

## Effects of gold plating on the resistance to high temperature discoloration of the cavity for ceramic packages

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**Abstract:** The effects of thickness and types of gold plating on the resistance to high temperature discoloration of gold plating on cavity surface of ceramic package were investigated. It was found that the thicker gold plating, the less discoloration degree for ceramic packages. Non-cyanide gold plating performed better resistance to high-temperature aging than cyanide gold plating. The relationship between the gold plating thickness and the amount of diffused Ni to the gold plating of ceramic packages with Au/Ni and Au/Ni-Co platings after heating at 420°C for 15 min was also studied. When the gold plating thickness reach 2.0 μm and 1.6 μm for Au/Ni and Au/Ni-Co plating systems, respectively, no discoloration was observed on the gold plating surface of cavity, and the corresponding diffused Ni amounts (mass fraction) are 1.0% and 0.4%, while the diffused Co to the gold plating is 0.04%.

**Key words:** cavity; discoloration; gold plating; high temperature aging; ceramic package

### 1 Introduction

Gold and nickel are often required to be electroplated on the lead frame and metallized alumina substrate for multilayer ceramic packages to ensure the die attachment in the cavity, wire bonding and lid sealing [1,2]. High temperature aging is an important method to evaluate the plating quality. Strictness A, B, C and D are distinguished in one of Chinese standard (*i.e.* GB/T6649-86), of which strictness D (at 420°C for 15min) is commonly used in plating quality examination for ceramic package. The failure is marked with any observable tarnishing, spalling, blistering, or discolouring after aging test [3]. When the gold plating is too thin or low purity, poor adhesion, discoloration is easy to occur. It has been shown that the discoloration mainly occurred on gold plating surface of ceramic package cavity, while discoloration is hard to be observed on the lead frame. Previous study [2,4,5] has proved that the discoloration is caused by the diffusion of Ni to the gold plating surface and forming NiO. A replacement had been sought to enhance the durability of the package. The Ni-Co alloys generated by codeposition can be the alternative [6,7]. The appropriate Co content in the Ni-Co plating and the influence of underlayer on the discoloration of ceramic packages have been investigated in previous study [8,9]. For the application of Au/Ni-Co system in ceramic fabrication, the effect of the gold plating thickness and the gold electroplating bath types on the re-

sistance to high temperature ageing was investigated in this paper, especially the relationship between the gold plating thickness and the discoloration degree, and the amount of diffused Ni or Ni and Co.

### 2 Experimental

#### 2.1 Specimen

Ceramic dual-in-line package (CDIP) with 16 leads.

#### 2.2 Ni and Ni-Co alloy Electroplating

Ni electroplating bath:  $\text{Ni}(\text{NH}_2\text{SO}_3)_2 \cdot 4\text{H}_2\text{O}$ , 410 g/L;  $\text{NiCl}_2$ , 6 g/L;  $\text{H}_3\text{BO}_3$ , 40 g/L.

Ni-Co alloy electroplating bath was made up by adding  $\text{Co}(\text{NH}_2\text{SO}_3)_2 \cdot 4\text{H}_2\text{O}$  to the above Ni electroplating bath, and the ratio of Co to Ni in the bath was adjusted to 1:50.

Bath pH: 3.8-4.0.

Bath temperature: 50°C.

Current density: 1.5 A/dm<sup>2</sup>.

Ni and Ni-Co alloy plating thickness: 4 μm, 6 μm, 8 μm.

#### 2.3 Gold electroplating

Strike gold electroplating was firstly carried out in cyanide gold electroplating bath and then racked gold electroplating in neutral cyanide bath. In order to study the effect of different type of gold plating on the

discoloration of ceramic packages, non-cyanide gold plating was compared with cyanide gold plating according to the discoloration.

## 2.4 Characterization

The plating morphology and composition were observed and analyzed by Cambridge S360 SEM (Scanning Electron Microscopy) with EDAX (Energy Dispersive Analysis by X-ray). The plating thickness was determined with X-ray fluorescent measurement.

## 2.5 High temperature evaluation

According to GB/T 6649-86, high temperature evaluation of ceramic package was carried out in muffle furnace under condition of strictness D.

## 3 Results and discussion

### 3.1 Influence of gold plating thickness on the discoloration of package cavity after high-temperature evaluation

Gold with different thickness were electroplated on packages with Ni and Ni-Co alloy underlayer in cyanide gold electroplating bath. The underlayer thickness were controlled at about 4  $\mu\text{m}$ , 6  $\mu\text{m}$ , and 8  $\mu\text{m}$ . By visual inspection, the discoloration degrees of package cavity surface were divided into eleven degrees (from 0 to 10), of which 0 means no discoloration and 10 means the worst discoloration. The results are shown in figure 1.

