Effects of Galvanic Corrosion on Au-Sn Plated Contacts in Electronic Cable Interconnect

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August 2011 (revised February 2013)

***Abstract* – Galvanic corrosion may cause bimetal contact surface damage particularly when the contacts immersed in electrolyte solution. However, little has been found in the literature for in-depth study on galvanic corrosion in the electronic interconnects application. This paper presents the accelerated tests for galvanic corrosion employing multi-directional, varying intensity and frequency of vibration on gold-tin contacts. Repetitive thermal shock tests were also carried out to study contact resistance changes and qualitative assessment on physical damage to contact surfaces. Preliminary findings show no substantive evidence of galvanic corrosion affecting contact resistance between tin-plated FFC and gold-plated connector. The measured contact resistance falls within the acceptable specification limit of recommended 60mΩ utilizing JIS C60068 and EIA 364 for consumer electronic product applications.**

***Keywords* –** Galvanic Corrosion, Contact Resistance, interconnect, flexible flat cable, flexible printed circuit, electronic connector

I. INTRODUCTION

Galvanic corrosion is also known as dissimilar metal corrosion and bimetallic corrosion. This type of contact corrosion happens when there are two dissimilar metals conducting electrically with the presence of electrolyte in the operating medium.

1.1 Conditions and Mechanism of Galvanic Conditions

Galvanic corrosion exists when the following conditions:

1. A pair of Galvanic couple formed by dissimilar metal as referred to Galvanic series chart
2. Electric contact between the Galvanic couple
3. Electrolyte (i.e. corrosive medium) in contact with the Galvanic couple

Figure 1 shows the example of Gold-plated connector mated with Tin-plated FFC. Gold-plated surface has higher nobility than tin-plated surface as stated in galvanic series chart. Gold-plated contact surface forms the cathode while tin-plated contact surface forms the anode and tends to corrode under immersed electrolyte solution. The electrons flow across the bimetals contact surfaces. The anode surface (i.e. tin-plated) promotes oxidation by losing electrons and corrodes at a faster rate. Concurrently, the cathode surface (i.e. gold-plated) gains electrons and forms deposition of tin oxide.

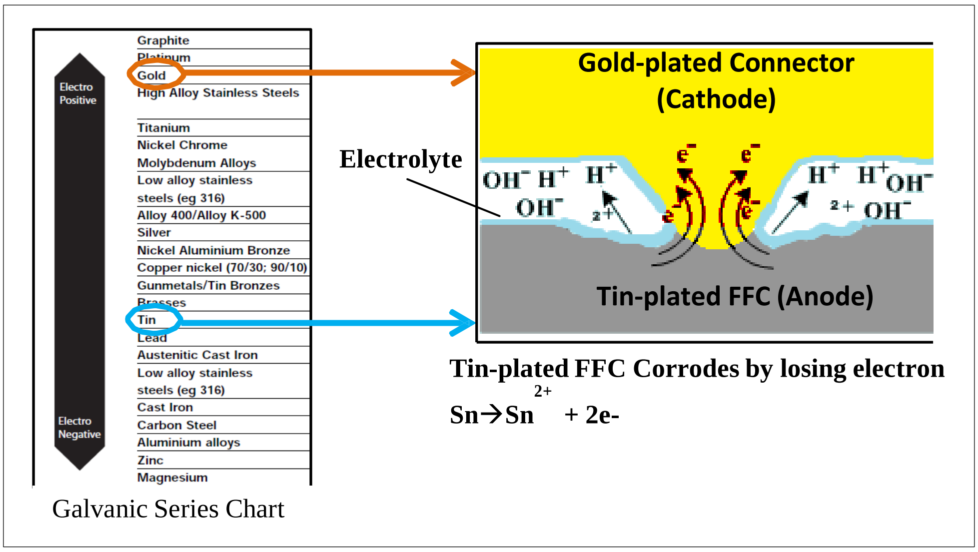


Figure 1 Mechanism of Galvanic Corrosion

1.2 Anodic Index

The greater the dissimilar metal described in the Galvanic Series table, the greater potential of galvanic corrosion. By referring to the Galvanic Series in Figure 2, gold has the anodic index of 0.00V while tin has the anodic index of 0.65V. The contact of gold-to-tin has 0.5V of difference and relatively potential different under relatively low humidity environment.

