HIGH PERFORMANCE GOLD COATED NICKEL POWDERS FOR PACKAGING APPLICATIONS IN ELECTRONICS

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Abstract

Metal-based powders are used as fillers to make polymers conductive for various devices in electronics packaging technologies. Many applications require the fillers to have high conductivity and robust electrical stability that can only be achieved through using composite gold-coated powders. Packaging components such as keypads, microphone holders, z-axis connectors and specialty conductive adhesives, tapes, inks and polymer thick films depend on gold-based fillers for electrical interconnection. The increasing material cost of gold is a primary motivating factor to reduce, or minimize the gold content of these fillers. This work shows how electrical conductivity and stability are related to the amount of gold that is applied to nickel and nickel graphite powders with particle sizes ranging from 10 to 100 microns (µm). It is shown that these powders attain their maximum conductivity values at surprisingly low gold weight percentages. The very thin layers of gold also provide electrical stability as shown in tests where they are exposed to conditions of elevated temperature (80°C) and humidity (95% relative humidity, RH). Addition of 1% gold by weight in the form of a coating increased the measured conductivity of a 30 µm Ni powder from 0.00005 $(\Omega\cdot cm)^{-1}$ to 640 $(\Omega\cdot cm)^{-1}$, a factor of over ten million. The same filler was stable when exposed to 80°C, 95% RH for 143 hours. The amount of gold that is required to produce a maximum saturation level of conductivity is a function of the surface area of the particles. As particle size increases, the amount of gold by weight percent required to coat the particle surface with a thin film decreases. Each type of base powder has a characteristic saturation point where further addition of gold does not increase conductivity.

Keywords: conductive filler, electrical interconnection, gold coated powder.

1. Introduction

The uses of composite powders as conductive fillers are increasingly popular as applications in packaging technology become more demanding. Composite powders are designed to control density, morphology, composition, size distribution and shape. New and future applications are requiring combinations of properties that can only be accomplished through use of composites. An example is coating nickel powder with gold to produce fillers that are highly conductive and ferromagnetic to be magnetically aligned to optimize the orientation and position of the powder when loaded within the polymer [1]. Cost optimization can be achieved by coating the powder with the minimum amount of precious metal to produce the desired electrical performance and stability that is required by the application. Since precious metal content is an important factor in determining the cost of conductive fillers, it is useful to know the minimum amount that is required to meet or exceed the design requirement of the device. This investigation characterizes relationship between electrical conductivity (volume resistivity), gold content and particle size for gold coated nickel and gold coated nickel graphite. Compared to gold coated nickel, gold coated nickel graphite has lower density, and irregular particle shape that can allow further cost reduction through less weight loading into polymers.

2. Experiment

Nickel powder was produced by Sulzer Metco's hydrometallurgical process [2] in three different particle size distributions with average particle sizes of 40 µm, 65 µm and 100 µm (Table 1). The 10 µm powder was obtained commercially. A nickel coated graphite powder with average particle size of 30 µm, also produced by hydrometallurgy, was included in this study. The 30 µm nickel-coated graphite (Ni/C) powder had a composition of 95% nickel and 5% graphite. The powder samples were measured by a Microtrac X100 particle size analyzer.

Table 1: Size characteristics of test powders

Name	Size distribution by Microtrac (µm)		
	10% less than (d10)	50% less than (d50)	90% less than (d90)
10 µm Ni	5	10	19
30 µm Ni/C	18	30	47
40 µm Ni	30	41	58
65 µm Ni	48	65	89
100 µm Ni	78	97	125

The Ni and Ni/C powders were cleaned of surface oxides and then coated with gold [3] at Sulzer Metco to produce samples with varying gold weight percentages that ranged from 0.08% to 8.8%.

Each powder sample was measured for volume resistivity prior to cleaning, after cleaning, and after gold coating. The test instrument that measured the dry powder volume resistivity was developed by Sulzer Metco, and is referred to as the low resistivity dry powder (LRDP) test unit. The LRDP unit consisted of a vertical glass tube containing the test powder, terminated on the bottom with a fixed contact pad electrode, and a top electrode inserted into the top of the tube that floats on the powder surface. The electrodes are connected to a Keithley 580 Micro-ohmmeter. The glass tube and electrode assembly is set onto a Quantachrome Dual Autotap unit, and tapped 1250 times to fully settle the powder sample. The volume resistivity is calculated as:

Volume resistivity (Ω·cm) = measured resistance (Ω) x electrode area (cm^2)/column height (cm).

