High Temperature Resistant Gold Alloys for Switching Signal Relay Contacts

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Summary – Most telecom/signal relays are of the surface-mounted type nowadays. Since the introduction of lead-free soldering processes, the temperature exceeds 260°C during the soldering process. In a growing share of applications, these relays are additionally used in high-temperature environments such as motor compartments.

Regardless of the high ambient temperatures of up to 125°C at which the relays are operated, there are unchanged requirements of the stability of the contact resistance, with target values of less than 10 mΩ deviation during the entire lifetime.

In order to achieve low and stable contact resistance, the type of gold alloy and the way the gold layers are processed are of major importance. Sputtered and diffused gold layers showed better performance at high temperatures than rolled gold layers as well as gold alloys with no or very low concentration of non-precious metals. But not only the top layer has an impact; the base material too has a major impact on the contact resistance stability. PdRu10 as base material resulted in much better contact resistance stability than AgNi20.

When these contact materials are used in telecom/signal relays even at high ambient temperatures, extremely low and stable contact resistance values can be achieved for a long period of time.

Keywords: Telecom & signal relays, gold contacts, contact resistance stability, high temperature exposure

I. Introduction

For reliable conducting and switching of low-level signals, gold contacts are the first choice in switching devices. Depending on the plating method, many different alloys are used. The methods used include rolled, sputtered and electro-deposited layers (Table 1).

For rolled gold layers, any gold alloys may be used which can be produced by melting. For sputtered gold layers, any gold alloys as well as designated impurities can be realized. For electro-deposited gold layers, the number of gold alloys potentially available is very limited as the deposition process requires an associated galvanic bath. The most commonly used materials are either pure gold or gold cobalt alloys with a cobalt content of 0.2 to 0.5 percent. Sometimes gold nickel alloys with similar nickel concentrations of 0.2 to 0.5 percent are also used. Furthermore, recently data has been published for gold nickel alloys with a nickel concentration of approximately 0.02 percent [1]. Generally, for switching contacts the content of organic materials in the deposited gold layer is critical, as this might result in increased carbon generation during low-level switching.

Most information published on thin gold layers is related to contacts used in connectors. There are some relevant differences between switching and connector contacts, although they carry the same signal levels.

Firstly, the contact force is significantly different. While in relays the contact force is as low as 1 cN, in connectors a minimum of 20 cN can be expected. Secondly, the closing mechanism differs. Designs for switching contacts provide only a few µm of relative movement when contacts close, while inserting the connectors always provides at least 1/10 of a mm. Thirdly, the number of insertion cycles is far fewer for connectors than switching cycles for relays.

<table>
<thead>
<tr>
<th>Contact Material</th>
<th>Plating Method</th>
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<tbody>
<tr>
<td></td>
<td>Rolled</td>
</tr>
<tr>
<td>Au</td>
<td>X</td>
</tr>
<tr>
<td>AuAg 8 ... 10</td>
<td>X</td>
</tr>
<tr>
<td>AuNi 2 ... 5</td>
<td>X</td>
</tr>
<tr>
<td>AuPd 2 ... 4</td>
<td>X</td>
</tr>
<tr>
<td>AuNi 0.2 ... 0.5</td>
<td>X</td>
</tr>
<tr>
<td>Au Co 0.2 ... 0.5</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 1: Gold and gold alloys plated with different possible methods

Recently, new requirements have been introduced for SMT (Surface Mount Technology) soldering. Due to environmental issues, lead-free soldering is the standard process in electronics nowadays. In consequence the process duration and the peak temperature has increased to values of 265°C.

The stability of the contact resistance at this temperature level will become critical e.g. for electro-deposited layers. In addition, for switching contacts the combination of pure gold with pure gold, which provides the highest contact resistance stability, leads to a high risk of cold welding. Most other gold alloys which can be deposited by galvanic processes, such as AuCo 0.2, AuNi 0.2, have a high tendency towards oxidation at temperatures higher than approx. 120°C. Huck [2] has already reported very stable contact resistance values when AuCo (1.5 µm) and AuNi (2 µm) galvanic layers were stored at 125°C for 1500 hours. The contact resistance increase was less than 10 mΩ. The same layers stored at 300°C showed no
increase of contact resistance values up to an exposure time of 1 minute, but a significant increase after approx. 1 hour of storage. Maximum values of more than 1 Ω were found for AuCo and of 575 mΩ for AuNi.

In applications where no other economical plating method than galvanic coating can be used, no really suitable alternative gold alloys with better characteristics are available for high-temperature applications. In principle, two different strategies can be applied to solve this problem:

- efficient protection from oxidation at high temperatures by applying nitrogen in the critical manufacturing processes or
- protection of the AuNi or AuCo layers from oxidation by adding a thin oxidation-resistant coating.