Metallurgy Anodic Index	Index (V)
Gold, solid and plated, Gold-platinum alloy	0.00
Tin-plate; tin-lead solder	0.65

Figure 2 Anodic Index

II. FACTORS AFFECTING RATE OF GALVANIC CORROSION

2.1 Distance Apart in Galvanic Series

Figure 3 shows that in general, metals with lower potential difference do not corrode easily. These metals are noble such as gold, platinum and silver. In contrast, metals with higher potential difference tend to undergo corrosion, such as zinc, magnesium and aluminum.

	Volts	
Magnesium	1.58	
Zinc	1.04	
Cadmium	.88	Less Nobility
Mild Steel	.79	
Aluminum alloyed	.71	
Lead	.52	
Tin	.50	
Brass	.31	
Stainless Steel	.24	More Nobility
Monel	.12	
Silver	.08	
Gold	.00	
Platinum	.00	

Figure 3 Potential Difference in Galvanic Series Table

Since the higher the potential difference between dissimilar metals in contact tends to promote galvanic corrosion, it is often recommended to avoid the use of dissimilar metals for interconnect applications. However, the magnitude of potential difference between dissimilar metals alone is not sufficient to predict the risk associated with galvanic corrosion[1]. For instance, metals with a potential difference of 0.05V have shown significant bimetallic corrosion in certain applications environment; while other metals with a potential difference of 0.8V have successfully been coupled with negligible evidence of galvanic corrosion.

2.2 Area Ratio of Cathodic and Anodic Index

The rate of corrosion is influenced by the relative area ratio of cathodic and anodic surfaces. As a general rule to minimize galvanic corrosion, the anode area should be relatively larger and the cathode area is smaller. This area ratio factor is an amplifying factor when $A_{cathode}/A_{anode}>1$, and is stifling factor when $A_{cathode}/A_{anode}<1$, as shown in Figure 4(a) and (b).

Formated tin-plated FFC with gold-plated connector applications, gold-plated connector surface acts as cathode while tin-plated FFC surface acts as anode. The surface area of tin-plated FFC (i.e. anode) is relatively larger than the connector (i.e. cathode) as described in Figure 3(b).

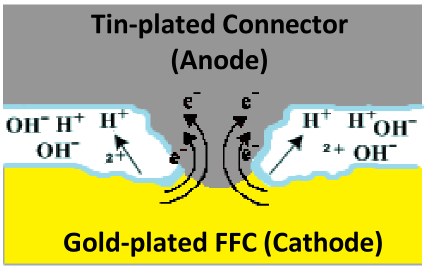


Figure 4 (a) $A_{cathode}/A_{anode}>1$, an **amplifying factor** when large cathode area mating with small anode area.

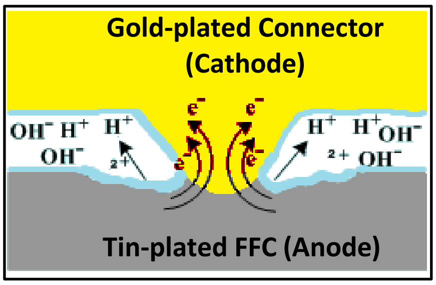


Figure 4 (b) $A_{cathode}/A_{anode}<1$, a **stifling factor** when large anode area mating with small cathode area.

2.3 Electrolyte Medium Between Contact Surfaces

Galvanic corrosion becomes severe when bimetal is **under immersed liquid solution** as compared when it is in atmosphere condition[4]. The severity of galvanic corrosion is dependent on the conductivity of the electrolyte solution residing medium in between contact surfaces. For example, sea water is highly conductive solution gives rise to more galvanic corrosion than fresh water, which generally has relatively lower conductivity.

One of the conditions for galvanic corrosion is to immerse the dissimilar metal couple in an electrolyte. However, it is not necessary for the metal contact to be immersed in electrolyte for galvanic corrosion to take place[1]. A contact surface of moisture condensed in air could provide condition for galvanic corrosion. The potential of formation of conductive surface film depends on three variables: temperature, humidity, presence of dust particles [2]. However, in atmospheric operating condition of electronic interconnects application, when there is conductive surface film exists, it would likely to cause short circuit or malfunction to the circuitry.

2.4 Temperature and Humidity

Rate of galvanic corrosion tends to increase with the rising temperature. Higher temperature accelerates the diffusion of oxygen due to its influence on the solubility of oxygen in electrolyte. In consumer electronic circuit application, these interconnects are exposed in atmospheric condition. There is unlikely to have the present of electrolyte solution between the contact surfaces.

One of the fundamental requirements for galvanic corrosion processes happen on contact interface between connector and FFC is the presence of a thin film electrolyte that can form on metallic surfaces when exposed to a critical level of humidity as there is potential condensation happening on the metal surface.

