



Reliability of low current electrical spring contacts in power modules

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Abstract

Advanced power module designs simplify the assembly process by electrical pressure contact technology. This technology can be applied to load connectors, control contacts and auxiliary sensor contacts. While the advantages for the assembly process are widely accepted, there is still concern about the long term stability of electrical spring contacts in power applications. However, knowledge base on wrap connector contacts which seems to support this concern cannot be applied due to important differences in construction. Employing Sn plus or Ag plated surfaces on the spring contact interface leads to reliable electrical contacts, that meet the demands of contact force and environmental stability. Accelerated thermal, environmental and mechanical tests will be presented, that prove the excellent reliability of the spring contact system.

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1. Motivation

Contact stability of electrical interfaces over aging time is a concern often related to pressure contacts. This concern is mostly based on experimental data published on wrap connectors [1,2]. However, there are important differences in contact design and force distribution in electrical contact technologies (Fig. 1).

The normal force in the interface between the two partners that form an electrical pressure contact is an important parameter for all technologies. For wrap connectors, those normal forces are limited due to the resulting mating and unmating forces and the requirements for the lifetime of a wrap connector system in a multitude of connection and disconnection processes. For spring pressure contacts as used in power semiconductor modules, the contact normal force is supplied during the mounting process by mounting bolts and allows much higher forces to be

applied to the contact interface. Further more, only a small number of connection and disconnection cycles are expected in a power electronic contact system. Therefore, the range of contact normal forces are quite different in wrap connector and pressure spring contact systems and the failure mechanisms of both technologies have to be considered with care.

Among others friction, wear and fretting can influence the lifetime of an electrical contact system. As power modules cover a wide range of different applications the contacts might be subject to vibrations or thermo-mechanical movement. Standardized tribological tests are commonly accepted to check the stability of a contact material combination. Different contact shapes – e.g. pin on pin, rod on rod – are used as model systems. A constant force load is applied onto the contacts prior to moving one of the contact partners in the contact interface plane against the other partner at a given frequency and displacement. These tests are

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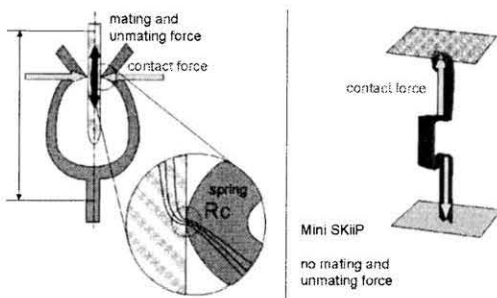


Fig. 1: Force distribution in wrap connector (left) and pressure contact system (right).

designed according to experiences with wrap connector reliability and lifetime [2].

Sn is one of the most convenient contact materials in terms of environmental stability. Sn platings are a well investigated and widely-used surface finish for electrical contacts. However, Sn platings might be affected by micro-vibrations. In model tribology tests standard Sn|Sn contact behavior is quite poor in a pressure range typical for wrap connectors [2]. After an initial contact resistance deterioration in the first 500 cycles the final contact failure occurs after up to 4000 cycles. A similar behavior is reported for SnPb|SnPb micro-vibration tests [2]. The final failure in both cases is associated with fretting corrosion, a friction induced type of corrosion. However, the number of cycles to failure does not necessarily apply to contact systems of different geometry and force distribution. Therefore, application relevant tests had to be conducted.

Besides the Sn platings ennobled material systems are of growing interest. One major reason for this trend are the regulations on Pb-free components and assemblies [3]. As the material choice for pressure contacts mainly depends on contact force, geometry and environment, new combinations have to be adapted and reliability ensured. A very popular measure to avoid Pb application is a Ni/Au flash plating on printed circuit boards. As contact partner in pressure contacts, the Ni-underplating is known to form insulating oxides if affected by fretting corrosion especially under low power conditions. Since the contacting Au layer has an acceptable thickness of only up to 200 nm to ensure solderability, a possible destruction of the Au film by wear has to be avoided by an appropriate design of the contact geometry.

The choice of an appropriate contact partner for ennobled printed boards is limited by the demands of contact stability. Hard gold and silver are reliable mating partners. However, tolerable contact normal

forces for hard gold platings are rather low (< 2 N) and Ag offers a larger range of up to 20 N applicable load. Therefore, increased contact forces tolerable for an Ag plated spring contact system offer an enhanced stability against shock and vibration.