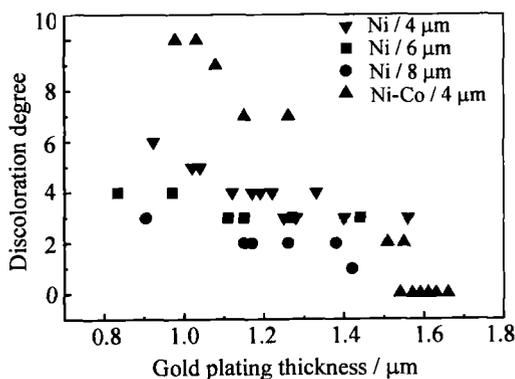


Figure 1 Relationship between the discoloration degree and gold plating thickness.

It can be seen from figure 1 that: (1) when the underlayer thickness is about the same, the resistance of package cavity surface to high-temperature discoloration increases with the increase of gold plating thickness; (2) when the gold plating thickness is about the same, the thicker underlayer thickness, the higher resistance to high temperature discoloration for Au/Ni and Au/Ni-Co packages; (3) when the gold plating thickness is thinner than 1.3  $\mu\text{m}$ , the discoloration degree of Au/Ni-Co plating system is larger than that of Au/Ni, contrarily, the former is less than the latter.

When the gold plating thickness reaches a certain value, no discoloration occurs for Au/Ni-Co packages.

### 3.2 Influence of gold plating types on the resistance to high temperature discoloration of ceramic packages

Ceramic packages with Ni underlayer of 4  $\mu\text{m}$  were divided into two groups, one group was electroplated in cyanide gold bath and the gold plating thickness was controlled at 1.3  $\mu\text{m}$ , the other group was electroplated in non-cyanide gold bath and gold plating thickness was controlled at 1.0  $\mu\text{m}$ . Gold plating surface morphologies in cavity are shown in figure 2 and figure 3.

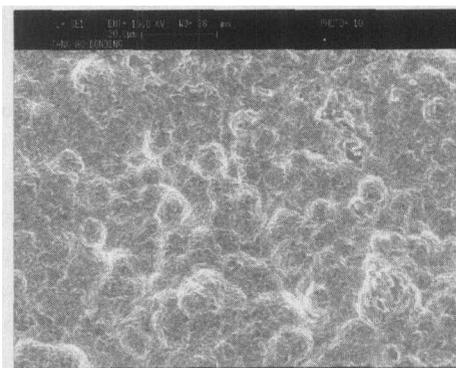


Figure 2 Cyanide gold plating surface morphology in cavity.

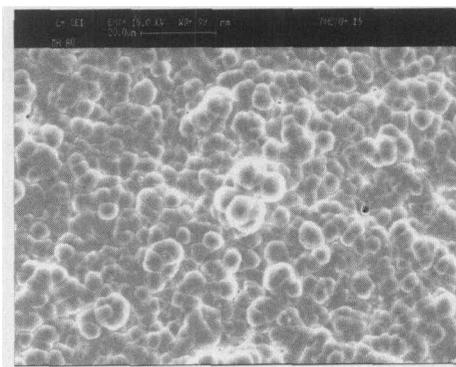


Figure 3 Non-cyanide gold plating surface morphology in cavity.

After the strictness evaluation, discoloration was found on packages with thicker cyanide gold plating, while no discoloration occurs on packages with thinner non-cyanide gold plating. It proves that packages with non-cyanide gold plating have better resistance to high temperature discoloration than that of cyanide gold plating. This can be attributed to the better throwing power and leveling action of non-cyanide gold bath, which leads to more fine and uniform gold plating, as seen in figure 2 and figure 3.

### 3.3 The amount of diffused Ni on package cavity surface

Ceramic packages with 4  $\mu\text{m}$  Ni or Ni-Co alloy underlayer were electroplated in cyanide gold bath. The gold plating was controlled at different thickness by

adjusting the plating time. Relationship between discoloration degrees of cavity surface for ceramic packages after strictness evaluation and gold plating thickness was described in figure 4.

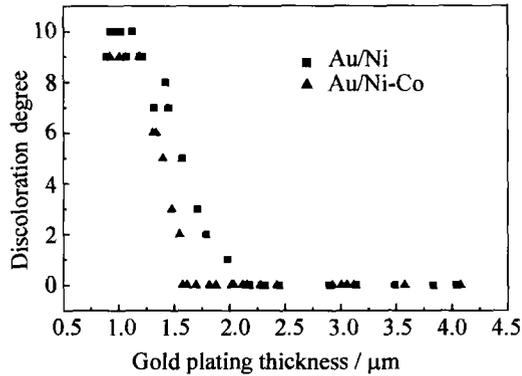


Figure 4 Relationship between the discoloration degree and gold plating thickness for Au/Ni and Au/Ni-Co packages.

