Modern multilayers using ESL thick film systems containing mixed metals

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1. INTRODUCTION

Sophisticated, screen printed, wiring looms in the form of multilayer hybrid circuits have been made for over thirty years. In their earliest forms these were made throughout with a single metal that was typically gold though copper was tried at a time when the gold price was inordinately high in the early 1980s. Some circuits of this era had a solderable palladium gold conductor for acceptance of previously packaged semiconductor components on the uppermost layer.

In the early 1990s the term multichip module (MCM) was used to describe these electronic modules incorporating multiple integrated circuits (ICs), semiconductor dies or other discrete components in one assembly. It was around this time that the need to use silver based buried layers to reduce costs was acknowledged and much experimentation took place at that time to ensure that a mixed metal system utilising lead containing thick film pastes did not present problems. One problem that was identified was the need for a superior dielectric that did not exhibit the so-called battery effect. The use of regular dielectrics with mixed metals (silver based buried layers with gold on the top surface) presented difficulties in that, at the firing temperatures when the films were in near molten state, a chemical cell was produced resulting in movement of silver or gas into the gold layers and denuded vias. Consequently blisters or white gold regions were seen in the uppermost layers and voids in the vias due to the migration of silver and this meant that circuits were non-functional. Work was carried out to determine the best material to use as a via fill. A small addition of palladium to the silver, as in ESL 9695, was found to be the best solution.

Multilayer circuits have continued to be built, however, since the advent of lead-free thick film pastes (circa 2005), these modern materials have replaced lead containing thick film pastes[2]. Other requirements for such multilayers, such as higher operating temperatures as used in deep well applications, mean that there is a need to ensure that silver based circuits may be built with modern materials and that they will be robust.

This paper describes work that was customer driven and necessitated the preparation of a new test pattern to test a modern silver based system. A further pattern was designed to test the integrity of the junction between a high silver containing paste, a silver palladium paste and a gold paste after multiple firing operations.

2. PREPARATION

Blisters had been observed by one customer when three different silver bearing conductors (one base, one via fill and a top layer) were stacked on top of each other in a lead-free multilayer build. There were blisters observed in other parts of the circuit. A pattern was designed in collaboration with the customer to test all then known potential problem areas.

Another customer wanted to know the effect of multiple firing on the junction between silver and silver palladium (with silver printed first followed by the silver palladium and also the other way round) and between both silver and silver palladium and gold over dielectric and directly onto alumina. A pattern was designed to demonstrate the effects and conductors printed over dielectric also confirmed test work done using the first pattern.

2.1 Silver based test pattern

Figures 1- 5 show the design of the test pattern (printed parts rather than photopositives). The pattern was designed to fit onto a 50mm x 50mm x 0.635mm alumina substrate. Layers 3 (via fill of the twelve large vias) and 4 (repeated dielectric layer to give good insulation between layers) are not shown here.