Pressure contacts designed in compliance with the requirements made from the material combination Ni/Au flash versus Ag plating are known to be stable against fretting corrosion conditions. However, the stability of pure Ag platings against sulfur containing atmospheres is poor. Therefore, a passivating film has to be applied to the Ag plating that does not affect the long term stability of the electrical contact interface.

Again, the functionality of passivations is mainly qualified for wrap connector systems. These results cannot be directly transferred to spring pressure contacts because of the differences in contact force and force direction, so that existing solutions and new passivations recently introduced along with the trend to ennobled contact materials have to be qualified for spring pressure systems in power electronic applications.

In consideration of the major differences between wrap connector and pressure contact systems the reliability of spring contacts can only be ensured with accelerated lifetime tests on application based set-ups. The tests that are supposed to have a major influence on the contact stability are micro-vibration tests, temperature cycling and exposure to sulfur contaminated atmospheres.

2. Test system and test conditions

In the MiniSKiiP[®] system, all electrical contacts are established by spring pressure contacts, combining load contacts for high current and low current contacts for temperature sensor and control contacts in one system. Therefore, the MiniSKiiP[®] system is the ideal test environment to investigate the reliability of spring pressure contacts for the whole application range.

Large current loads or voltage drops normally establish enduring spring contacts. However, low power, low voltage contacts like sense or control contacts are sensitive to small surface changes. In order to test the contact stability, suitable testing parameters have to be selected.

Contact reliability was checked by measuring the contact resistance as shown in Fig. 2. The resistance tests were carried out with a μ -Ohmmeter, Sefelec type MGR 10, in a four-point set-up. A constant current of

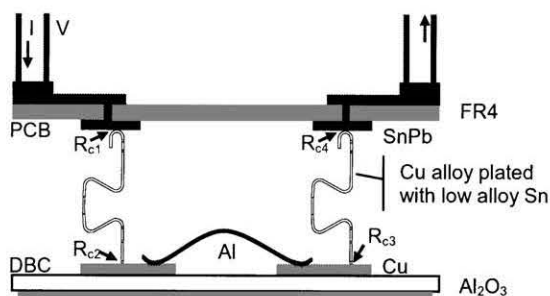


Fig. 2: Schematic set-up of samples (without housing).

10 mA with 50 mV resp. 5 V voltage limitation was applied to measure the contact resistance. The correlated resistance resolution of the μ -Ohmmeter is 1 m Ω . The initial resistance consists of the four contact resistances indicated in Fig. 2 with an additional ohmic resistance of the current path on the PCB, the DBC and along the springs.

The end-of-life is specified at contact resistance changes of 400 m Ω per pair of spring pins which directly reflects the sum of changes of four contact resistances. This specification limit guarantees a reliable and stable behavior of the control and auxiliary board functions.

3. Sn plus plated spring pins

Tribometer test parameters

In contrast to the set-up of standardized tribological tests (e.g. Sn|Sn) the mating contact materials of MiniSKiiP[®] are not identical (e.g. Cu|Sn plus). Additionally, the contact designs are complex and each spring pin establishes two contacts. Therefore, both sides might be affected by micro-vibrations or thermo-mechanical movement. To get access to the contact resistances significant tests had to be carried out with a modified MiniSKiiP[®] substrate layout and a test PCB as contact counterpart. The MiniSKiiP[®] was mounted onto a heat sink and the PCB pressed on top. The resulting set-up and material combinations are given in Fig. 2.

The spring pin plating is Sn plus. This is a Sn alloy improved in terms of fretting corrosion resistance and whiskering. However, fretting resistance remains in the same order of magnitude as for pure Sn contacts. The PCB was actuated via a tribometer with a 5 Hz vibration and 20 μ m amplitude.

During the test the resistance characteristics over two spring pins has been recorded. The design of the

spring pins is given as enclosure in Fig. 3 and 5. The spring pin shows two characteristic directions – orthogonal and parallel to the cylindrically shaped spring pin top. These directions are indicated with x (orthogonal) and y (parallel). Both vibration directions have been examined.

