

# Elimination of Surface Defects For Printable High Density Gold Conductor Pastes

**Dong Zhang, Brian Kistler, Weiming Zhang**  
Heraeus Inc. Thick Film Materials Division  
24 Union Hill Road  
West Conshohocken, PA 19428 USA

## Abstract

*Surface defects for screen-printed gold conductors were investigated in order to identify their root causes. Several mechanisms were proposed to explain different types of surface defects, such as domes or blisters. Using these mechanisms, modifications to the paste formulation and the manufacturing process were established to prevent these defects. The new methodology provided several gold conductor pastes with defect free surfaces and lower cost to use.*

*Key words: thick film, gold conductor paste, surface defect, dome, blister, screen print*

## INTRODUCTION

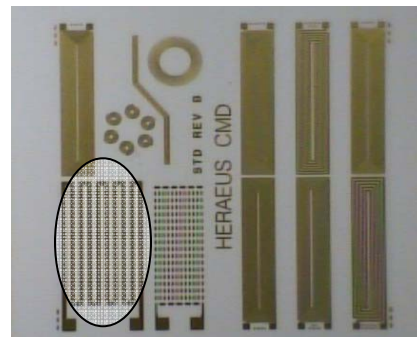
Screen-printable high density gold conductor pastes have many important applications in high reliability applications such as medical devices and military circuits. Basic requirements are the ability to print fine lines/patterns, a high fired density, excellent electrical properties, and high bonding strength. In high reliability automotive applications, surface defects on the fine lines and patterns can cause the need for wirebond rework and more frequent bonder setup. Surface defects such as domes are a much greater challenge to eliminate for gold rather than silver pastes because of the greater fired film density of gold. It is necessary to investigate the root causes of surface defects to be able to develop defect-free gold conductors.

## EXPERIMENTAL

### Process and Equipment

Two gold pastes were used for the following study. One was a reference paste and another was a newly developed paste called C6. The gold slurry used in the pastes was made by Heraeus proprietary methods, starting from gold solutions and ending with very fine gold particles. This included two process stages: a flushing step and an in-process intermediate step. The final paste was homogenized by a typical three-roll milling process. The rheology of the pastes was monitored by RS50 RheoStress from Haake. Viscosities were tested using a

Brookfield HBT viscometer. Alumina substrates (0.25"×2.5"×2.5") from CeramTec North America were used. The pastes were printed on the substrates by a TF100 screen printer from MPI. The printed substrates were dried in an oven at 150 °C for 10 minutes, and then fired in a furnace from BTU. The furnace profile was a typical 35 minute profile, peaking at 850 °C for 10 minute dwell. Fired film thicknesses were measured with the Alpha-step 200 surface profilometer from Tencor Instruments. Resistivity was measured by a digital multimeter with four point measurement probes. Backlit density was viewed and measured by a microscope with Color Video Camera CCD-IRIS from Sony. Wire bonding strength was measured with the Micro-Pull Tester 22 from Dage. Domes or blisters were counted with a stereoscope on a 25 mil line serpentine pattern as show in Figure 1.



**Figure 1.** The 25 mil line serpentine pattern.

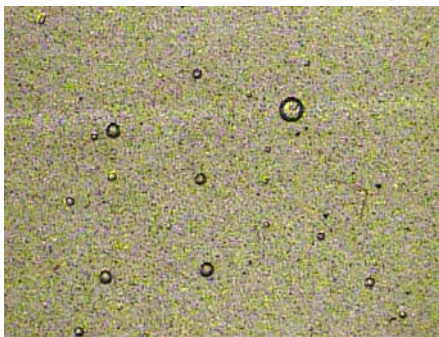
## MECHANISMS

From our observations, the surface defects included round shaped dots and irregular shaped dots on the serpentine pattern. They can be further classified as being either hollow or solid. Solid irregular shaped dots can be seen in Figure 2. The most frequent surface defects were hollow round shaped dots, also called domes or blisters. Their diameter ranged from over 3 mils to less than 1 mil as shown in Figure 3. This gives us four total types of defects:

- Type A: solid irregular shaped dots
- Type B: solid round dots
- Type C: hollow irregular shaped dots
- Type D: hollow round dots/domes/blisters



**Figure 2.** Solid irregular shaped dots on a printed gold surface.



**Figure 3.** Domes/blisters on a printed gold surface.

In order to explain the root causes of these defects, the following mechanisms were proposed.