2.5 Impurities and Acidic Solution

Dust on a surface and pores in an already existing oxide film could form fine capillaries that permitting the condensation of moisture on mating surfaces [2]. The acid solution (pH<7) solutions are more corrosive than neutral (pH=7) solutions or alkaline (pH>7) solutions [3]. For example, Figure 5 shows that in acidic environment, the corrosion rate is above 0.8mm per year at pH=2.9. However, in alkaline environment with pH>10, the corrosion rate is below 0.3mm per year.

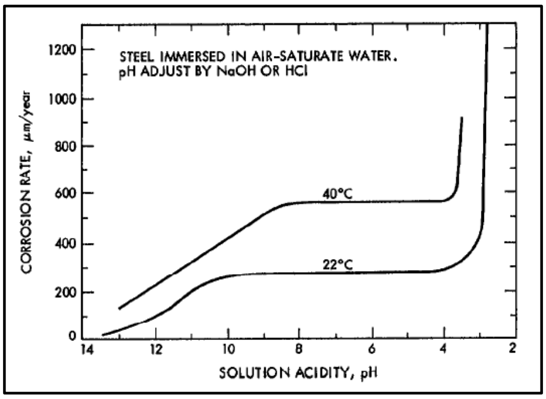


Figure 5 Effect of Solution Acidity on Corrosion Rate [3]

III. RESULTS AND DISCUSSION

3.1 Galvanic Corrosion Tests

Since this paper focus in the area of electronic interconnects application, the use of electrolyte and acidic solutions for accelerating galvanic corrosion test are not applicable. The tests were directed to employ constant current, multi-directional vibration with varying frequency and intensity, and also thermal shock with humidity as accelerating factors to stimulate galvanic corrosion.

Two samples of tin-plated FFC for different pitch are soldered on PCB board and are electrically connected for 1,000 hours and the recorded data are shown in Figure 6.

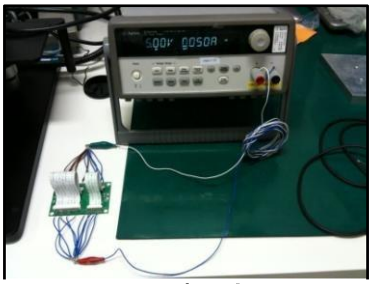


Figure 6 Equipment setup for Galvanic Corrosion Test

Figure 7 shows the comparison of the contact resistance and traces on V-Flex® tin-plated FFC before and after the galvanic corrosion. While figure 8 represents the readings and average contact resistance of galvanic corrosion test for one month. The results are evidence that no significant change in contact resistance performance and reading values are within the manufacturer's specification of 60mΩ.

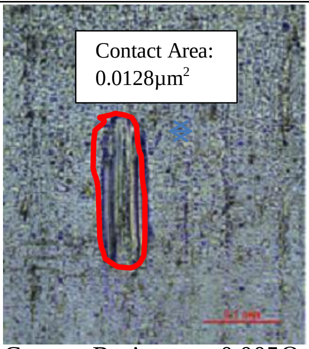
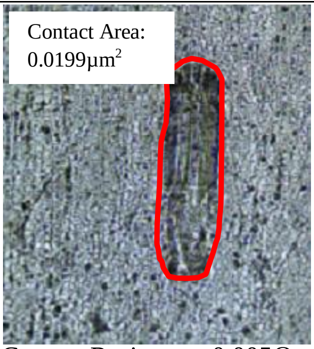
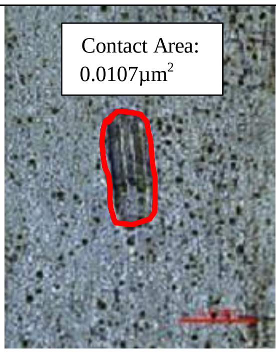
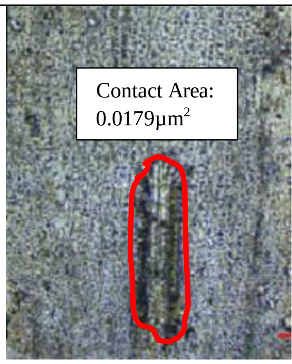
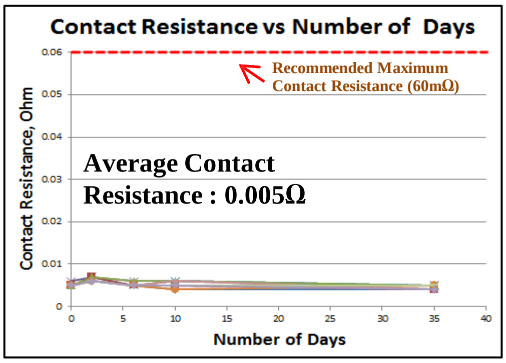
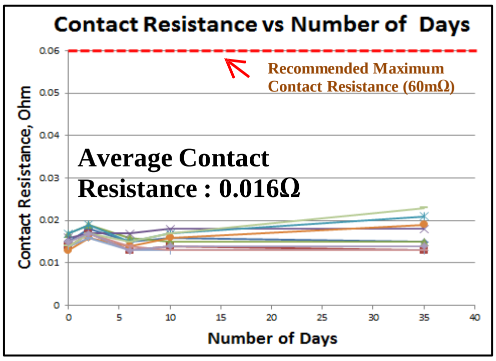
Connector Specimen	Surface Area Before Test	Surface Area After Test
Specimen 1	 Contact Resistance: 0.005Ω	 Contact Resistance:0.005Ω
Specimen 2	 Contact Resistance:0.005Ω	 Contact Resistance:0.006Ω

