

Cost Effective Use of Gold in Thick Film Conductors

Samson Shahbazi and Mark Challingsworth

Heraeus Materials Technology, LLC, Thick Film Materials Division
24 Union Hill Road
West Conshohocken, Pennsylvania USA

Abstract

The scope of this paper is the use of different forms of gold in thick film pastes for decorative colors and electronics. Gold can be made into a powder form, which is ideally suited for thick film pastes, by using chemical precipitation process with different shapes and particle sizes as well as into gold resins and metal-organic complexes. Gold powder and resins are used to make thick film paste for screen printing application with optimize back light density. Although gold is more expensive than other precious metals it provides a stable and reliable fired film. Fired films produced from gold do not suffer from migration because gold does not easily form a free Au ion. Gold thick film conductor pastes in general are used in high reliability applications such as military, high frequencies, interconnection-microwaves, and medical.

Gold is a noble element with the symbol Au and it is part of the transitional metal group with the atomic number of 79. It is a precious metal that's been desired since the beginning of history. It is well documented in the history books that gold has been used in sculptures, jewelry, and coins. The modern uses for gold include dentistry, decorative and electronics.

Data and information is presented to show the wide uses of gold in thick film conductor paste with reliable results. This data includes fired film density, resistivity, and wire bond adhesion.

Key words: Thick film, gold conductor, wire bonding, high reliability, lead and cadmium free

INTRODUCTION

The demands placed on thick film conductors used in electronics are increasing with smaller, lighter handheld electronics and the propagation of devices into harsher environments, especially military, high temperature and aerospace applications. Smaller and lighter handheld devices require high conductivity and fine line printed conductors that are able to withstand severe environments. Increasing IC chip requirements demand more from the thick film conductors in terms of wire bond adhesion and reliability. Thick film gold conductor pastes are well-matched for this type of challenging application.

In addition to the performance demands placed on gold thick film conductors, there also is a need for cost competitive application of these materials. This can be achieved by reduced material usage and easy processing while still maintain performance.

There are several forms of gold materials used to manufacture gold thick film conductors. There is a spherical powder type, flake/sphere powder type, gold resinate type, and

gold flake type. We will only cover the use of the first three types in this paper.

Gold Material Selection

The gold material type selection is very critical since it has a direct influence on the fired film characteristics. Depending on the application, cost and fired film requirements gold powder vs. gold resinate is selected. Traditionally, the sphere/flake type of gold powder has been used in the general purpose lower cost thick film conductor pastes, where spherical powder types are used for a paste with high fired film density, and fine line printing capability. Gold resinate is used where lower fired film thickness is required. The use of each gold type will be reviewed in the following sections.

Spherical Gold Powder

A spherical gold powder is generally chemically precipitated in small scale batches because of the complex manufacturing steps used in fabrication. With excellent process controls a mono size powder, free of

agglomeration can be produced. A very dense fired film can be obtained with a spherical powder. In the past, powders like this were dried and then re-dispersed into thick film pastes. For the best results this form of gold powder is never completely dried and is often stored in a solvent typically used in the final paste formulation. Depending on the application there are different particle sizes, tap density and surface area available to meet the final thick film paste requirements.

The advantages of using the powder type are, (1) better line resolution is possible, (2) a denser fired film is achievable, and (3) a smoother fired film surface, in which tighter wire bond results is achieved. Figure 1 shows the SEM photo of a spherical gold powder where the particles are uniform and mono size.

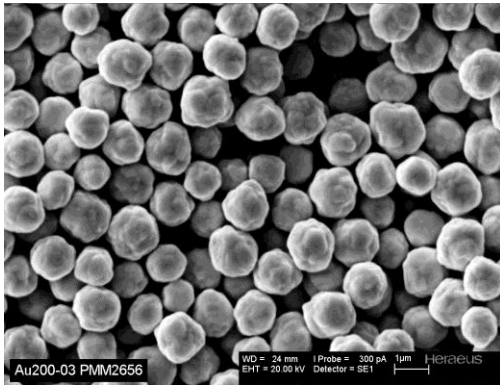


Figure 1. SEM photo of a spherical gold powder.