### Formation of Gold Chunks

In the manufacturing process of the gold slurry used in the reference paste, there is equilibrium between primary fine gold particles

and large gold particle agglomerates or gold chunks. The equilibrium is favorable to form gold chunks which can be seen in Figure 4. These chunks may either appear as a solid round dot or a solid irregular shaped dot, depending on the size of the chunks.



**Figure 4.** A gold slurry printed on an alumina substrate. The tiny dots are the agglomeration of gold particles.

There were two processing stages to consider the equilibrium of: stage A, the flushing step, and stage B, an intermediate step in the process. During stage A, the material is in the most unstable state, so it is easy to form gold chunks. Stage B is more stable than stage A, but there is still a tendency to form gold chunks. Only the final gold paste is in a stable state.

### Type A Defects: Solid Irregular Shaped Dots

Solid irregular dots could be caused by large gold chunks.

### Type B Defects: Solid Round Dots

Solid round dots could be caused by small gold chunks.

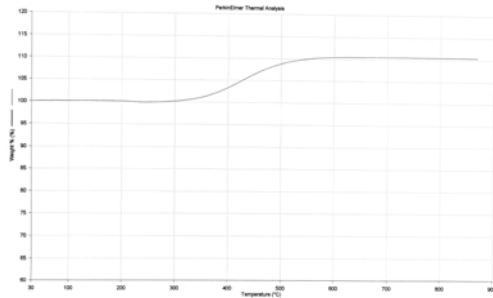
### Type C Defects: Hollow Irregular Shaped Dots

Hollow irregular shaped dots could be caused by large inorganic chunks used as ingredients in the pastes. The TGA curves for these inorganic materials are shown in Figures 5 and 6. Run in an air atmosphere, the inorganic appears to gain weight during heating while, in a nitrogen atmosphere, there appears to be a weight loss. This could be used to simulate the behavior of the inorganic during firing.

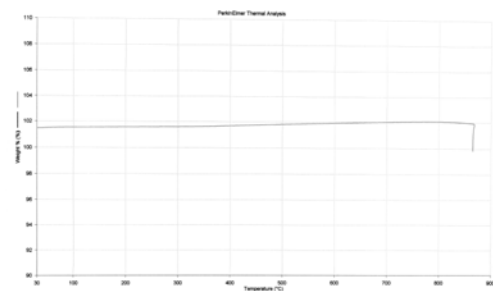
### Type D Defects: Hollow Round Dots

Hollow round dots/domes/blisters could be caused by specific sizes of gold particles combined with specific sizes of inorganic particles as shown in Figure 7. Once the

combined chunks experienced high temperature in the furnace, the inorganic would release air which could “inflate” the gold chunks to form the domes. If the gold particles are too large, it may cause solid dots, Type A or Type B defects. However, if the inorganic particles are too large, it may cause the hollow irregular shaped Type C defect. If the particles are smaller than the specific sizes, no surface defects would be visible under the stereoscope.



**Figure 5.** TGA curve of the inorganic in air.



**Figure 6.** TGA curve of the inorganic in nitrogen.



**Figure 7.** Grey oval spots represent an inorganic chunk with a specific size, while golden oval spots represent a gold chunk with a specific size. This figure shows the two chunks meeting together in a specific orientation, with the organic chunk embedding itself underneath the gold particle.

Therefore, in order to prevent the formation of domes, it was important to inhibit the formation of specifically-sized gold and inorganic particles. It was also important to

prevent the gold particles from embedding the inorganic particles.

For both the Type C and Type D defects, inorganic would be the source to inflate the gold chunks to form the hollow dots.

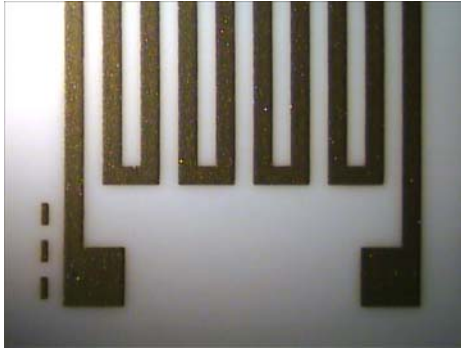
### Methods for Dome Free Surfaces

Based on the mechanisms discussed, particle sizes of both gold and inorganic would cause the surface defects. A series of investigations were performed to understand the effect of formulation modifications and processing on the formation of defects. It was determined that it was possible to minimize the surface defect rate by 1) replacing inorganic ingredients to eliminate hollow dots, 2) adding a pore opening agent to prevent the inflation of the gold chunks, 3) changing the surface tension to prevent agglomeration of gold and inorganic particles, and 4) making a series of adjustments to the manufacturing process and timeline which would minimize the time the gold slurry would be in an unstable, agglomerate-forming state. The side effects of these methods may be a reduction in wire bonding strength, increased resistivity, or poor backlit density.