As can be seen in figure 4, the thicker gold plating, the lower discoloration degree, which is similar with regularity shown in figure 1. When the gold plating thickness reaches 2.0  $\mu\text{m}$  for Au/Ni packages and 1.6  $\mu\text{m}$  for Au/Ni-Co packages, no discoloration was found on packages' cavity surface. It shows that Ni-Co alloy can be used to replace Ni as underlayer of gold plating to improve its resistance to high temperature discoloration.

The amount of Ni or Ni and Co on gold plating surface of cavity before and after high temperature evaluation was measured. Their relationships with gold plating thickness are described in figure 5, 6, and 7 respectively.

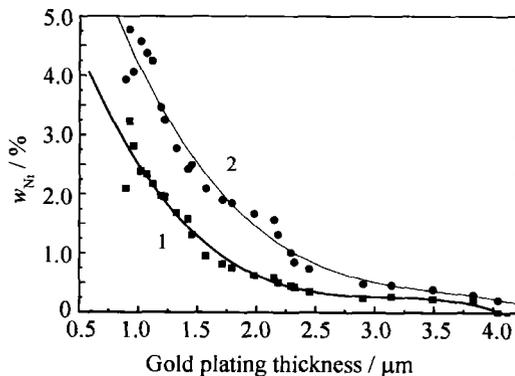


Figure 5 Relationships between the amount of Ni on cavity surface and gold plating thickness for Au/Ni packages. 1—before high-temperature evaluation; 2—after high-temperature evaluation.

Because EDAX analysis uses electronic beam to bombard the sample surface and records the characteristic X-ray emitted by provocative atom in the transition process, the characteristics of the materials within several microns of thickness can be detected. When the gold coating is very thin, certain amount of

Ni or Co was still detectable before aging as the partial underlayer was penetrated by electron beam. However, an increase of the amount of Ni or Co detected after aging is expected to be the Ni diffused into the gold platings. Therefore, the amount of Ni or Co on gold surface within the detectable depth of X-ray penetration before and after high temperature ageing can be quantitatively measured to represent the amount of Ni that diffused into the gold during aging, and further related to the discoloration of the packages.

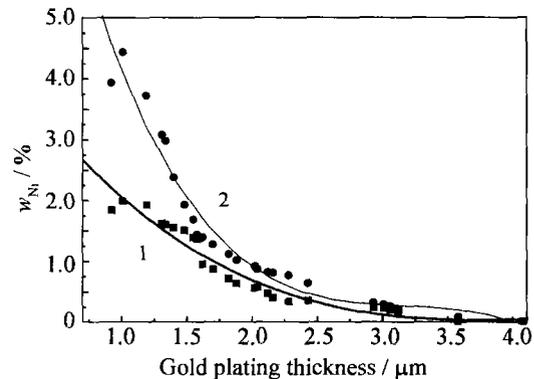


Figure 6 Relationships between the amount of Ni on cavity surface and gold plating thickness for Au/Ni-Co packages. 1—before high-temperature evaluation; 2—after high-temperature evaluation.

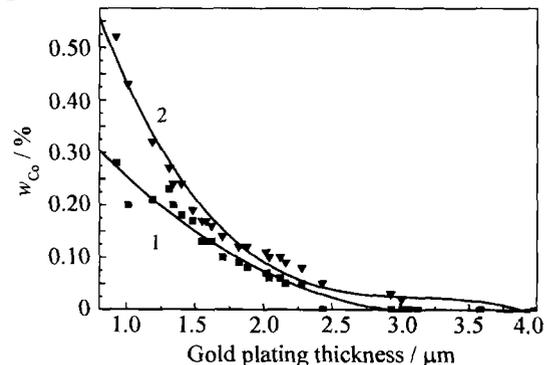


Figure 7 Relationships between the amount of Co on cavity surface and gold plating thickness for Au/Ni-Co packages. 1—before high-temperature evaluation; 2—after high-temperature evaluation.

It can be found from the figures 5, 6 and 7 curves that the amount of Ni and Co detected on cavity gold plating surface decreases with the increase of gold plating thickness. When the gold plating thickness is more than 1.3  $\mu\text{m}$ , the two curves in figure 6 are closer than those in figure 5, which indicate that the amount of diffused Ni for Au/Ni-Co is fewer than that of Au/Ni, since the difference of Ni amount on the cavity surface before and after high temperature can be viewed as the diffused Ni. It shows that the addition of Co to the plating can reduce the diffusion of Ni to the gold plating in high temperature evaluation.

Figure 7 shows that Co also diffused to the gold

plating surface during high temperature evaluation. The regularity of Co diffusion likes that of Ni, which decreases with the increase of gold plating surface. When the gold plating is thin (such as  $< 1.3 \mu\text{m}$ ), although the amount of Ni diffused of Au/Ni-Co packages is slight fewer than that of Au/Ni packages, because there is also much Co diffuses to the gold plating during high temperature aging, the diffused Co on the gold plating surface will also be oxidized. Together with the oxidation of Ni, it will lead severer discoloration than that of Au/Ni packages. When the gold plating thickness reaches  $1.5 \mu\text{m}$  or more, the amount of diffused Co is little.