The first solution is easy to realize in manufacturing but only possible in finished relays if the housings of the relays are hermetically sealed and no oxygen is present in the relays during the SMT soldering process.

The second way of protecting the existing gold layer seemed to be the easier and more cost-effective solution. Thin layers of precious metal have been used for a long time to improve the solder ability of terminals. In 1956 Keil [3] found a significant improvement in the wetting characteristics of platinum terminals by coating them with a very thin gold layer of approximately 0.05 µm. Huck [4] carried out investigations into the characteristics of thin galvanically-plated gold (0.2 µm) and palladium (0.2 µm) layers. The test specimens were stored at temperatures between 100 and 250°C. The galvanic coating with a thickness of only 0.2 µm provided good protection against oxidation – much better than a gold layer of the same thickness. Even when heavy wear was applied, the thin palladium layer provided good protection, resulting in stable contact resistance values.

As regards roll-plated layers with Au or AgPd alloys produced in melting metallurgy, systematic diffusion into the Au layer is general practice. The diffused gold material consists of a thin layer (0.25 µm) of gold which is diffused into the palladium surface during inlay processing [5, 6].

The relatively large profiles with approx. 5 µm high-carat gold on silver and its alloys, which have been used so far, have become so expensive that they have a serious impact on the total cost of the product.

For several years, attempts have been made to cut down the amount of gold whilst not impairing functioning, by using smaller profiles, specifically designed micro-contact profiles, low carat gold alloys, and by reducing the thickness of the gold layer [7… 11].

Very good results have been obtained with galvanic gold plating in the range of 0.5 µm on silver-palladium and silver alloys, followed by a diffusion treatment. By varying the temperature and storage time, the diffusion treatment can determine the composition of the alloy and the nature of the diffusion layer [9].

Diffused gold layers covering melting-metallurgic alloys, such as AgNi0.15 and AgPd30-60, have a wide area of application. Galvanic gold in powder-metallurgical silver alloys has diffusion properties which, in the area of the enclosed particles, are different from the melting technology, but the composition of the alloy can also be determined [12].

In order to protect the contacts from oxidation during the thermal conditioning and the SMT soldering process, thin layers of Pd (0.075 µm) and Au (0.005 µm) were deposited on the gold alloy contacts. Although the layers are extremely thin and therefore very cost-effective, excellent contact resistance stability was found. Even when the contacts are stored at a temperature of 265°C for a long time, no significant changes in the contact resistance were observed [13, 14].

The use of sputtered gold layers is preferred, as they provide the cleanest contact surface and in consequence the most stable contact resistance. Furthermore, asymmetric combinations of gold layers are more reliable, as the risk of cold welding is less and the stability of the contact resistance is better.

The thickness of the gold layer itself is not necessarily an important factor for the performance and reliability of the relays. Typical are gold layers with a thickness between 1 and 5 µm, whereas thicker layers are not automatically better. For sputtered gold layers, the performance is best between 1 and 2 µm. When the thickness exceeds 2 µm, the contact resistance stability is not increased any further, but the performance during load switching is decreased as eroded gold particles have a negative impact on contact resistance as well as on the isolation characteristics.

II. Experimental

In order to determine the performance of the different gold alloys, investigations were carried out on contact profiles as well as on contact profiles assembled into standard 4th generation signal relays. These are ultra-miniature (10 x 6 x 5.65 mm), hermetically plastic sealed relays with a 2-pole change-over configuration and a load range of 60W/62.5VA, a current range from 0 to 2A and a voltage range from 10µV to 250V.

Fig. 1: Contact profiles used for the investigations. Top layer is made from gold alloys given in Table 2.

The resistance measurements on the contact profiles were performed with a “KOWI” contact resistance measurement tester, which measures the resistance of the contact profile against a gold wheel with a contact force of 1.5 cN and an electrical load of (c≤30 mV≤10 mA).

