaller activity of deposition process. On the other hand, the self-sustained process permits to forming much more homogenous layers (without any particles of labour gas).

In the goal to observe the deep-seated of magnetron sputtering process the cross-sections of test samples were made. The some of they are presented in figure below.



Through hole with 0.3 mm diameter
(self-sustaining mode)



Through hole with 1.0 mm diameter
(self-sustaining mode)

Fig. 3. The cross-sections of test samples after deposition of copper by magnetron sputtering process

In figure above, it can be seen that the magnetron sputtering process permits to deposition of copper layer in sub-μm holes in which depth is much more higher than diameter.

5. Conclusions

The magnetron sputtering process to microvias metallize has been investigated. The method of magnetron sputtering allows to metallize the walls of microvia which aspect-ratio is much more higher than 1. The realized experiments shows that the quality of drilled holes walls is very important. The guaranty of metallization process effectiveness is resident in the smooth walls of holes. The movement of samples during process significantly facilitates the deposition of copper on the via walls. The presented results are the base point for the investigations in the future.

6. References

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