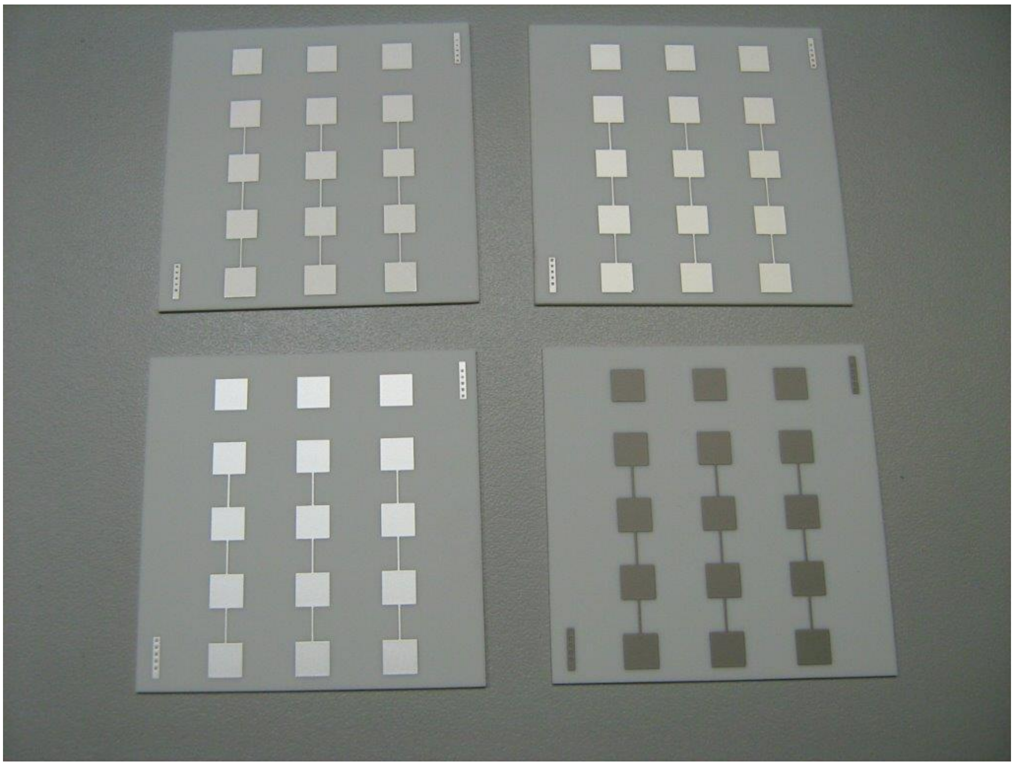

Figure 1 Base layer (layer 1)