Fine Line Printing Capability

The industry trends are for finer line resolution. However, manufacturers want to keep the cost of the circuit down by using screen printing techniques, as opposed to using thin film techniques such as etching. Currently many thick film circuit production facilities are successfully printing 5 mil (125 microns) lines and spaces, but the drive has been to go down to 3 mil (75 microns) on a consistent basis. This is possible with this type of gold material by taking careful consideration of process conditions. There are five factors that can affect the print resolution. They are:

- screen mesh
- amount of paste on the screen
- squeegee speed
- paste viscosity
- printer set up
- screen quality

The most important factor is the screen mesh. Print tests were performed with different

mesh screens using the same screen printing conditions. The traditional 325 and 400 stainless steel mesh screens. In addition, we included in our matrix a 350SA screen. This type of screen is made from exceptionally strong and thin special alloy wires. With the increased strength of the wires, finer sized wires can be used to achieve the same tension and thus increasing the percent open area of the screen. This is significant because more open area will minimize the obstruction of the paste flow through the screen and increase the resolution capability of the pattern. For a 400 mesh, stainless steel screen with 0.7 mil diameter wire, the percent open area is 51%. For the 350SA mesh screen, with 0.63 mil diameter wire, the percent open area increases to 61%. The switch to the 350SA screen made a noticeable difference on our ability to consistently achieve 3 mil (75 microns) line resolution. Figure 2 is a SEM photograph of the 3 mil (75 micron) lines and spaces achieved.

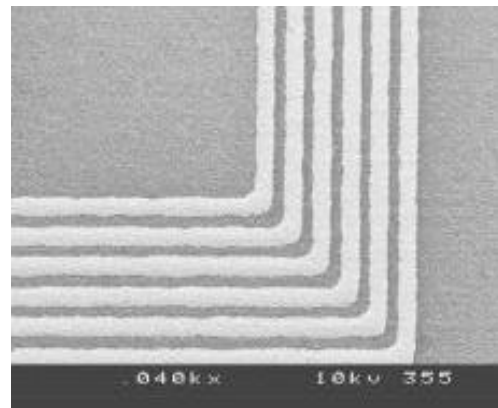


Figure 2. 3 Mil lines and spaces achieved with a 350SA screen.

Fired Film Density

To examine the back lit density of the fired surface; parts were viewed under magnification at 50x, with a light source under the part. Figures 3 shows the photograph of the back lit density for the sphere/flake gold conductor, and Figure 4 is photo of the spherical gold conductor. The extremely dense fired surface is apparent with the spherical gold conductor surface. Even though the conductor made with the sphere/flake powder was printed at a fired film thickness of 10-12 microns, and the conductor made with the spherical gold is printed at a fired film thickness of 5-8 microns you can see a significant improvement in the backlit density by how little light gets through the film

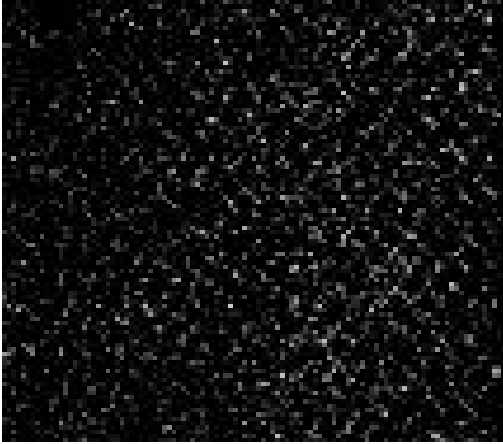


Figure 3. Back lit density of sphere/ flake paste at 50x.



Figure 4. Back lit density of spherical gold paste at 50x.

Wire Bond Results

All of the initial wire bond testing was done with manual wire bonders. The following wire sizes were tested: 1.25 mil (31.25 microns), 5 mil (125 microns), 8 mil (200 microns), 10 mil (250 microns) and 20 mil (500 microns). Wire bonds were placed on gold conductor films that were printed on alumina substrates and lead-free multilayer dielectric pastes. Aging studies were done at 150°C for up to 1,000 hours. Figure 5 is the 10 mil aluminum wire adhesion results.

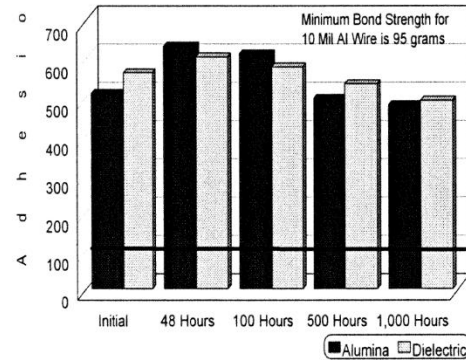


Figure 5. 10 mil Al wire bond adhesion data @ 150°C.

