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Study of Foil Resistors Under Exposure to High-Temperature, Moisture, and Humidity

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Abstract

An often overlooked reliability concern in many surface-mount resistor applications is long-term high-temperature exposure in combination with moisture and humidity. This can lead to malfunctions in merely a few hours of operation, which can result in either a gradual increase or decrease in resistance over a longer period of time, or in some extreme cases, to catastrophic failure. This study was performed in order to mimic these harsh field conditions. Surface-mount Bulk Metal® Foil chip resistors feature a special coating and internal construction, in addition to utilizing a specially designed metal foil. This combination has been shown to enhance reliability and endurance of the resistors in extreme environmental conditions.

Introduction

Foil resistor technology is based on Bulk Metal Foil, which in many cases is comprised of NiCr-based alloys. These are layered and adhered onto an insulating substrate. In most cases these solid metallic alloys also contain small amounts of other precipitation elements. These act as grain boundary stabilizers and stoichiometric phase formation agents, which enhance the resistive values of the foil after being subjected to the appropriate temper conditions. Typical thickness of Bulk Metal Foil is 2 µm to 5 µm, depending on the final required resistivity for a particular type and size. A typical SEM cross section through a VSM resistor can be seen in Figure 1. This metallic layer is fine, homogeneous, and has a uniform and constant thickness throughout the whole resistor cross section.

Thin film resistors, in principle, are manufactured using a different technology. An extremely thin layer of sub-micron conductive material, such as NiCr (50:50) or Ta_2N, is deposited via vacuum, plasma, or ion deposition system on top of a dielectric layer that functions as an insulator as well (e.g., SiO_2 or Si_2N_3). Compared to the bulk foil, it is usually a magnitude of order thinner, i.e., 0.1 µm to 0.25 µm (see Figure 2). These sub-micron grain deposits tend to agglomerate and form a uniform continuous layer. Nevertheless, in the final stage of manufacturing thin film resistors, a relatively thick protective overcoat glaze is deposited and then baked and fired at peak temperatures of about 850ºC for a very short period of time. Although this operation seals off the resistor from the exterior, the conductive layer remains essentially in its powder-like metal form. A sintering effect can only be achieved at temperatures in access of 0.6 Tm, and at longer time durations.

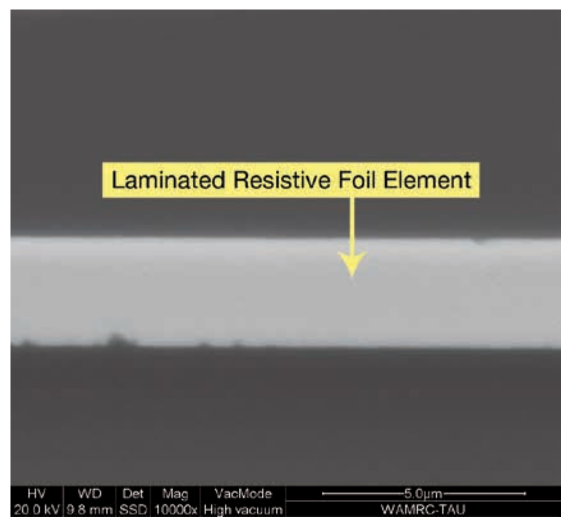

Figure 1. VSM0805 100R (X10,000)

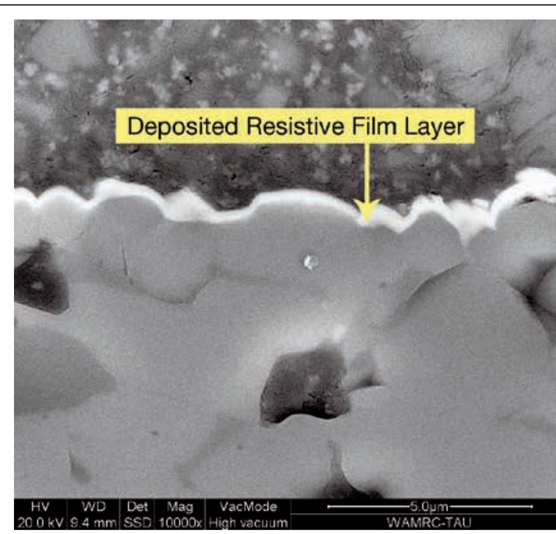

Figure 2. Thin film resistor 110R (X10,000)