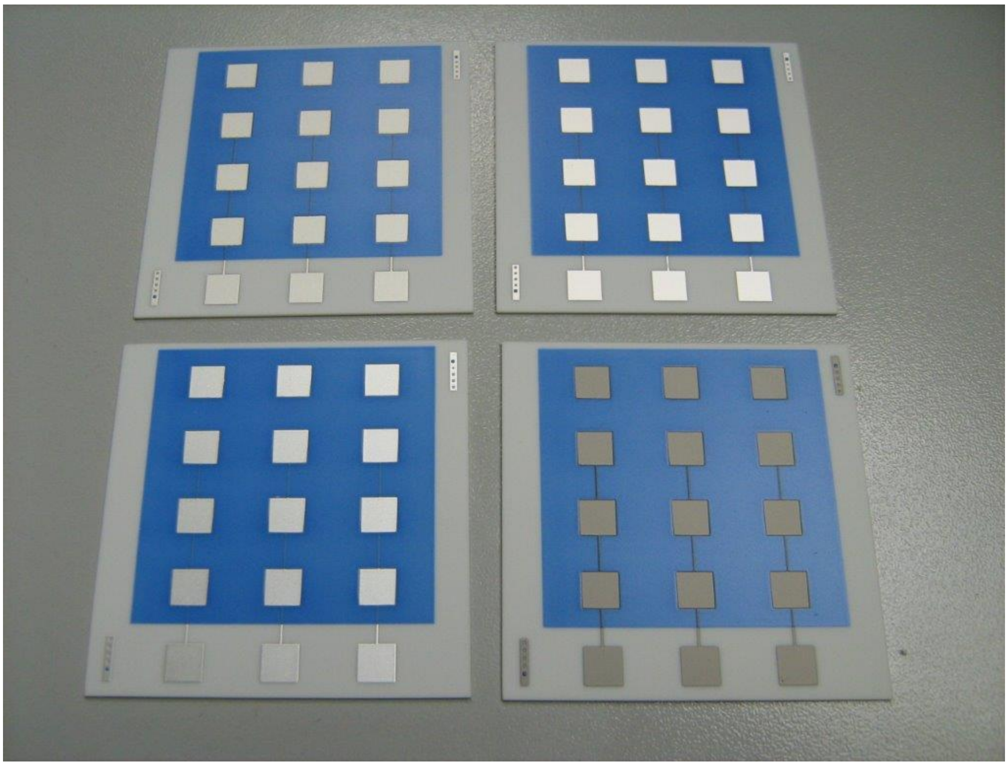

Figure 2 Dielectric layer (layers 2 and 4) superimposed on the first layer

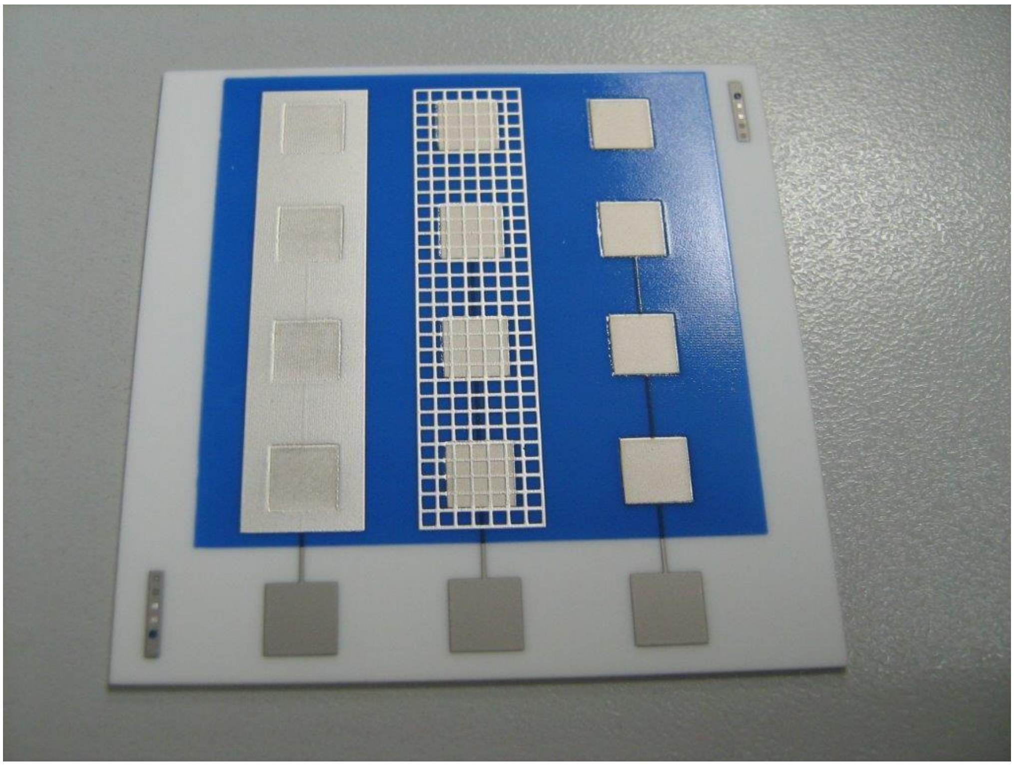

Figure 3 First top conductor (solid block to the left and hashing in the middle) – layer 5