Figure 7 Comparison of Contact Surface and Contact Resistance before and after Galvanic corrosion
(Constant voltage follow at 0.005A, 1kΩ; Connector (gold-plated) with FFC (1mm, tin-plated);
Temperature 24C, Humidity 60%; Duration: 1,000hrs)



FFC 1.0 mm Pitch FFC



FFC 0.5mm Pitch FFC

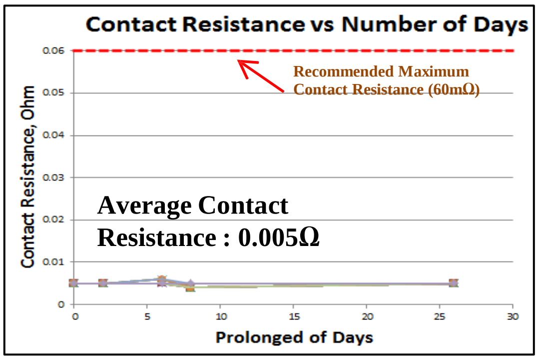
Figure 8 Contact Resistance VS. Number of Days, for 0.5/1.0 mm pitch Tin-plated FFC
(Constant voltage follow at 0.005A, 1kΩ; Connector (gold-plated) with FFC (0.5/1mm, tin-plated); Temperature 24C, Humidity 60%)

3.2 Fretting at Position X and Y with Galvanic Corrosion Test

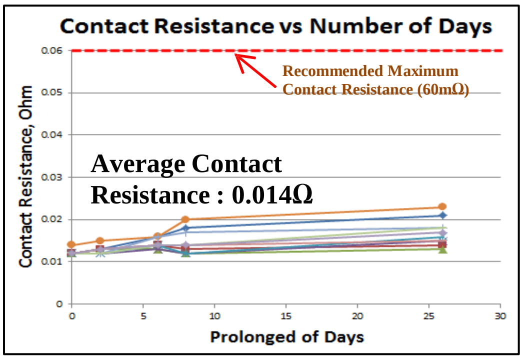
Further testing is conducted to observe the effect of possible corrosion to contact resistance changes. The mated tin-plated FFC and gold-plated connector were placed on the electrodynamic shaker in various vibration directions to simulate the condition for fretting motion as shown in Figure 9. The mated interconnect is supplied with constant current.

Figure 9 PCB with mated FFC and connectors were placed in position X and Y with electrical connected on the electrodynamic shaker for one month.

Figure 10 shows the result for fretting at position X with galvanic corrosion. There is no significant increase in contact resistance and the measured values fall within the Manufacturer's specification of 60mΩ.