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Methods of Evaluating Moisture

There are many acceptable industrial tests for evaluating resistance to temperature, moisture, and humidity. Some are under specified terms and conditions, and others are accepted accelerated quick test performances. In all cases, the traditional criteria for determining the moisture penetration is to measure ΔR (ppm) at known intervals of time and to compare it to a baseline. The shift in resistance change can predict and indicate how the resistor will act during real service life. Among the known test methods are:

1) HAST test (highly accelerated temperature and humidity stress test). Performed under 2 atm for 96 hrs at 121ºC under 10% Pn.
2) 85 / 85 humidity test, which is a test for 1,000 hrs at 85ºC and 85% RH under 10% Pn.
3) Moisture test per MIL-STD-202 method 106 for 10 days at 65ºC and 93% RH under 10% Pn or 100% Pn (or without load).
4) Steady-state humidity test per MIL-STD-202 method 103 for 56 days at 40°C and 90% RH (1,344 hrs) under 0.01xPn or 0.1xV.
5) Pressure cooker test performed under 2 atm pressure for 2 hrs at 121°C and 99% RH with or without 1 V bias.

Experimental Results

Regular linear resistors where chosen for this study. They contain various types (e.g., surface-mount wraparounds, molded, hybrids, and network resistors) as well as different sizes and resistance values. The following graphs represent the performance of foil resistors under different environmental tests.

Moisture Test Per MIL-STD-202 Method 106 for 10 days at 65ºC and 93% RH

Figures 3 to 6 represent a series of various surface-mount FRSH, FRST, and HTHG devices, which have been tested without bias. Molded devices and network resistors have been tested under different power ratings.

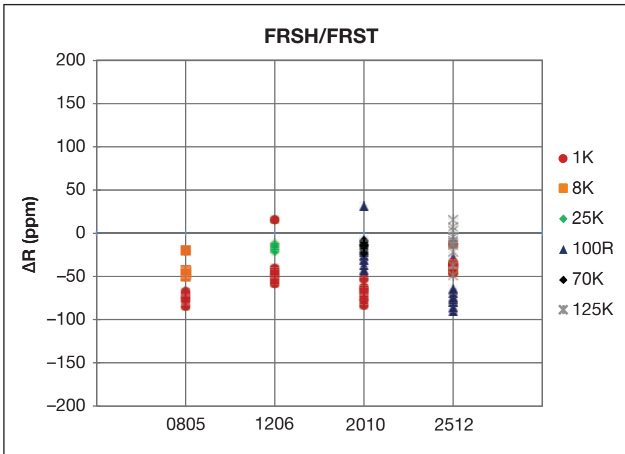

Figure 3. High-temperature wraparound surface-mount chip resistors (without bias)

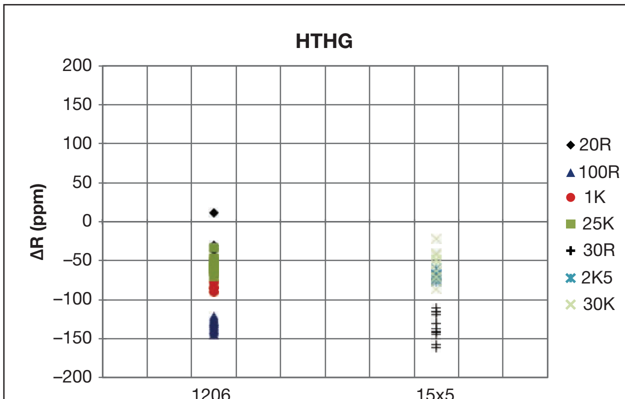

Figure 4. Hybrid chips for gold wire bonding (without bias)