The contact resistance measurements on the relays were performed with an RT290 relay tester, the electrical endurance tests with the RT96 relay tester, all under the same electrical conditions.
A. Test Parameters

1) Multilayer contact profiles

- Contact force: 1.5 cN
- Contact load: \( \leq 30 \text{ mV/} \leq 10 \text{ mA} \)
- Measurement: Initial
  - After storage of 260°C / 30 minutes
- Contact materials: Dimensions and base material as per Fig. 1. Top layer according Table 2

<table>
<thead>
<tr>
<th>Top layer</th>
<th>Base material</th>
<th>Material</th>
<th>Base material</th>
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<tbody>
<tr>
<td>AuAg 8 s</td>
<td>PdRu</td>
<td>x</td>
<td>AgNi</td>
</tr>
<tr>
<td>AuAg 8 p</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>AuNi 5 p</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>AuNi 2 s</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>AuNi 1 s</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Au Pd 5 s</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Au Co 0.5 d</td>
<td></td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

| Au d      |               | x        |              |

Table 2: Combination of base material and top layer for multilayer contact profiles (s = sputtered, p = rolled, d = diffused)

2) Relays - initial

IM relays with the following combinations of contact materials were manufactured and the contact resistance measured after production, including a 260°C / 20-minute pre-aging process

- Fixed contacts: AuAg 8 s
- Moveable contacts: AuNi 2 s, AuNi 1 s, Au d, AuPd 5 s

3) Relays - thermal endurance

IM relays were stored for 2000 hours at an ambient temperature of 125°C. Relays were measured initially and after storage on the first activation under dry load conditions (U \( \leq 30 \text{ mV/} I \leq 10 \text{ mA} \)).

4) Relays - electrical endurance tests

IM relays were SMT-soldered 3 times and then the electrical endurance tests were performed

- Electrical load: \( \leq 30 \text{ mV/} \leq 10 \text{ mA} \), 0.5V/10 mA
- Number of operations: 20 million
- Ambient temperature: 85°C
- Contact material: AuAg 8 s/ Au Ni 2 s, AuAg 8 s/ Au Ni 1 s, AuAg 8 s/ Au d

III. Results

A. Multilayer contact profiles

The results are presented in Fig. 2 for all contact materials with a PdRu10 base material and in Fig. 3 for AgNi20 base material.

Fig. 2: Multilayer contact profiles measured before and after 30 minutes storage at 260°C in air – base material PdRu 10
a) top layer Au d, AuAg 8 s and AuPd 5 s
b) top layer AuNi 1 s, AuNi 2 s

Fig. 3: Multilayer contact profiles measured before and after 30 minutes storage at 260°C in air – base material AgNi 20
a) top layer Au d, AuAg 8 p
b) top layer AuNi 1 s, AuNi 2 s and AuNi 5 p

Shown in these figures are the initial values as received from the supplier and after storage of 30 minutes in air at 260°C. The results are presented separately for gold alloys containing only precious metal and gold alloys containing non-precious metal such as nickel.

Figs. 2a and 2b show the results for PdRu10 base material. While AuPd5s as well as AuAg8s showed no contact resistance increase caused by the temperature storage, the Au d resulted in even lower contact resistance after the storage. When nickel is added to the gold, stable contact resistance values can still be found initially, but the temperature storage has a significant impact on the final contact resistance values. While AuNi1 was found to be almost stable, AuNi2 showed a significant increase in the contact resistance.

In Figs. 3a and 3b, the results for AgNi20 base material are presented. Based on the better electrical conductivity of AgNi20 compared with PdRu10, the contact resistance values are lower for AgNi20 base material. Fig. 3a shows very stable resistance values for Au d and AuAg 8 p. The gold alloys containing nickel show a significant increase in the contact resistance values, and the increase is higher, the greater the nickel content in the alloy. While AuNi1 s has a maximum value of 13 mΩ, the maximum values for AuNi2 and AuNi5 are 18 and 20 mΩ respectively.

**B. Relays**

The contact resistance of the relays was measured after the pre-aging process at 260°C / 20 minutes. The results are presented in Figs. 4a to 4d. The maximum contact resistance values are well below the requirements of 50 mΩ for new relays. All tested parameters result in peak values of approx. 37 mΩ. The combination of AuAg 8 s with AgNi2 s (Fig. 3a) gives very stable and well-distributed contact resistance values. The results are comparable for the combination of AuAg 8 s with AgNi1 s (Fig. 3b). Au d (Fig. 3c) and AuPd5 showed less good results, e.g. at the normally open contacts. Up to approximately 85%, the contact resistance values are stable, but then the distribution curve shows a tendency towards higher contact resistance values.

**C. Relays – thermal endurance**

Results of the thermal endurance tests are presented in Fig. 4 and Fig. 5 for both normally closed and normally open contacts. During storage, the relays were not energized. After storage, the contact resistance of the normally closed contacts was measured, the relays activated and then the resistance of the normally open contacts measured on the first activation. On contact materials with a PdRu10 base material [Fig.5], for both normally open and normally closed contact materials stable contact resistance values were measured, except for AuNi2 and closed contacts during thermal exposure. The results for AgNi20 as base material showed very stable contact resistance values for the normally closed contacts, while on the normally open contacts a relevant increase was observed.
D. Relays – electrical endurance

As the results for make and break contacts were almost identical, only the results of the make contacts are presented in Fig. 7.

