Surface Morphology and Characteristics of Electroplated Au/Ni Films for Connector Contact Materials

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Abstract
The surfaces of the connector terminals used for electrical connection of components are electroplated with Sn, Au, or Ag in order to improve reliability. For electronic devices that require particularly high reliability, hard gold is used. The characteristics of gold deposits of various surface morphologies were examined. Gold films with increased surface roughness exhibited superior friction and wear properties without a large increase in contact electrical resistance after friction testing. Increasing the surface roughness also resulted in higher solder adhesion strength and improved corrosion resistance to sulfur dioxide gas.

Keywords: Connector, Hard Gold Plating, Surface Morphology, Friction and Wear Property, Contact Resistance

1. Introduction
Recent electronic devices and cables generally use a connector as an electrical connection component. From the viewpoint of spring properties and conductivity, most connector terminals use copper or a copper alloy as the substrate material on which Sn, Au, or Ag is electrodeposited, depending on the contact reliability and solderability requirements of the application. Connector terminals that require particularly high reliability often use a hard Au film on a Ni electroplated substrate. However, the high cost of Au has accelerated the trend to limit the Au plated area and thin the deposit in order to reduce Au consumption. Although the applied area of the Au film has been reduced and thinned, for connectors that are inserted and pulled a number of times or are required to have high corrosion resistance, efforts to reduce Au consumption while maintaining reliability have been insufficient. The reliability of connectors is ensured by electrodepositing a thick Au film.[1] Therefore the effect that the film surface morphology of the connectors has on friction and wear properties, contact resistance, soldering strength, and corrosion resistance as an approach to reducing precious metal consumption was investigated.

2. Experimental
2.1 Sample preparation
As the base material, a 0.5 mm thick oxygen-free copper plate was used. The plate was cut into 30 mm × 40 mm pieces and pretreated according to the previously reported method.[2] Following pretreatment, smooth surface samples were electroplated in a sulfamic-acid-type Ni bath to give a 2 µm thick Ni film, and then electroplated in a commercially available hard Au bath to give a 0.05 µm thick Au film. The Au film thickness was measured with an X-ray fluorescence analyser (SFT-9500: SII, 0.1-mm-diameter collimator). As a post treatment, samples were treated with a commercially available water-soluble sealing agent (hereafter referred to as “smooth surface plating”). Micro-hollowed surface samples were prepared using the method described except that additives were included in the Ni plating bath to induce rough surfaced deposition (hereafter referred to as “micro-hollowed surface plating”).

The surface morphology of each sample was observed with a FE-SEM system (S-4800: Hitachi), the surface roughness and specific surface area were measured using a laser microscope (VK-9700: Keyence), and cross-sectional observation was performed with a FIB system (FB-
2.2 Evaluation of friction and wear properties

The friction and wear properties of each sample were evaluated using a reciprocating slide friction tester (SSWT: Shinko Engineering). A 9.8-mm-diameter brass ball with a 0.4-µm thick electroplated hard Au layer on a 2-µm thick Ni substrate was repeatedly slid on each sample for 3,600 cycles with a sliding length of 4 mm and load of 0.5 N applied on the ball. During this time, the friction coefficient was measured. For friction coefficient measurements, data was collected after every 20 cycles from the beginning of the test until its termination and then averaged. Following the test, the film surface of each sample was observed with the FE-SEM system and analyzed with an EDX system (EX-350: Horiba) at an acceleration voltage of 20 kV. In addition, a micro ohmmeter (CRS-113-AU: Yamasaki-Seiki) was used to measure changes in contact resistance that occurred due to the friction and wear test.

2.3 Evaluation of soldering strength

The soldering strength was measured in accordance with JIS H 8504. A 0.5 mm thick oxygen-free copper plate was used as the L-type metal fitting. Test samples were prepared by press-molding the substrates into the shape specified to provide a soldering area of 5 mm by 5 mm prior to electroplating. A Pb-free solder paste (TCS-254-5042SF 12-1: Tarutin Kester) was applied to an 8 mm by 0.2 mm area on one of the samples and then heated for 30 seconds at 260°C to solder the sample to the L type metal fitting. Soldered samples were measured using a tensile testing machine (3382: Instron).

2.4 Evaluation of corrosion resistance

Corrosion resistance was evaluated by a sulfur dioxide gas test and a neutral salt spray test. The sulfur dioxide gas test was carried out in accordance with JIS H 8502 for 96 h. A constant flow gas corrosion test cabinet (GPL-91-C: Yamasaki-Seiki) was used for the sulfur dioxide gas test, with sulfur dioxide gas concentration set at 10 ppm at 40°C and relative humidity at 80%RH. Samples without the sealing treatment were also tested for comparison. For the neutral salt spray test, the test was carried out in accordance with JIS Z 2371 for 96 h using a salt spray test instrument (CAP-90: Suga Test Instruments). In both tests, the corrosion resistance was judged using the rating number method. For the samples tested with sulfur dioxide gas, the surfaces were observed with an optical microscope (VHX-900: Keyence) and the FE-SEM system, and surface analysis was performed with the EDX system.