Mil Standard Requirements for Wire

The minimum bond strength requirement according to Mil STD 883E for a 10 mil Al wire is 95 grams. The minimum bond strength requirement according to Mil STD 883E for a 1.25 mil Au wire is 3.5 grams. Figure 6 shows the test pattern used to evaluate large wire diameter bond adhesion.

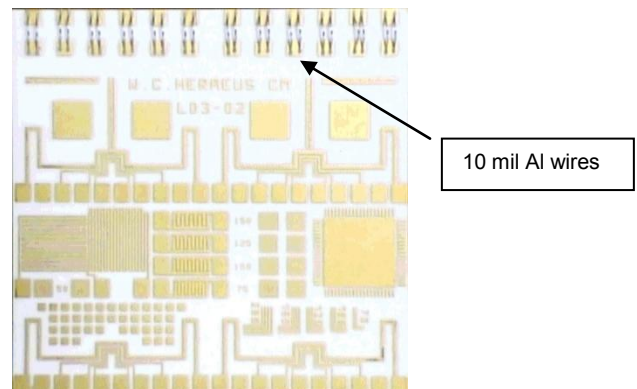


Figure 6. Test Pattern for printing & wire bonding evaluation

Sphere/Flake Gold Powder

Sphere/flake gold powder is the traditional gold powder type used for many years in thick film gold conductor pastes. This type of gold powder is comprised of a mix of gold spheres and gold flakes. Figure 7 is the SEM photograph of this type of powder. Due to the manufacturing process this type of gold powder is usually slightly less than the cost of the high performance, mono sized, spherical powder discussed earlier. Thick film pastes made with this type of gold powder are used for applications with less strict requirements. For example, the paste made with this gold type will print thicker and the line definition requirement may be 6-8 mils (150-200 microns) instead of 3 mils (75 microns). Moreover the backlit density will be slightly lower than paste made with

100% spherical powder (as seen comparing Figure 3 to Figure 4).

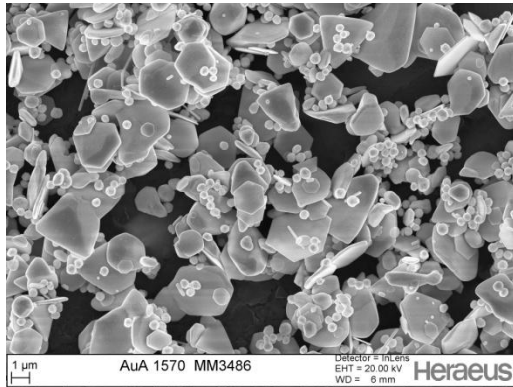


Figure 7. SEM photo of a Sphere/Flake Gold powder

But just like the thick film paste made with spherical gold powder, paste made with the sphere/flake powder provides excellent wire bond adhesion well above the Mil Standard requirement. Table 1 shows the wire bond adhesion with different size Al wire on Al_2O_3 substrates and lead-free dielectric.

Wire size	Initial adhesion				Adhesion after 150 Hours			
	On Al_2O_3		On IP9227		On Al_2O_3		On IP9227	
	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
8 mils	320	16	281	56	288	33	261	46
5 mils	137	5	141	6	126	10	115	10
2 mils	35	3	32	4	26	3	27	3
1.25 mils	18	2	18	1	15	1	15	1

Table 1. Wire adhesion data at 150°C Aluminum wire

The wire bond testing was done with manual wire bonders. The following wire sizes were tested: 10 mil (250 microns) Aluminum and 1.25 mil (32 microns) Gold. Aging studies were done at 150°C for up to 250 hours.

Gold Resinate Paste

Gold resinate pastes or metallo-organics provide can be a low cost option for production of components based on substrates made of ceramic, glass, and stainless steel enamel. Resinate pastes can be used in screen printing application to achieve film thicknesses matching those of thin film from 0.1 to 1.0 microns. Figure 8 is a photo of gold resinate packaged in a glass bottle. Unlike other types of gold material discussed previously, gold resinate is a liquid with no discrete gold particles in suspension.