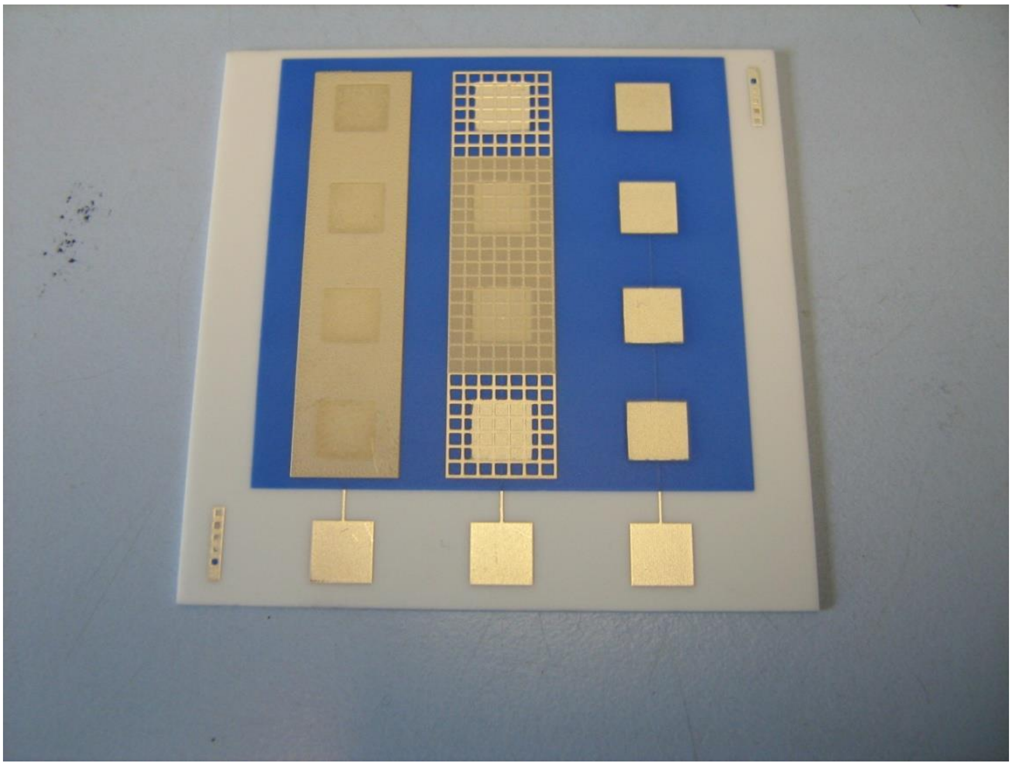

Figure 4 Second top conductor (solid block added to the centre hashed conductor) – layer 6

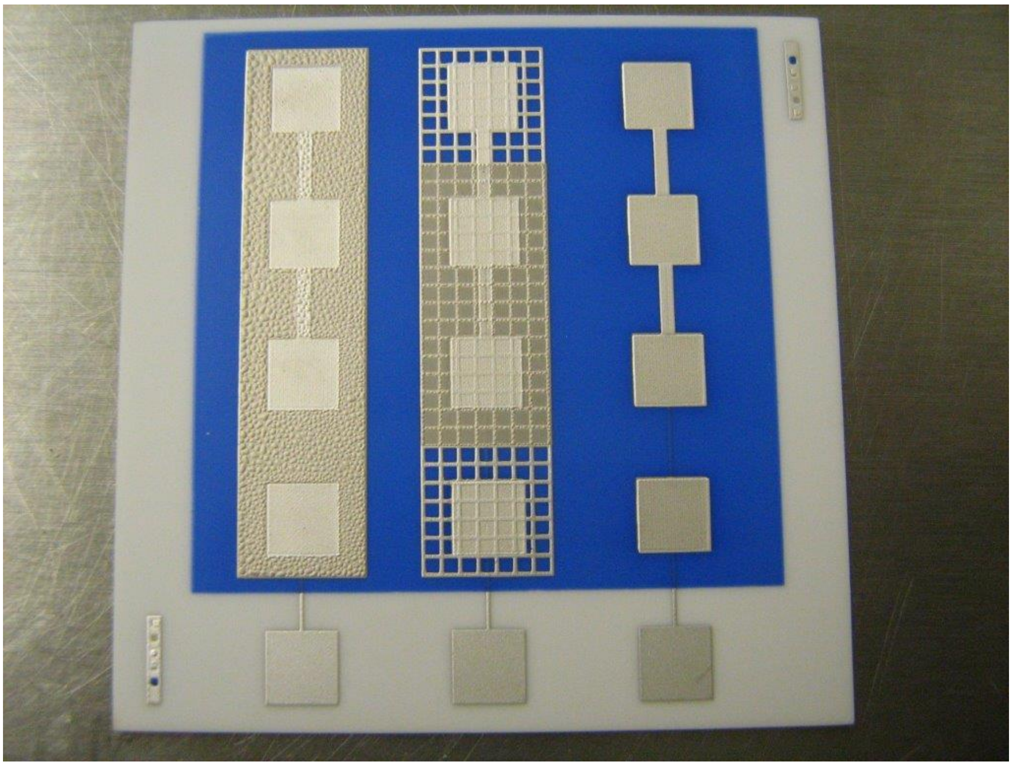

Figure 5 Third top conductor (via fill) shown as the final part of the total build – layer 7