The LRDP unit had an upper detection limit of 18400 Ω·cm.

The Ni powders were measured for specific surface area by the BET (Brunauer, Emmett and Teller) method. The BET measurement could not be applied to the Ni/C powder because any small amount of exposed graphite would interfere with this gas-phase measurement method.

For stability testing the powder samples were set onto ceramic trays in a thin bed (3mm) and placed in an environmental chamber set at 80°C and 95% relative humidity for 143 hours and then tested by LRDP. The 40 µm powder samples were tested after 143,214 and 305 hours.

3. Results and Discussion

Examples of gold-coated nickel powders are shown in an optical image in figure 1, and as an electron micrograph cross-section in figure 2.

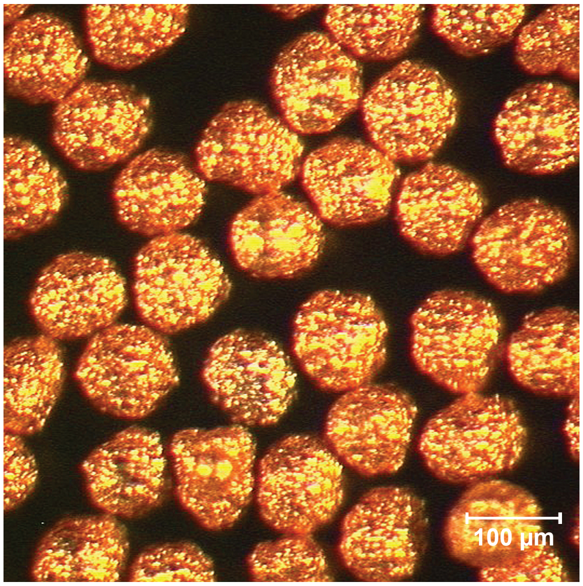

Figure 1: Optical image of 2% Au coated 100 µm nickel powder.

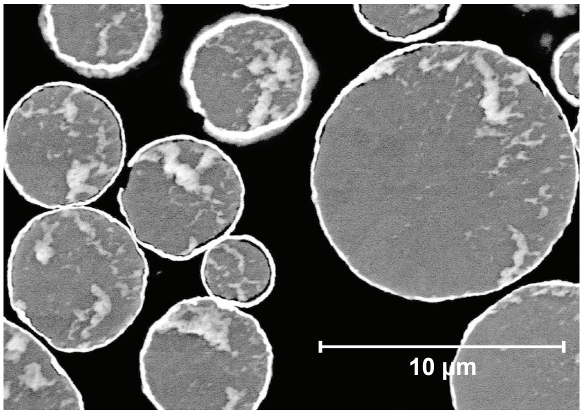

Figure 2: Electron microscope image of cross-sectioned 8.8% Au coated 10 µm nickel powder.

The nickel and nickel graphite powders were measured for volume resistivity as functions of gold weight percent (Figure 3). Prior to coating with gold, the powders were measured prior to and following the cleaning process that removed the surface oxides. Prior to cleaning the volume resistivities were

18,400 Ω·cm or greater, which was the high resistance detection limit of the instrument. The subsequent cleaning of the powders did not change the volume resistivities, except for the 40 µm powder which decreased to 3,096 Ω·cm. Addition of a very small amount of gold coating, 0.08% by weight lowered the volume resistivity to less than 0.02 Ω·cm on the 30, 40, 65 and 100 µm powders (Figure 3); a factor of roughly 10^{-6}. The 10 µm powder produced a similar decrease with a 0.25% gold coating. Further gold addition continued to lower the volume resistivity to gradually approach saturation values of less than 0.002 Ω·cm. The 30 and 40 µm powders attained 0.002 Ω·cm at approximately 1% Au and the 65 and 100 µm powders attained 0.002 Ω·cm at approximately 0.5% Au. The 10 µm powder required 4.4% Au to attained 0.002 Ω·cm. Further addition of gold caused the volume resistivity to gradually decrease to approach a saturation level.