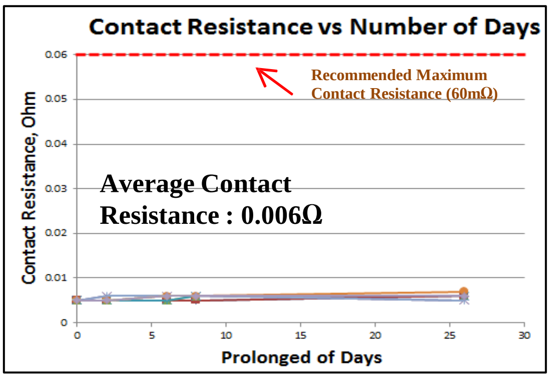
FFC 1.0 mm Pitch FFC



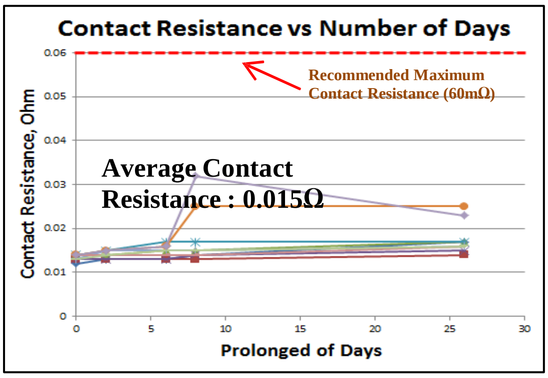
FFC 0.5mm Pitch FFC

Figure 10 Contact Resistance VS. Prolonged of Days, for 0.5/1.0 mm pitch Tin-plated FFC
(Vibration Frequency: 500, Acceleration: 20g; Constant voltage follow at 0.005A, 1kΩ; Connector(gold-plated) with FFC(0.5/1mm, tin-plated); Temperature 24C, Humidity 60%)

Figure 11 shows the result for fretting at position Y with galvanic corrosion. There is no significant increase in contact resistance and the measured values fall within the Manufacturer's specification of 60mΩ. Similar readings were also obtained from Z vibration direction.



FFC 1.0 mm Pitch FFC



FFC 0.5mm Pitch FFC

Figure 11 Contact Resistance VS. Prolonged of Days, for 0.5/1.0 mm pitch Tin-plated FFC
(Vibration Frequency: 500, Acceleration: 20g; Constant voltage follow at 0.005A, 1kΩ; Connector(gold-plated) with FFC(0.5/1mm, tin-plated); Temperature 24C, Humidity 60%)

IV. CONCLUSION

To ensure the electronic cable interconnect to have sufficient **wear resistance** within an acceptable range of contact resistance, application designer needs to consider the effect of galvanic and fretting[6] corrosions on **contact stability and reliability** under various operating environments. Galvanic corrosion resulting from the use of bimetal contact materials may potentially increase contact resistance when present in electrolyte medium. Little has been found in the literature on galvanic corrosion for the electronic interconnect application. This paper presents quantitative and qualitative findings on galvanic corrosion for bimetal Au-Sn contacts and provides substantive evidence to suggest that:

1. The mated V-Flex® Tin-Plated FFC with Gold-Plated Connector demonstrates negligible change in contact resistance when subject to accelerated vibration and thermal shock tests. The change in contact resistance was measured to fall within maximum contact resistance value of 60mΩ recommended by leading manufactures specification as accepted industry practice (JIS C60068, EIA 364).
2. Contact force and sharp-edge chamfered tip contact were found to be major characteristics responsible for stable contact performance, achieving low contact resistance and prevent galvanic corrosion.
3. The ZIF type gold-plated connector pairing with V-Flex® Tin-Plated FFC demonstrated no evidence of galvanic corrosion despite subject to prolong period of over 1,000 hours of tests.
4. Subsequent study of accelerated test would present the effect of high humidity and Salt Spray (ASTM B 117) on the extent of galvanic corrosion[8]. External independent 3rd party test for Mixed Flowing Gas Corrosion Testing (IEC-60098-2-60) on mated FFC and Connector contacts is presented.

The interconnect components used in the consumer electronic applications utilizing flexible flat cable mated with connector do not present in electrolyte medium andsubmersed acidic solutions. The risk of galvanic corrosion is greatly reduced. Based on present evidences tests, mated V-Flex® Tin-Plated FFC with Gold-Plated Connector is found no evidence of galvanic corrosion and tolerable for used consumer electronic applications.

REFERENCES

[1] “Bimetallic Corrosion”, National Corrosion Service, National Physical Laboratory, UK.

[2] A. de Rooij, “Bimetallic Compatible Couples”, ESA Journal 1989, Vol.13

[3] T. Charng, F. Lansing, “Review of Corrosion Causes and Corrosion Control In a Technical Facility, DSN Engineering Section, TDA Progress Report, March and April 1982.

[4] “Commentary on Corrosion at Bimetallic Contacts and its Alleviation”, PD 6484: 1979.

[5] ASTM B 117, Salt Spray (Fog) Test Standard.

[6] Technical Report, “Effect of Fretting Corrosion on Au-Sn Plated Contact in Electronic Cable Interconnect”, JSB TECH Pte Ltd: 2011.

[7] Technical Report, “Salt Spray Accelerated Test for Galvanic Corrosion on Au-Sn Plated Contact in Electronic Cable Interconnect”, JSB TECH Pte Ltd: 2013.