2.2 Mixed metal test pattern

Figure 6 shows a completed test part using the pattern designed to test a mixed metal system. The effective substrate size was 94mm x 57mm.

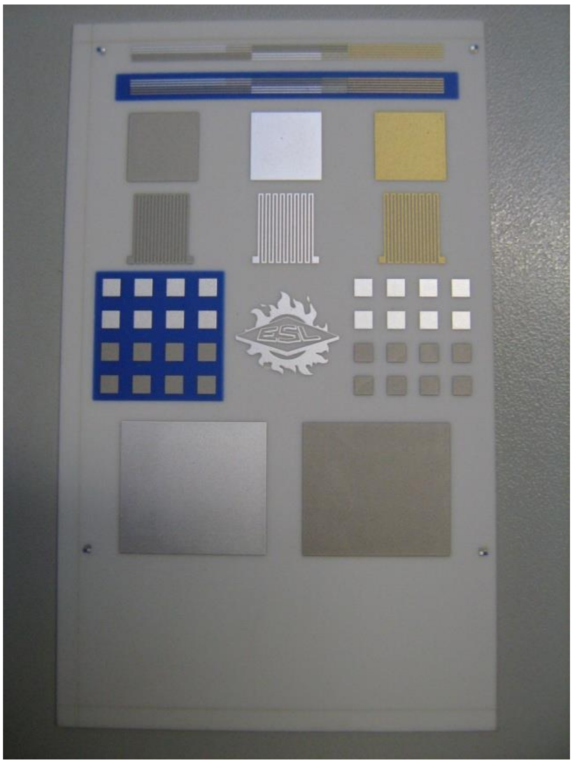

Figure 6 Mixed metal test pattern

The narrow tracks on both alumina and dielectric in the top of the pattern are 150µm wide with 250µm separating them. The dielectric layers are printed first of all and then the six gold lines to the right of the pattern at the top. Then three lines (silver) in the top left are printed. The three lines at top centre are printed next using a silver palladium paste. At the same time three lines are printed beneath the silver lines already there. This gives a contact between the silver palladium paste used for this print and superimposed on the silver that has already been deposited. The next layer is the three centre lines which link the silver palladium to the left and the gold to the right. This print gives three junctions where silver palladium has been deposited over the silver. The earlier print operation results in silver underneath the silver palladium. The rest of the test pattern is for trimming purposes and is not the subject of this study.

3. EXPERIMENTAL

3.1 Silver based test pattern

Each substrate was marked with the paste number for identification purposes at each of the seven levels. All layers were fired at 850°C in a standard one hour profile.

3.1.1 First layer. The base conductor pattern (see Figure 1) was printed using 4 separate conductors. 192 substrates with each conductor were printed using a 280 mesh, 15µm emulsion screen. 9633-G, 9562-G, 9695-G and 9912-K were deposited.

3.1.2 Second layer. The parts were divided into three groups of 64 for each conductor. A dielectric layer (see Figure 2) was applied using a 280 mesh 15µm emulsion screen. Double wet passing was used throughout the dielectric printing operation. 3 dielectrics, 4913, 4938 (a blend of 4917 and 4913) and 4917, were printed. The fired thickness of the first layer of dielectric was 23-27µm.