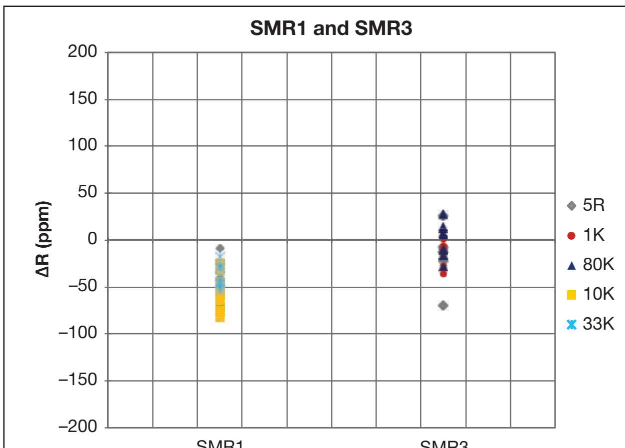

Figure 5. Molded surface-mount resistors (with bias, Pn)

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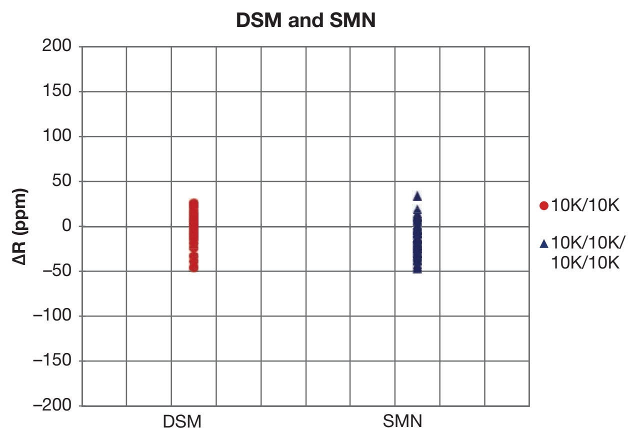

Figure 6. Network resistors (with bias, 10% Pn)

Humidity Test Per MIL-PRF-914C for 1,000 hrs at 85ºC and 85% RH

Figures 7 and 8 represent a series of various surface-mount resistors tested for humidity resistance per MIL-PRF-914C under 85ºC and 85% RH conditions (with and without bias) for 1,000 hrs.

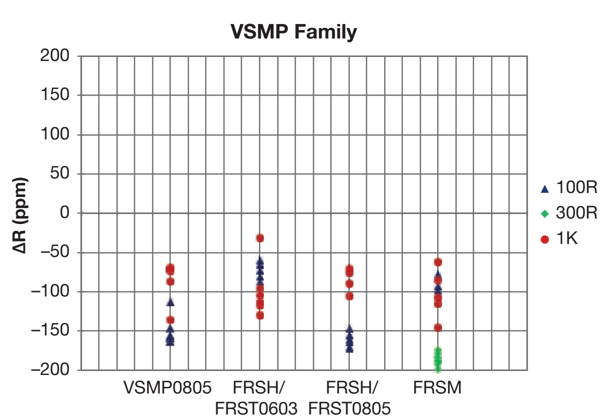

Figure 7. Surface-mount wraparound resistors (without bias)

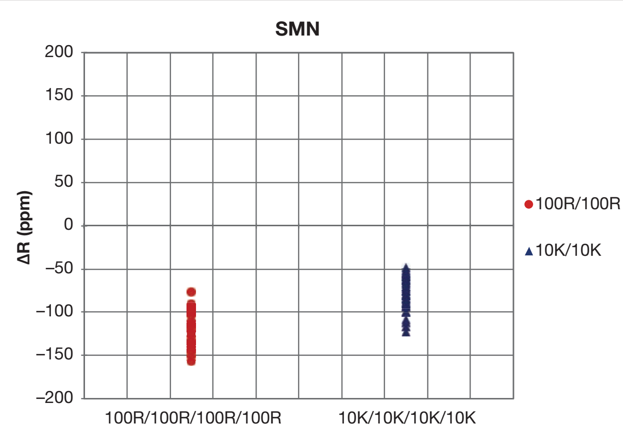

Figure 8. Network resistor (with bias, 10% Pn)

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Pressure Cooker Test (PCT) Under 2 atm at 121°C, 99% RH

Figure 9 compares two different surface-mount resistor technologies tested for accelerated conditions (without and with 1 V bias).