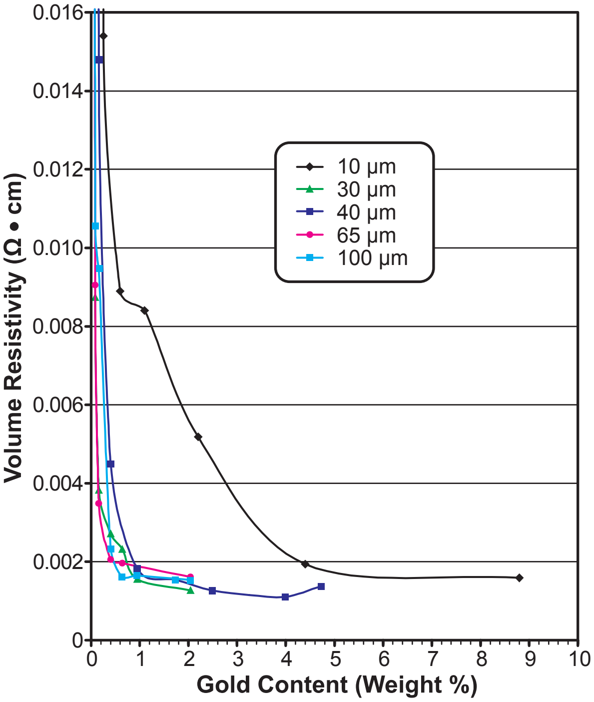

Figure 3: Volume resistivity by LRDP of 10, 40, 65, 100 µm nickel powder and 30 µm nickel graphite powder versus gold coating weight percentage.

Saturation of volume resistivity with gold addition is related to the specific surface (area per unit mass) of the nickel powder. In figure 4 the measured specific surface areas of the 10, 40, 65 and 100 µm Ni powders are plotted against the gold content required to attain 0.002 Ω·cm. The 30 µm nickel graphite powder is omitted because the graphite core interfered with the specific surface area measurement. The plot in figure 4 illustrates that low volume resistivity is dependant on the surface area of the substrate nickel powder. The linear relationship between specific surface area and gold content shows that 0.01 g of gold is required to cover 0.04 m^2 of powder surface for the nickel powders used in the present study. If the gold coatings are assumed to be uniform in thickness, the same data in figure 4 can be used to show that the derived gold coating thickness is ~0.012 µm (equals ~12 nanometers or ~45 atomic layers) for each of the data points in figure 4.

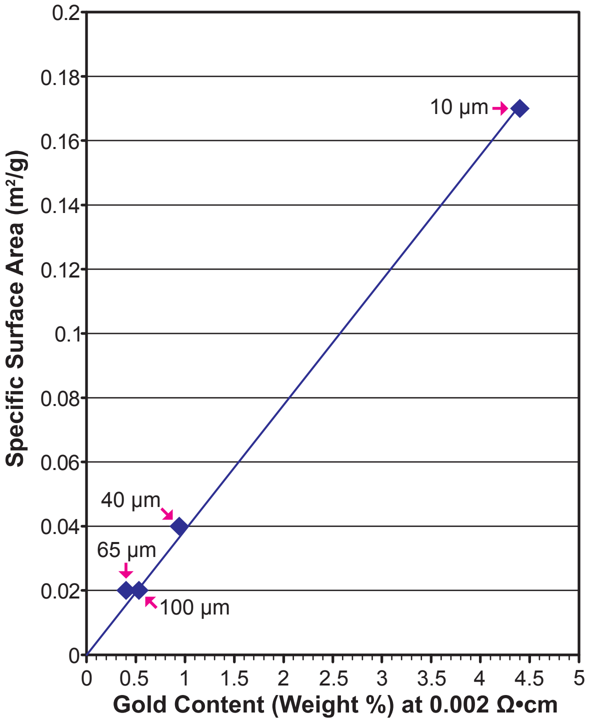

Figure 4: Measured specific surface area of 10, 40, 65 and 100 µm nickel powders versus quantity of Au required to produce volume resistivity of 0.002 Ω·cm.

Electrical stability of the gold-coated powders was evaluated by exposing them to 80°C and 95% relative humidity in an environmental chamber. All powders were exposed for 143 hours, and then measured for volume resistivity (Figure 5). Comparison of figure 5 with figure 3 shows that only the 10 µm powder was significantly affected by the exposure. The other samples (all larger in particle size) were only marginally affected. The volume resistivity of the 10 µm powder increased for gold content less than 5% as a result of the exposure to elevated temperature and humidity. For gold content 5% and greater, the volume resistivity was not significantly affected, and remained less than 0.002 Ω·cm.