If the thickness of gold plating is set as the horizontal axis and the amount of diffused Ni and Co as the vertical axis, the relationships between the amount of diffused Ni (or Ni and Co) and the thickness of gold plating are shown in figure 8 and 9.

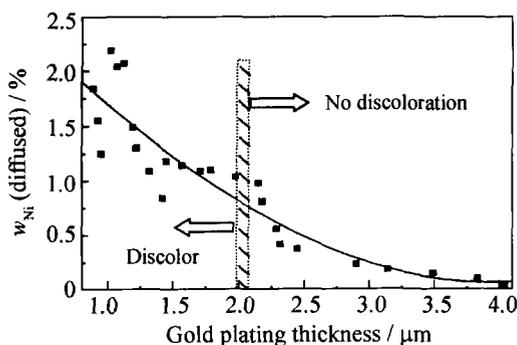


Figure 8 Relationships between the amount of diffused Ni and gold plating thickness for Au/Ni packages.

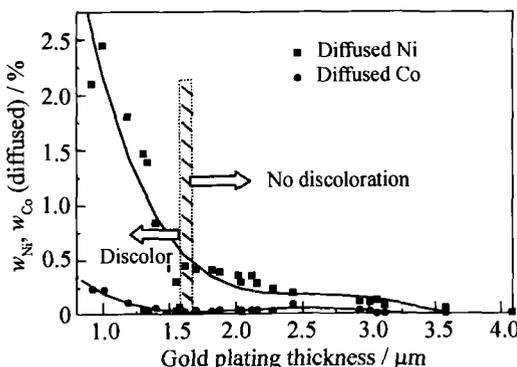


Figure 9 Relationships between the amount of diffused Ni and Co and gold plating thickness for Au/Ni-Co packages.

It can be seen from figure 8 that the thinner gold plating thickness, the more diffused Ni on the gold plating surface and the heavier discoloration, which further verify that discoloration is caused by the diffusion of Ni to the gold plating surface and the formation of NiO. The amount of diffused Ni decreases rapidly with the increase of the gold plating thickness. When the gold plating thickness is more than  $2 \mu\text{m}$  for Au/Ni packages, discoloration is hard to be seen on cavity surface, and the corresponding amount of dif-

fused Ni is lower than 1%. Thus, 1% Ni diffused to the gold plating surface can be defined as the critical value of discoloration. The corresponding Ni atom percent is 3.3%, which means that if there is more than 3.3% Ni atom diffused to the gold plating, then the discoloration will occur on the cavity surface of package.

Similarly, the amount of diffused Ni and Co for Au/Ni-Co packages decreases with the increase of gold plating thickness. Comparing with the critical gold plating thickness  $2.0 \mu\text{m}$  for Au/Ni packages,  $1.6 \mu\text{m}$  is enough for Au/Ni-Co packages to ensure no discoloration on cavity surface. The corresponding amount of Ni and Co diffused are 0.4% and 0.04%, respectively. It can be seen that the addition of Co to the Ni can reduce the diffusion of Ni to the gold plating during high temperature evaluation. Because some positions of Ni atoms will be replaced by Co atoms in Ni-Co plating, the diffusion activation energy of Ni will increase. In the other side, Co will also diffuse to the gold plating in the same way as Ni during high temperature aging. The diffused Co may have greater influence on the discoloration of ceramic package in comparison with Ni when the gold plating is relatively thin. This is the reason why the Au/Ni-Co ceramic packages discolor more severely than that of Au/Ni when the gold plating thickness is thinner than  $1.3 \mu\text{m}$ .

## 4 Conclusions

(1) Gold plating thickness is an important factor affecting the resistance of ceramic packages to high temperature discoloration. The thicker gold plating, the slighter discoloration degree.

(2) Under the condition of about same gold plating thickness, packages with non-cyanide gold plating have better resistance to high temperature discoloration than that of cyanide gold plating.

(3) When the gold plating is more than  $1.6 \mu\text{m}$  for Au/Ni-Co packages and  $2.0 \mu\text{m}$  for Au/Ni packages, no discoloration will occur on the package cavity surface. The corresponding amount of diffused Ni is 1.0% for Au/Ni packages, while corresponding 0.4% Ni and 0.04% Co for Au/Ni-Co packages.

(4) When the gold plating thickness is thinner than  $1.3 \mu\text{m}$ , Au/Ni-Co packages have no more resistance to high temperature discoloration than Au/Ni packages. This can be attributed to the diffusion of much Co to the gold plating surface and the oxidation of Co together with Ni under high temperature evaluation.

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