3. Results and Discussion

3.1 Surface and cross-sectional morphology of samples

Figure 1 shows the surface morphology, cross-sectional images, and surface roughness parameters of the smooth surface plating and the micro-hollowed surface plating as observed with the FE-SEM system, FIB system, and laser microscope. Unlike the smooth surface plating, the plating surface and cross-sectional images of the micro-hollowed surface exhibited non-uniform circular hollows in the surface. However, the Au film could not be observed with the FIB system because the film was too thin. Thus, both the
specific surface area and surface roughness in terms of both the Ra and Rz of the micro-hollowed surface plating were confirmed to be greater than those of the smooth surface plating.

### 3.2 Friction and wear properties

Figure 2 shows the results of the friction and wear test on each sample. At the beginning, the friction coefficient of the smooth surface plating was stable at about 0.4, but after 2,000 cycles of sliding the friction started to increase leading to seizure before reaching 3,000 cycles at which point the test was terminated. The average friction coefficient was 0.436. On the other hand, for the micro-hollowed surface plating, the friction coefficient increased sharply at the beginning of the test and started decreasing gradually from about 100 cycles. After about 500 cycles, the friction coefficient stabilized at about 0.3 and was maintained until termination of the test. Figure 3 shows the SEM and EDX surface analysis of the tested sections after the friction and wear test. C and Cu could not be detected, but for the smooth surface plating, a large amount of Ni was detected at the center of the tested section compared to the micro-hollowed surface. On the other hand, a larger amount of

![Fig. 2](image_url)

**Fig. 2** The relationship between the friction coefficient and slide frequency of electroplated Au/Ni film from various Ni plating bath.

<table>
<thead>
<tr>
<th>Sliding direction</th>
<th>Smooth surface</th>
<th>Micro-hollowed surface</th>
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<tbody>
<tr>
<td>SEM images</td>
<td>Plate</td>
<td>Ball</td>
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![Fig. 3](image_url)

**Fig. 3** Observation results of wear tracks by FE-SEM/EDX image of various electroplated Au/Ni film after sliding test.
Au was detected in test region of the micro-hollowed surface plating compared to the smooth surface plating. The ball used on the smooth plating in the test exhibited a higher degree of Au film wear and a larger area of Ni exposure at the tested section despite fewer cycles, clearly illustrating the difference in wear. The increased Au wear on the sample and Ni exposure of the ball suggests partial shearing during the test. Detection of O along the sliding path at the tested section of the ball used on the smooth plating surface may have arisen due to removal of Au exposing Ni and the heat of friction causing surface oxidation. This result provides an explanation for the seizure that occurred during the test. Contact resistance values shown in Table 1 were measured before and after the friction and wear test. The results show that the initial contact resistance value of the micro-hollowed surface plating was lower than that of the smooth surface plating. Post-test, both samples increased in contact resistance, the smooth surface plating more so than the micro-hollowed surface plating despite fewer sliding cycles. These results show that the plated film surface morphology has a significant influence on the friction and wear properties and that friction and wear characteristics could be improved using micro-hollowed surface plating. This variation may result from a wider real contact area and a lower shear force provided by the multiple real contact points of the micro-hollowed surface plating, which has many hollows.

### 3.3 Soldering strength

Table 2 shows the results of the solder bonding strength per unit area measurement. When both the substrate and the L-type metal fitting were smooth surface plated, the solder bonding strength was 0.5 N/mm², which increased to 0.8 N/mm² when the L type fitting was micro-hollow surface plated and the substrate was smooth surface plated. It further increased to 1.1 N/mm² when both surfaces were micro-hollow surface plated. The increase in soldering strength is most likely due to the wider specific surface area and consequently wider actual joint area that the micro-hollow surface plating has in contrast with the smooth surface plating.

### 3.4 Corrosion resistance

Table 3 shows the results of the neutral salt spray test and sulfur dioxide gas tests. Neither sample showed significant corrosion in the neutral salt spray. However, the sulfur dioxide gas test resulted in visible spot-like corrosion of the smooth surface plating, less pronounced on the sample where sealing treatment was performed. In comparison, both of the micro-hollowed surface plating samples showed minimal corrosion, which was reduced even further by the sealing treatment. The presence of Cu in the corrosion on the surfaces could be due to the sulfur dioxide gas test. Figure 4 shows optical microscope images of the surface of each sample that underwent the sulfur dioxide gas test, and Fig. 5 shows the FE-SEM/EDX observation results. Both O and S were detected in the corrosion that formed, suggesting that SO₂ oxidized Ni to produce Ni and sulfoxide ion containing compounds.
smooth surface plating indicates deep localized corrosion. These results suggest that the micro-hollowed surface plating infinitely dispersed galvanic corrosion,[6] which improved the corrosion resistance similar to the mechanism by which micro-porous chromium plating does so.[7]

4. Conclusion
The correlations between surface morphology and the durability, soldering, and corrosion characteristics of Ni/Au plating for connector terminals were examined. The formation of a micro-hollow composed Ni surface was achieved by the use of additives to the Ni plating bath used prior to hard Au plating. The micro-hollowed surface was
found to considerably improve friction and wear properties, soldering strength, and corrosion resistance, all important characteristics required of connectors. In all three cases, the mechanism for improvement appeared to be related to the surface microstructure. When Au electroplating has been used as a surface treatment, increasing the Au film thickness was the only previous means for improving the reliability. This technique of controlling surface morphology may provide an alternative means of ensuring reliability such that Au consumption could also be minimized. In future work, the optimization of surface morphology for connector terminals will be studied.

References