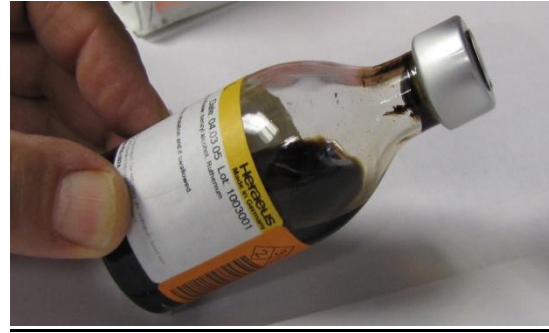


Figure 8. Photo of gold resinate bottle

Gold resinate pastes are available in a wide range of metal contents and viscosities. Standard gold contents are 10%, 12.5%, 15%, 18%, 20% to a maximum 22%. The films containing 10 and 12.5% gold contents are often strengthened with the addition of copper or nickel. They are used almost as bonding agents to promote adhesion of the film to the substrates. Resinate paste with 14 and 18% gold contents are used to produce pressure sensors. The higher gold contents pastes are used when higher conductivity is required as in the current supply of thermal print heads. Figure 9 shows different substrates made with gold resinate pastes.

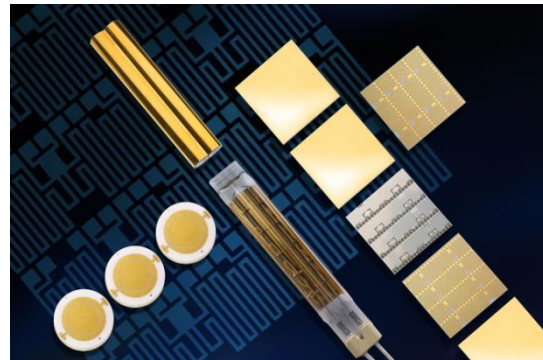


Figure 9. Photo of substrates made with gold resinate paste.

Gold resinate pastes can be applied by various methods. Besides the main application method of screen printing; spraying, pad printing, dipping and brush painting is possible. The rheological properties of the paste however must be adjusted to the application method.

The non thick film use of the gold resinate pastes is in the decorative ceramic application. Figure 10 shows an example of this application.



Figure 10. Photo of gold resinate in the decorative ceramic application

DISCUSSION

As highlighted in the material selection section, there are different screen printable gold systems suitable for various applications. Table 2 summarizes the relative cost and performance of each system. The systems each offer different performance and cost structures based on the fabrication cost, overall gold deposition needed and application (wire bondable vs. not bondable).

Material Type	Fabrication Cost (relative)	Conductor Thickness (μm)	Coverage (cm ² /gm)	Wire Bondable	Overall Cost Comparison
Au Spherical Powder	High	4 - 8	> 100	Excellent	Low
Au Flake/Powder	Low	10 - 20	50-70	OK	High
Au Resinate	High	0.1 - 1	400	N/A	Low

Table 2. Screen Printable Gold System Comparison.

While, the wire bond adhesion values listed above exceed the minimum bond strength requirement for the Mil Standard 883E, there are subtle differences between the fired films made using the spherical powder and powder/flake materials. Most notable is the more open fired film structure of the latter material. The more open structure can lead to more sporadic wire bonding results and therefore higher manufacturing costs. Also, the ability of the spherical gold systems to produce the finest patterns enables more bonds per area, thereby increasing component density, decreasing the overall materials need to build the electronic device and effectively decreasing overall device costs.

For resinate materials, the advantage can be seen with the coverage of the material. Due to the low metal content and thin printing capability, resinate pastes exhibit coverage 4-10x that of traditional thick film materials. This property can allow for the production of

many more devices using far less gold, resulting in lower overall costs. Although, there are limitations in their use, gold resinate in the right application can provide the manufacturer with a cost competitive alternative to thick film gold pastes and other more capital equipment intensive gold deposition technologies.

CONCLUSION

The combination of a spherical gold powder technology, and advanced manufacturing techniques make it possible to develop an economical thick film paste with excellent fired film density, with fine line resolutions of 3 mils (75 microns) lines through screen printing. It is demonstrated that gold paste made with sphere/flake gold powder has good wire bond adhesion on both 96% Al₂O₃, and lead-free dielectric. This thick film gold product is robust and is capable of good fine line resolution. Gold resinate pastes enable the use of low cost screen printing that obtain film thicknesses that could otherwise only be achieved with more expensive and complicated technologies. The combination of these gold material types provides the hybrid circuit manufacturer with the ability to produce high reliability, cost effective circuits for a variety of applications.

Acknowledgments

The authors would like to acknowledge and thank Lorenzo Burch for his assistance in this study.

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