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Perspectives on the climatic reliability issues of electronic devices

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This paper provides a short overview of the climatic reliability issues of electronic devices and components with a focus on the metals/alloys usage on PCBA surface together with cleanliness issues, humidity interaction on PCBA surface, and PCBA design and device design aspects.

The miniaturization of electronic systems and the explosive increase in their usage has increased the climatic reliability issues of electronics devices and components especially having metal/alloys parts exposed on the Printed Circuit Board Assembly (PCBA) surface or embedded within the multi-layer laminate. Problems are compounded by the fact that these systems are built by multi-material combinations and additional accelerating factors such as corrosion causing process related residues, bias voltage, and unpredictable user environment. Demand for miniaturised device has resulted in higher density packing with reduction in component size and closer spacing thereby increasing the electric field, while thinner metallic parts needs only nano-grams levels of metal loss for causing corrosion failures.

During the past couple of decades, use of electronic devices has increased in gigantic proportions. Mobile phones are obvious examples of how devices integrate more and more complex functions, such as camera, GPS and several wireless communication technologies. The integrated device is expected to be cheap, while the applications necessitate it to be robust, durable, and reliable at all environmental conditions including severe conditions to which the user can expose them. Industrial electronics is another sector where the electronic controls and other devices are used irrespective of the type of industries and environmental conditions. Vast majority of these electronics systems are not produced with serious consideration on the climatic reliability aspects. The climatic reliability issues of electronics leading to the corrosion can introduce intermittent malfunctions and permanent failures, which cause severe economic loss.

Corrosion issues on a PCBA surface under humid conditions can be summarized as shown in Figure 1. Three factors inherent on a PCBA surface, which are the essential ingredients to cause corrosion, are: (i) presence of metals/alloys, (ii) potential bias/electric field, and (iii) the humidity levels determining the thickness of the water layer.

However, pure water layer on a clean PCBA surface only has limited conductivity to introduce any significant leak current or corrosion effects. However, PCBA surface is seldom clean due to the process related residues [1-11] (as shown in Figure 1), which dissolves into the water layer. Water layer with dissolved ionic residues are more conducting, which cause first level corrosion effect such as the increased levels of leak current causing functionality problems.

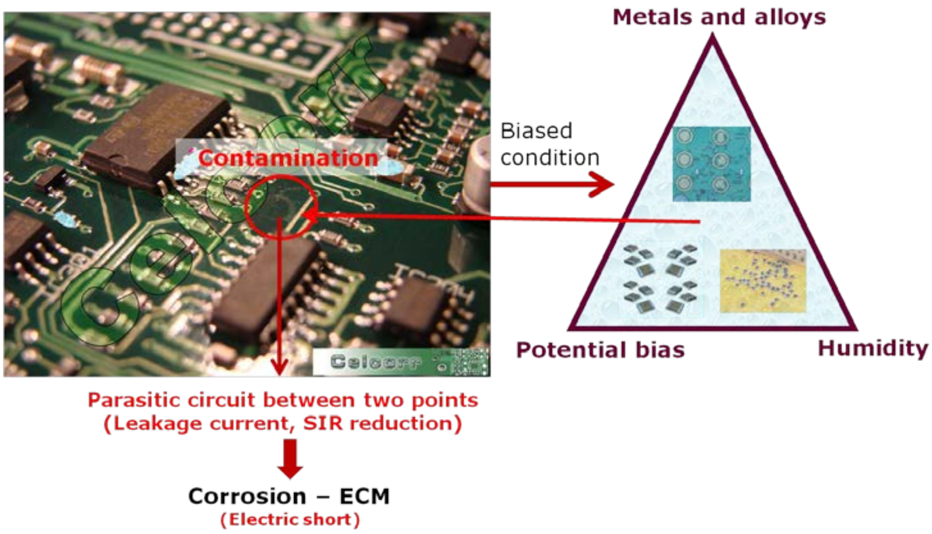

Figure 1: Schematic showing various factors on a PCBA surface causing leak current followed by corrosion such as ECM.