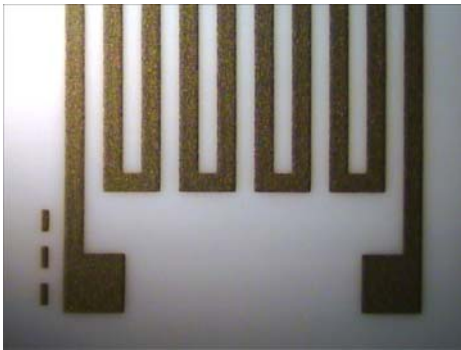
### RESULTS AND DISCUSSION

Applying the methods above, a new gold paste C6 was made. The fired surfaces of the reference paste and C6 on the 25 mil line serpentine patterns are shown in Figures 8 and 9, respectively. There were many domes on the surface of the reference that appear as shining spots in Figure 8. There were also hundreds of very tiny ( $< 1 \mu\text{m}$ ) shining spots, although, they were not easily viewed under the stereoscope and would not be counted as domes. For C6, however, there were no domes or shining spots observed. There were also no tiny shining spots and its serpentine pattern appeared very clean.

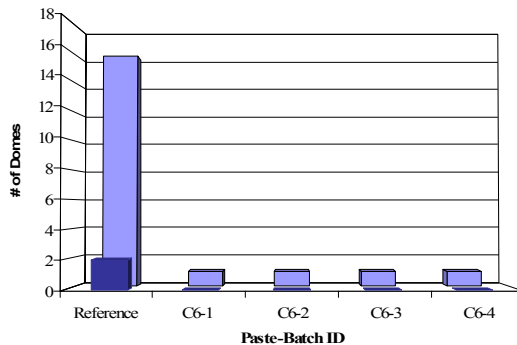
The dome counts for the reference paste and multiple batches of C6 are shown in Figure 10. The dome count for the reference paste was in the range of 2-16 while there was only 0-1 for C6. The backlit density of C6 is shown in Figure 11 and a comparison of wire bondability and resistivity between the two pastes is listed in Table 1. The new C6 paste had a similar backlit density, wire bondability, and resistivity with the reference paste.



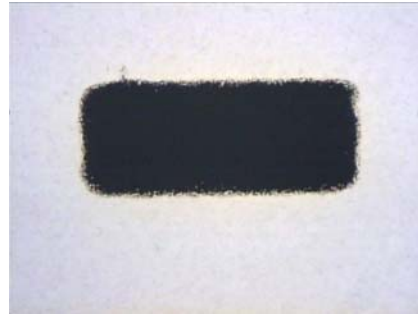
**Figure 8.** Fired surface of the reference paste on an alumina substrate with the 25 mil line serpentine pattern.



**Figure 9.** Fired surface of C6 on an alumina substrate with the 25 mil line serpentine pattern.



**Figure 10.** Dome counts for the reference paste and multiple batches of C6.



**Figure 11.** Backlit density of the new gold paste, C6.

**Table 1.** Comparison of wire bondability and resistivity for the reference paste and C6.

|                                                                                         | Reference      | C6             |
|-----------------------------------------------------------------------------------------|----------------|----------------|
| 1.25 mil wide Al wire bondability (g)                                                   | $13.3 \pm 1.5$ | $13.1 \pm 1.0$ |
| Resistivity @ 10 $\mu\text{m}$ thickness and 25 mil wide ( $\text{m}\Omega/\text{sq}$ ) | $3.5 \pm 0.2$  | $3.4 \pm 0.1$  |

## SUMMARY

New mechanisms were proposed to explain the root causes of surface defects for high density gold pastes. Based on the mechanisms, several methods were used to prepare a gold paste. The new methods provided effective ways to make defect free surfaces for the gold paste while maintaining good backlit density, wire bondability, and resistivity.