3.1.3 Third layer. The samples were then divided into two (groups of 32 – marked again) and the large vias were filled with 9695-G and 9562-G. Blisters were noted at the edge of the vias on those samples that had 9633-G as the bottom conductor with 9695-G as the via. There may have been some slight difference depending on the dielectric that was used but at this stage any such difference was hard to quantify. Use of 9562-G as the via fill showed no blisters at this stage.

3.1.4 Fourth layer. The second layer of dielectric was then printed. 4913, 4917 and 4938 were used. The thickness of each dielectric was 4913 - 41µm, 4938 - 43µm and 4917 - 50µm.

3.1.5 Fifth layer. The first of three **top conductor patterns** was printed (Figure 3) using 9695-G. Three other conductors, 9562-G, 9635-G and 9635-HG, were also printed so that groups of eight for each different combination were made.

3.1.6 Sixth layer. The four conductors used for the first top conductor were used for the second top conductor pattern (Figure 4). The paste lots used were the same as for the first conductor. There two of each combination at this penultimate stage.

3.1.6 Seventh layer The 768 substrates were split into two and half were printed with a final via fill print in 9695-G and half with 9562-G (Figure 5).

3.2 Mixed metal test pattern

Each substrate was marked with the paste number for identification purposes at each of the six levels (two dielectric layers). All layers were fired at 850°C in a standard one hour profile. Four substrates were printed. 4938 was used for the dielectric in this pattern. 8846-G was used as the gold conductor. The silver based conductor was either modified 9912-G, 9512-G, 9562-G and 9695-G. The next layer was 9635-G and then the silver used for each substrate was used again. Each substrate received a further fourteen firings at 850°C. Inspection was made for cleavage at the conductor overlaps and for blisters.

4. RESULTS

4.1 Silver based test pattern

Tables 1-4 show where defects occurred on circuits built using the four separate base conductors. The definition of each abbreviation used is given at the end of the section on tables.

1st top cond.	2nd top cond.	Via Fill	BASE CONDUCTOR 9912-K					
			DIELECTRIC					
			4917		4938		4913	
			VIA FILL					
			9695-G	9562-G	9695-G	9562-G	9695-G	9562-G
9562-G	9562-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9695-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9635-G	9695-G	BEV2?	-	-	-	-	-
		9562-G	BEV2	-	-	-	-	-
	9635-HG	9695-G	BEV2?	-	-	-	-	-
		9562-G	BEV2	-	-	-	-	-
9695-G	9562-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9695-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9635-G	9695-G	BB12	BB12	BB12	BB12	BB12	BB12
		9562-G	BB12	BB12	BB12	BB12	BB12	BB12
	9635-HG	9695-G	BB12	BB12	BB12	BB12	BEV12	MBB12
		9562-G	BB12	BB12	BB12	BB12	BEV12	MBB12
9635-G	9562-G	9695-G	BEV12	-	-	-	-	-
		9562-G	BEV12	-	BEV1	-	-	-
	9695-G	9695-G	BEV12	-	-	-	-	-
		9562-G	BEV12	-	BEV1	-	-	-
	9635-G	9695-G	BEV12	S?	-	-	VD12	-
		9562-G	-	-	-	-	-	-
	9635-HG	9695-G	-	-	BEV12	VD12	-	-
		9562-G	-	-	BEV1	-	-	-
9635-HG	9562-G	9695-G	BEV1	-	-	-	-	-
		9562-G	BEV12	-	MBB1	MBB1	-	-
	9695-G	9695-G	BEV12	BMV1	BEV12	-	-	-
		9562-G	BEV12	-	BEV1	-	-	-
	9635-G	9695-G	BEV12	-	-	-	-	-
		9562-G	BEV12	-	-	-	-	-
	9635-HG	9695-G	BEV12	-	BEV12	BB1	-	-
		9562-G	BEV12	MBB1	BEV1	MBB1	-	-