Tribology results

Fig. 3 gives the results for the specified standard contact force of 5 N applied on the spring pins. The contact resistances are stable within a narrow range in both directions for more than 100 kcycles. Despite the improved material composition of Sn plus the contact stability is far beyond the values that could be expected from wrap connector results. In x-direction even an initial contact resistance decrease can be found. The mean resistance over 100 kcycles is 13.7 ± 0.5 m Ω in x- and 19.0 ± 0.5 m Ω in y-direction. The difference in the initial resistance value is due to minor changes in the electrical path on the Mini SKiiP substrate.

The contact stability against fretting is known to depend on the applied contact force. For pressure contact systems the contact stability might decrease due

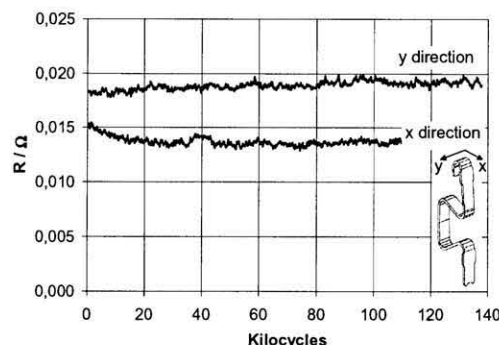


Fig. 3: Tribometer test MiniSKiiP[®]: x- and y-directions, 5 Hz, 20 μ m, 5 N.

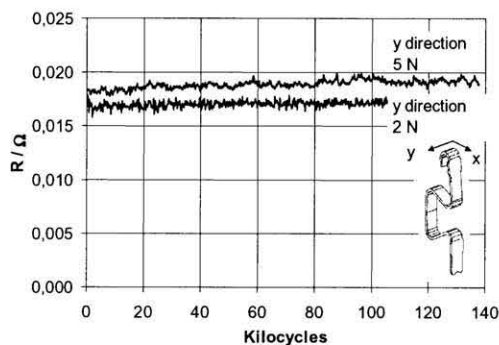


Fig. 4: Tribometer test MiniSKiiP[®]: y-direction with standard (5 N) and reduced force (2 N), 5 Hz, 20 μ m.

to a degradation of the spring force and a consecutive reduction of the contact forces over time. Therefore, it is of interest to evaluate contact stability under reduced pressure conditions. The acceptable minimal contact force for Sn and SnPb contacts according to literature values is 2.5 N [2]. Thus, tests have been carried out for comparison with a reduced contact force of 2 N. Fig. 4 shows the results for the y-direction for contact forces 5 N (standard) and 2 N. Even with reduced contact force no significant contact resistance change could be measured for more than 100 kcycles. The mean resistance for 100 kcycles is $17.0 \pm 0.4 \text{ m}\Omega$ in y-direction.

The first significant contact resistance deterioration occurred after 1.175 million cycles with a drastic resistance increase to approximately 10Ω within a single step connected with very erratic contact resistances. This indicates the end-of-life of the pressure contact system.

4. Contact geometry

The spring pin geometry is designed to ensure a reliable spring force over lifetime (Fig. 5). However, the contact geometry has to be chosen according to the contact materials and forces.

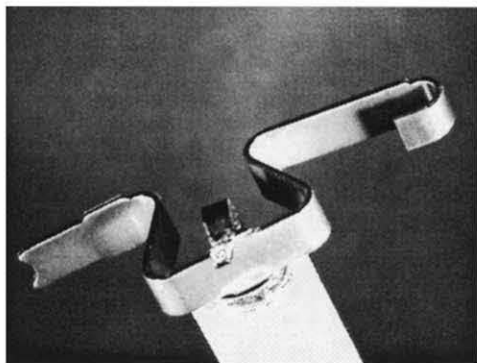


Fig. 5: Spring pin design MiniSKiiP® II.

Loads of $> 2 \text{ N}$ are required to break the native oxide layer and ensure fretting corrosion resistance for reliable Sn contacts. The concave design of the Sn plated spring pin to SnPb plated PCB contact is meant to ensure two defined contact areas and a gas tight connection.

Ag surfaces are suitable for the same contact force range as Sn. Therefore, Ag plated contacts are a suitable replacement for Sn plated surfaces and do not necessarily require changes in the contact system.

However, an ultrathin Au flash counterpart contact on a printed circuit board is very sensitive to abrasion and demands a smooth interface to prevent destruction by

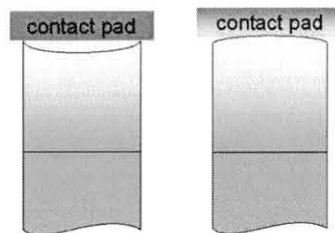


Fig. 6: Schematic spring pin contact geometries suitable for Sn/SnPb (left) and Ag/Ni/Au flash (right) interfaces.

wear and direct contact to the Ni underplating. A correlated change in the contact geometry leads to a flat or slightly convex shape of the contact area to PCB.