While the contact resistance values for AuNi2 s top layer [Fig.7a] showed good results up to approx. 5 million operations, after 5 million operations an increase in the average as well as the maximum values of the contact resistance was observed.

AuNi1 s as top layer [Fig.7b] of the moveable contacts showed the most stable contact resistance values – almost no change was observed up to the required 20 million operations.

Au d as top layer results in lower contact resistance values. While the contact resistance was very stable up to approx. 17 million operations, afterwards a sharp increase in the contact resistance values was observed [Fig.7c]. As the thickness of the diffused layer is very thin, wearing of the gold layer was found.

Fig. 5: Contact resistance values before and after the thermal endurance tests 125°C for 2000 hours, base material PdRu 10
a) normally closed contacts
b) normally open contacts

Fig. 6: Cumulative distribution of the contact resistance values before and after the thermal endurance tests 125°C for 2000 hours, base material AgNi 20
a) normally closed contacts
b) normally open contacts

c) Au d

Fig. 7: Electrical endurance tests at 0.5V/10 mA. Minimum, average and maximum contact resistance values of 20 contacts are given. Base material PdRu 10, Ambient gas SF6
a) Fixed contacts AuAg 8 s – moveable contact AuNi 2 s
b) Fixed contacts AuAg 8 s – moveable contact AuNi 1 s
c) Fixed contacts AuAg 8 s – moveable contact AuNi d
IV. Discussion

The high-temperature exposure in air of multilayer contacts resulted in low contact resistance and almost normally distributed values for all gold layers containing only precious metal – AuAg8 s, AuPd5 s Au d, independent of the base material. While AuNi alloys on PdRu10 base material still give normally distributed contact resistance values [Fig.2], on AgNi20 base material a relevant percentage of readings have a tendency towards higher contact resistance values and there is no longer a normal distribution. The higher the Ni content is, the higher the increase in the contact resistance [Fig3].

Relays after the pre-aging process showed acceptable results below 50 mΩ [Fig.4] for all combinations of contact materials. Normally open contacts showed lower contact resistance values due to slightly higher contact force on the normally open contacts.

The thermal endurance test for relays showed good results for all gold alloys on PdRu10, except for AuNi2, where a significant increase in the contact resistance was observed [Fig.5]. The reason for the increase was the formation of nickel oxide on the contact surface as found during EDX analysis. Significant contact resistance increase was measured on AgNi20 base material for both Au d and AuCo 0.5. For both materials, oxidation is the reason for contact material increase. For Au d, the nickel diffused through the gold layer, whilst in the case of AuCo 0.5 the cobalt oxidized.

Although the electrical endurance tests were performed in an inert atmosphere, the results achieved from AuNi1 [Fig.7] are significantly better than for the other materials. Au d is almost equivalent, but clear indication of wearing out can be seen after approx. 17 million operations.

V. Summary

Electromechanical signal relays suitable for SMT soldering processes and for use in high-temperature environments should address the following points:
- sputtered gold layers offer the best contact resistance stability in high-temperature applications
- diffused gold is only suitable on top of a palladium base material, but not on a AgNi base material, due to diffusion of Ni through the thin gold layer
- a combination of pure gold or AuAg provides the best contact resistance stability, but results in an extremely high risk of cold welding and is therefore not suitable
- a combination of sputtered AuAg8 and AuNi1 provides the best contact resistance stability in manufacturing, thermal exposure and electrical endurance tests. Gold alloys with more than one percent nickel should not be used in high-temperature applications
- hermetically sealed relays filled with inert gases such as N2 or SF6 support good contact resistance stability in signal relays

References

Werner Johler received his Ph.D. degree in electrical engineering from the Technical University of Vienna, Austria in 1988 and his MBA in 2003. From 1984 to 1988 he was a scientific staff member at the Institute of Switchgear at the Technical University of Vienna. Since 1988 he has been with Tyco Electronics in Au, Switzerland. He is Director for AXICOM relays. He has been Chairman of the Technical Committee TC94 “All or nothing relays” within CENELEC since 1999 and Swiss representative of ICEC (International Conference on Electrical Contacts) advisory group. He received the Scientific Award from the state of Vorarlberg, Austria in 2004, the Albert Keil Award from VDE in 2005 and the IEC 1906 award in 2007. He has published more than 60 papers on relay technology, miniaturization of electromechanical devices, contact physics and reliability of electromechanical relays.