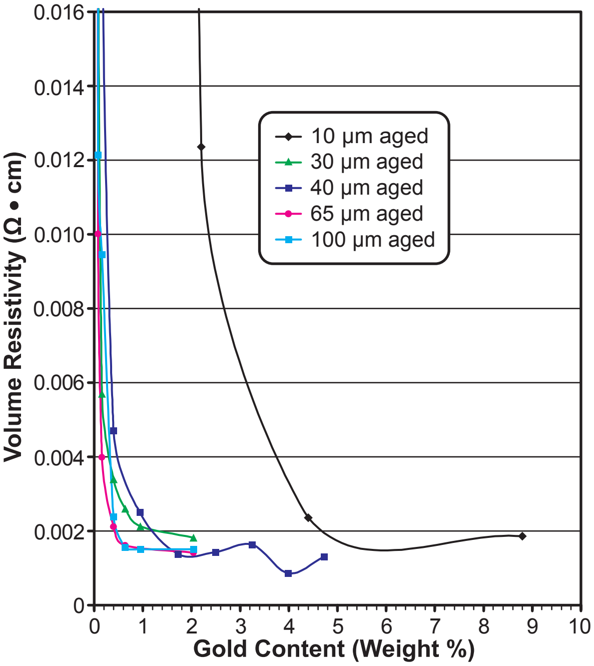

Figure 5: Volume resistivity by LRDP of 10, 40, 65, 100 µm nickel powder and 30 µm nickel graphite powder versus gold coating weight percentage following exposure to 80°C and 95% relative humidity for 143 hours.

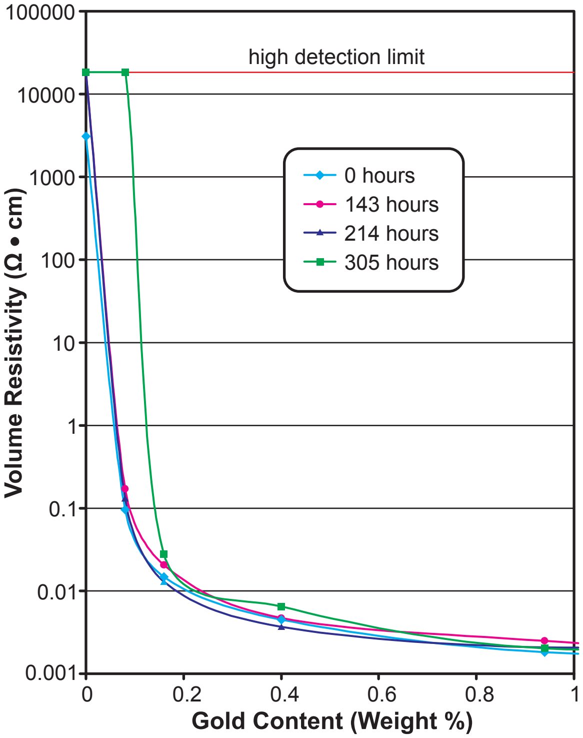

Figure 6: Volume resistivity by LRDP of 40 µm nickel powder versus gold coating weight percentage following exposure to 80°C and 95% relative humidity for 143, 214 and 305 hours.

The 40 µm Ni powder was exposed to 143, 214 and 305 hours at 80°C and 95% relative humidity (Figure 6). While the 143 and 214 hour tests had only a marginal effect on volume resistivity, 305 hours clearly produced a significant increase for gold content less than about 0.15%. From these data on heat and humidity exposure a trend has emerged that gold content to attain volume resistivity saturation is closely related to the gold content required for stability. An additional observation is the larger particle size samples being more resistant to exposure than smaller particles, when the gold content is below the value where volume resistivity stabilizes.

4. Conclusions

Highly conductive nickel-based powders can be produced through addition of a very thin gold coating. The quantity of gold required depends of the surface area of the substrate nickel, and hence the particle size. The nickel and nickel graphite powders used in this work show that gold coating, in only a few weight percent addition, is sufficient to completely cover the particles, and produce low volume resistivity that is resistant to elevated temperature and humidity. The relatively small amount of gold that is required to produce high-performance nickel and nickel-based composites is a cost effective approach in the design of conductive materials with challenging engineering requirements.

References

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