Fig. 6 shows an exaggerated sketch of the two types of interfaces to illustrate the idea of the geometry.

5. Ag plated spring pins

5.1 Sulfur stability of Ag platings

Pure Ag surfaces show a high affinity to sulfur. Resulting layers or whiskers can affect the functioning of the electrical contact. An appropriate measure to prevent the formation of Ag_2S is the application of a passivation [4]. Protective layers intended for use in electrical contacts are designed not to affect the electrical properties of the contact. The following types of passivation are available: Thiol containing organic monolayers, anorganic conversion layers and ultrathin metallic films. First estimations on the durability of this protection have been carried out via a qualitative thioacetamide test according to ISO 4538.

Test parameters

The test set-up consists of a desiccator containing a sodium acetate trihydrate solution in the bottom and a petri-dish with thioacetamide powder. The samples are placed onto a perforated plate in the upper part of the receptacle. The closed desiccator is then stored at $40 \pm 2 \text{ }^\circ\text{C}$ for 16 h. The test results are evaluated by visual inspection of the surface appearance, e.g. tarnishing colors. As this type of test only gives qualitative results an unpassivated sample has to be included in the test for comparison. In Fig. 7 results for different types of passivations are given.

Results on sulfur stability

The Ag platings with different surface treatment show different stages of tarnishing after the storage test. However, the difference between unpassivated surface and organic passivation is rather small. Both surfaces appear in a dull black-blue color. The metallic passivation shows first signs of tarnishing in form of a dull surface. According to these results a higher lifetime of the metallic passivated surface can be anticipated.

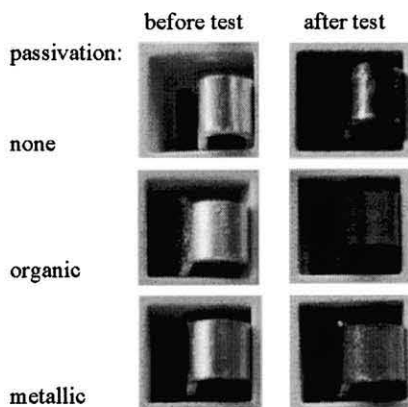


Fig. 7: Spring pin platings without and with passivation before and after the thioacetamide test.

5.2 Temperature cycling behavior of Ag platings

Temperature cycling is a significant lifetime test, because it reflects application near conditions. During this type of test the contact system is affected by thermal movements as well as humidity changes.

Temperature cycling test parameters

No voltage load is applied onto the contacts during the test as a steady current flow would result in a stabilizing effect for the contacts.

The applied cycling parameters are temperature shock between -40 and $+125$ °C. During the first cycles the temperature characteristics of one of the heat sink is recorded to ensure that the modules reach the temperature equilibrium in each cycle.

The test samples built according to Fig. 2 were measured at room temperature before the test and after 50, 100, 150 and 200 cycles. In application environments for open circuit condition a voltage of 8 V is applied to the contacts. To provide a security the voltage limitation of the test current is set to 5 V. Fig. 8 and 9 show the relative change of contact resistance

after temperature cycling with respect to the initial value, which is given by the design of the device under test. According to the test set-up seen in Fig. 2 four contacts contribute to the contact resistance. Shown are the mean values and standard deviations for the measured devices under test.

On the DBC side of the spring pin contact the standard material is Cu. However, for some applications Ni might be interesting as plating on the Cu surface. Therefore the following paragraph includes results of the following surface combinations:

- DBC Cu | spring pin Ag | PCB Ni/Au flash
- DBC Ni | spring pin Ag | PCB Ni/Au flash

All spring pins were surface treated with the metallic type of passivation.

Temperature cycling results

Fig. 8 gives the contact resistance characteristics for the Cu-DBC set-up. Already after 100 cycles a limiting value of about 60 m Ω is reached that remains approximately constant for the rest of the test duration. The contact resistance changes stay far below the specified limit of 400 m Ω for 200 cycles. The contact behavior is stable. No erratic resistance changes occur.