Table 1 9912-K as the base conductor

1st top cond.	2nd top cond.	Via Fill	BASE CONDUCTOR 9695-G					
			DIELECTRIC					
			4917		4938		4913	
			VIA FILL					
			9695-G	9562-G	9695-G	9562-G	9695-G	9562-G
9562-G	9562-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9695-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9635-G	9695-G	BEV2?	-	-	-	-	-
		9562-G	BEV2?	-	-	-	-	-
	9635-HG	9695-G	BEV2?	-	BEV2?	-	-	-
		9562-G	BEV2	-	-	-	-	-
9695-G	9562-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9695-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9635-G	9695-G	BB12	BB12	BB12	BB12	BB12	BB12
		9562-G	BB12	BB12	BB12	BB12	BB12	BB12
	9635-HG	9695-G	BB12	BB12	BB12	BB12	BEV12	MBB12
		9562-G	BB12	BB12	BB12	BB12	BEV1	BEV1
9635-G	9562-G	9695-G	BV12	-	BMV12	-	BV12	VD12
		9562-G	BV12	-	BV12	-	BV12	VD12
	9695-G	9695-G	BV12	-	BMV12	-	BV12	-
		9562-G	BV12	-	BEV12	-	BV12	-
	9635-G	9695-G	BV12	S?	BV12	VD12	BV12	VD12
		9562-G	BV12	-	BMV12	-	BV12	-
	9635-HG	9695-G	BV12	BEV1?	BEV12	-	BV12	-
		9562-G	BV12	-	BEV12	BEV1	BV12	-
9635-HG	9562-G	9695-G	BV12	BMV1	BMV12	BEV1	BV12	-
		9562-G	BV12	BV1	BV1	BEV1	BV1	MBV1
	9695-G	9695-G	BV12	BEV1	BV1	BV1	BV1	BV1
		9562-G	BV12	BV1	BV1	BEV1	BV1	MBV1
	9635-G	9695-G	BV12	BEV1	BEV	BV1	BV1	BV1
		9562-G	BV12	BV1	BEV1	BEV1	BV1	BV1
	9635-HG	9695-G	BV12	BV12	BMV12	BV12	BV12	BV1
		9562-G	BV12	BV1	BMV12	BV12	BV12	BV1

Table 2 9695-G as the base conductor

1st top cond.	2nd top cond.	Via Fill	BASE CONDUCTOR 9562-G					
			DIELECTRIC					
			4917		4938		4913	
			VIA FILL					
			9695-G	9562-G	9695-G	9562-G	9695-G	9562-G
9562-G	9562-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9695-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9635-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9635-HG	9695-G	BEV2	-	-	-	-	-
		9562-G	BEV2	-	-	-	-	-
9695-G	9562-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9695-G	9695-G	-	-	BMV12	-	-	-
		9562-G	-	-	-	-	-	-
	9635-G	9695-G	BB12	BB12	BB12	BB12	BB12	BB12
		9562-G	BB12	BB12	BB12	BB12	BB12	BB12
	9635-HG	9695-G	BB12	BB12	BB12	BB12	BB12	MBB12
		9562-G	BB12	BB12	BB12	BB12	MBB12	MBB12
9635-G	9562-G	9695-G	BEV12	-	BEV12	-	-	-
		9562-G	BEV12	-	BEV1	-	-	-
	9695-G	9695-G	BEV12	-	BEV12	-	BEV1	-
		9562-G	BEV12	-	BEV12	MBB2	-	-
	9635-G	9695-G	BEV12	S?	BEV12	VD12	VD12	-
		9562-G	BEV12	-	BEV12	-	-	-
	9635-HG	9695-G	BEV12	-	BEV12	-	-	-
		9562-G	BEV12	-	BEV12	-	BEV1	-
9635-HG	9562-G	9695-G	BEV12	-	BEV12	BB1	BEV12	-
		9562-G	BEV12	-	BEV12	-	-	-
	9695-G	9695-G	BEV12	-	BEV12	-	-	-
		9562-G	BEV12	-	BEV12	-	-	-
	9635-G	9695-G	BEV12	-	BEV12	-	-	-
		9562-G	BEV12	-	MBEV12	-	-	-
	9635-HG	9695-G	BEV12	-	BEV12	-	BEV1	-
		9562-G	BEV12	-	BEV12	-	BEV1	-