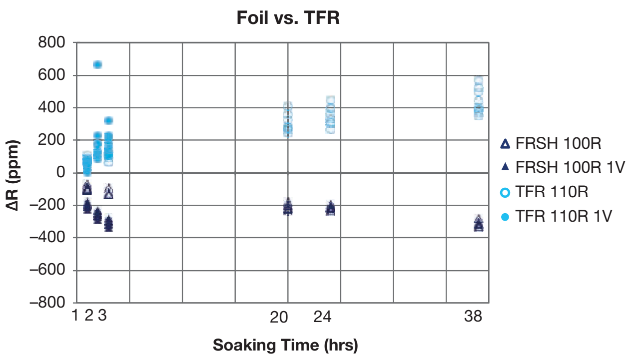

Figure 9. FRSH0805 foil resistor vs. thin film resistor (without and with 1 V bias)

In order to show the effect of extreme humid environments on the conductive elements themselves, uncoated (exposed) foil and thin film resistors (both 1206 size 10K value) were placed in a closed warm water container. This condition might simulate a situation where the protective overcoat is severely damaged, cracked, or even broken off. The resistors were biased with 5 VDC and monitored for constant ΔR change. It was found that thin film fails after one minute into the test (with shifts over +5%), whereas the foil lasts well over two hours (with shifts of –550 ppm).

Discussion

The failure mechanism is in most cases due to an electro-chemical reaction between the metallic composition and traces of moisture/humidity, which form oxides and a galvanic reaction between adjacent electro-negative areas. This is enhanced by a combination of elevated temperature and power according to the Arrhenius exponent. In case of foil resistors, this might occur between conducting grid lines and insulating bands. In case of thin film devices, this may occur as a result of overcoat cracking and infiltration of liquid / vaporous media between the sub-grained layers, which triggers the reaction. In both cases this causes distortion in regular electrical flow and shifts in resistance value. The foil is solid, uniform, relatively thick, and has an ordered crystallographic FCC structure with very distinct orientation of grains. Both matrix and γ' phase are of similar composition and structure. Foil resistors work under relatively low power during service. If there is local exposure to humidity, the forced power causes a heating and drying effect. Thus, it is less susceptible to inter-granular galvanic corrosion. In addition the use of advanced passivation and over-coating materials increases protection against moisture and humidity penetration.

On the other hand, thin film resistors are deposited and therefore very sensitive to the presence of impurities in the chamber. In such local areas that might contain undesirable elements (mostly oxides), or if the thin film contains areas that are less homogeneous in structure, uniformity, and thickness, a local galvanic attack may be catastrophic. The much larger surface area of those sub-micron grains acts as local nuclei and enhances formation of metallic oxides. Most likely, it will lead to further stress corrosion-induced failure. This is a mechanical failure in nature, and is observed as coating blistering and peeling or bursting of mold compound.

Electro-chemical reactions (corrosion) usually result in a positive change in resistance. Mechanical stresses can lead to either positive or negative changes in resistance. This depends on the structure, materials, and geometry of the resistive element. Shunting can also contribute to a negative change in resistance; however, if the resistor is dried out, this effect is reversible. The difference between these two tendencies is substantial; the corrosion effect can lead to catastrophic failure, whereas the stress effect is a parametric one.

While reviewing the performance reflected in the graphs, it is obvious that the foil products exhibit mostly negative or slightly mixed (negative and slightly positive) resistance drift. Thus, mechanical stresses are dominant, but can be relieved with proper drying. In most cases observed, the resistance drift is very small (less than 100 ppm). Furthermore, the pressure cooker test comparison, which is considered a highly accelerated test, indicates that the foil surface-mount chip resistor drifts consistently negative, reaching the –300 ppm level after 38 hours with a very small spread (<50 ppm). On the other hand, thin film resistors tend to drift consistently positive, reaching levels of +500 ppm with a relatively large spread (>100 ppm). This tendency repeats itself when the resistors are subjected to bias; however, the access voltage causes an immediate reaction in both cases. These tests were terminated after three hours.

Moreover, PCT on unprotected thin film and foil resistors conclusively exhibited the true nature of the foil element's robustness under harsh environmental conditions.

Conclusions and Recommendations

Experimental test results under different environmental conditions have confirmed the suggestion that foil resistors exhibit sound and reliable steady-state performance under harsh environmental conditions, with very little degradation over time compared to their initial benchmark resistive values.

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Acknowledgements

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