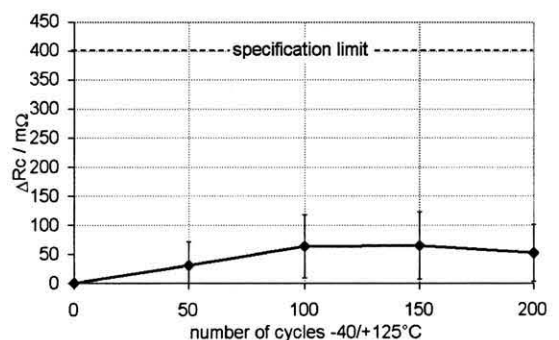


Fig. 8: Contact resistance characteristics of Cu DBC, Ag plated spring pins on PCB with Ni/Au flash during temperature cycling.

The Ni-DBC based modules show a limiting contact resistance after 100 cycles, as well. However, in contrast to the Cu type the Ni-DBC based modules show a high contact resistance change and a large standard deviation (Fig. 10). Sporadic eloping contacts with resistance change of more than 1 Ω after 200 cycles are observed. The contact resistance changes appear erratic in positive and negative directions on different contacts.

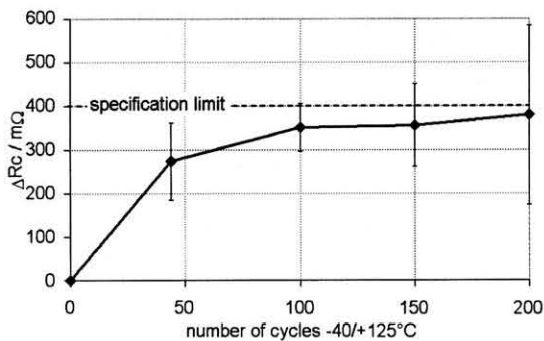


Fig. 9: Contact resistance characteristics of Ni plated DBC, Ag plated springs on PCB with Ni/Au flash during temperature cycling.

Additionally, a surface analysis of spring pin pressure contact to the printed circuit board was conducted to detect possible traces of aging. An SEM/EDX analysis of this interface was carried out immediately after the disassembly of the set-up (Fig. 10).

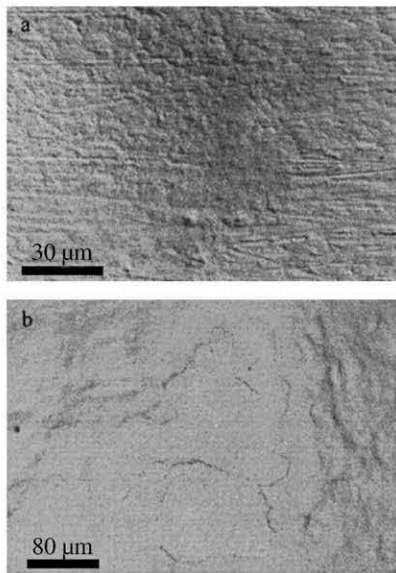


Fig. 10: SEM images of contact interfaces after T-cycling, DBC Cu, a) PCB (NiAu flash), b) spring pin (Ag).

After 200 temperature cycles the contact imprint on the Ni/Au flash PCB appears mechanically deformed and smooth. This effect can be seen by flattened surface marks in the middle area of the image. However, no signs for wear are visible. The Au flash layer is still intact. Bared Ni would look darker than Au. A transfer of spring pin plating material would result in a brightness contrast, too.

Fig. 10b shows the spring pin contact area. Correspondingly, the middle area appears mechanically deformed. The elevation is a bit flattened. However, the Ag plating is not affected by wear. No material transfer from the PCB plating can be seen, either.

6. Conclusion

Spring pin contacts show excellent long term reliability behavior and are well suited for power electronic applications.

This is in contrast to the typical behavior of wrap connectors. The major difference between the two contact systems is the contact normal force.

MiniSKiiP® Sn plus plated spring contacts exhibit a long term stability against fretting corrosion conditions. These contacts are by far more stable against micro-vibration than what could be assumed from published data on wrap connectors.

MiniSKiiP® spring contacts with Ag plating exhibit stable behavior against Sulfur containing atmospheres if a suitable passivation is applied. Accelerated lifetime tests such as temperature cycling show contact resistance changes far below the specification limit for standard Cu-DBCs. An optimized contact geometry ensures the reliability in combination with ennobled PCB plating materials.

Acknowledgement

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