Table 3 9562-G as the base conductor

1st top cond.	2nd top cond.	Via Fill	BASE CONDUCTOR 9633-G					
			DIELECTRIC					
			4917		4938		4913	
			VIA FILL					
			9695-G	9562-G	9695-G	9562-G	9695-G	9562-G
9562-G	9562-G	9695-G	-	-	VD12	VD12	VD12	VD12
		9562-G	-	-	VD12	VD12	VD12	VD12
	9695-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9635-G	9695-G	-	-	-	-	-	-
		9562-G	-	-	-	-	-	-
	9635-HG	9695-G	BEV12?	-	MBB12	-	BEV12	-
		9562-G	BEV2?	-	-	-	-	-
9695-G	9562-G	9695-G	BEV12?	-	VD12?	-	-	-
		9562-G	BEV12?	-	BMV1	-	MBEV12	-
	9695-G	9695-G	BV12	BV12	BMV12	BMV12	BMV12	BMV12
		9562-G	BMV12	BMV12	-	BEV12	MBV12	BMV12
	9635-G	9695-G	BB12	BB12	BB12	BB12	BB12	BB12
		9562-G	BB12	BB12	BB12	BB12	BB12	BB12
	9635-HG	9695-G	BB12	BB12	BB12	BB12	BEV12	BB12
		9562-G	BB12	BB12	BB12	BB12	BEV12	BEV12
9635-G	9562-G	9695-G	BEV12	-	BEV12	-	VD12	VD12
		9562-G	MBEV12	-	-	-	-	-
	9695-G	9695-G	BEV12	-	BEV12	-	VD12	-
		9562-G	MBEV12	-	-	-	-	-
	9635-G	9695-G	VD12	S?	BB1	VD12	VD12	VD12
		9562-G	MBEV12	-	-	-	-	-
	9635-HG	9695-G	BEV12	-	BEV12	-	-	-
		9562-G	MBEV12	-	-	-	-	-
9635-HG	9562-G	9695-G	BEV12	BB1	BEV12	VD12	VD12	VD12
		9562-G	BEV12	-	VD12	-	VD12	VD12
	9695-G	9695-G	BEV12	BB12	VD12	-	-	-
		9562-G	BEV12	-	VD12	-	VD12	VD12
	9635-G	9695-G	BEV12	-	-	-	-	-
		9562-G	BEV12	-	-	-	-	-
	9635-HG	9695-G	BEV12	-	BEV12	-	-	-
		9562-G	BEV12	-	BEV12	-	MBEV1	-

Table 4 9633-G as the base conductor

BMV = Blisters mainly in via; BEV = Blisters edge of via; BV = Blisters in via; BB = Blisters in body; 1= Left hand conductor; 2 = middle conductor with hash; VD = Via darkening; S = shiny; M at the start = mild.

4.1 Mixed metal test pattern

Blisters were found on the 9695-G printed over the 4938. In terms of cleavage the order of merit measured by the separation of the conductors was 9512-G, 9562-G, and then modified 9912-G. 9695-G was discounted due to the blistering.

5. DISCUSSION

These experiments were customer driven. There are so many aspects to multilayer circuit fabrication that have not been considered in this study which necessitated ~5400 print fire operations. Small via resolution (150-175µm), small via filling, conductor definition have not been considered. Only four conductors were chosen and there are a host of others that could have been considered.

6. CONCLUSIONS

1. The use of 9562-G in lead-free, silver based multilayer systems is to be preferred above 9695-G.

2. Care must be taken not to use a high palladium content silver as the base conductor.

3. Where high palladium content silver pastes are used it is recommended to use 4913 in preference to either 4917 or 4938.

4. In mixed metal systems 9512-G may be the preferred choice but this would need to be the subject of further investigation.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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