One of the predominant factors for accelerated corrosion in electronics is the intrinsic contamination on Printed Circuit Board Assemblies (PCBAs) originating from the soldering process used for component mounting. However, the amount, distribution, and morphology of flux residue varies considerably with specific soldering process and parameters, and temperature profile during the soldering process, while most important factors are the flux chemistry and its decomposition characteristics. The no-clean flux chemistry and residue left on the PCBA is not benign from the climatic reliability point of view. Active parts of the flux residue can cause increased water absorption due to their hygroscopic nature and in solution they will increase leakage current and corrosion such as electrochemical migration resulting in intermittent or permanent failures. Overall a number of factors can influence the corrosion reliability of electronics devices as shown in Figure 2, although the influence of some factors such as process residues, humidity, potential bias, design of devices etc. dominates.

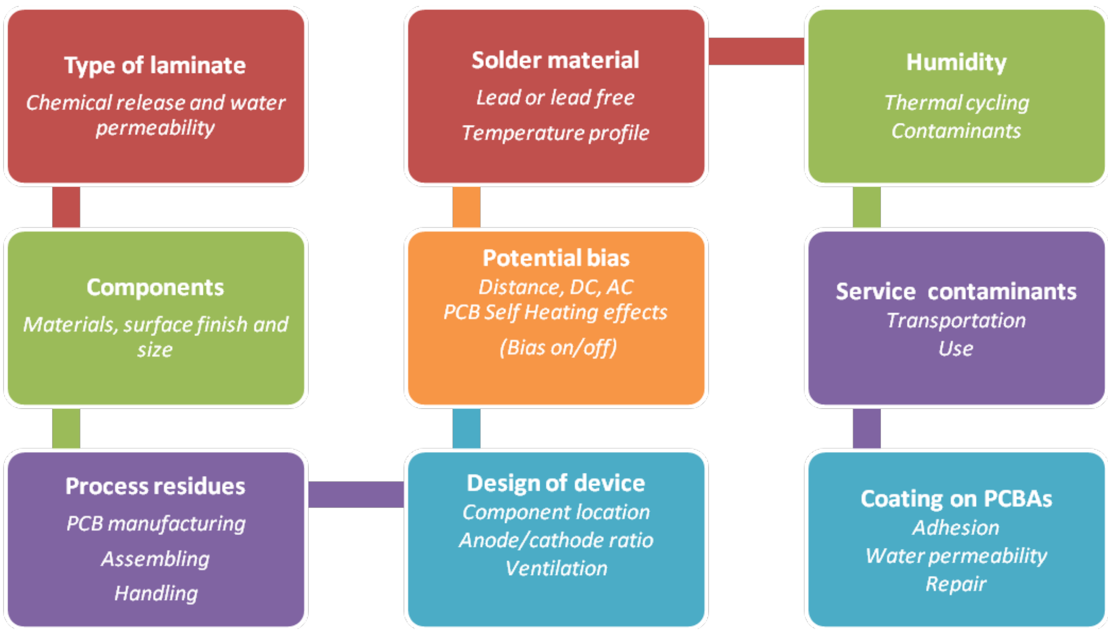

Figure 2. Overview of reliability threats in the life time of an electronic product.

Another important factor is the device design. Proper design of enclosure and other humidity control measures could reduce the humidity build up inside the device especially under device off conditions. Most moisture related failures are driven due to water layer formation on critical surfaces and interfaces together with entry of hygroscopic contamination from the atmosphere [14-20], which reduces the critical relative humidity/surface energy levels for water layer formation [14-20]. However, typically no reasons for failure will be found due to the disappearance of water traces while the device is subjected for failure analysis, which are frequently missing from the field failure data bases [13,19]. Therefore a good enclosure design and additional high efficiency, low energy spending humidity control mechanisms (e.g. controlled heating during off time) are an integral aspect of damage control to avoid entry of hydroscopic contaminations and humidity causing catastrophic or intermittent failures [1-12]. Further, any energy spending solutions such as off time heating of the enclosure should be optimized to avoid high energy use.

Improving climatic reliability: Some aspects to care

Material and component choice

Some thoughts to materials choice (if possible) is an important issue in controlling the corrosion reliability. This is due to the fact that the different metals/alloys have different reactivity towards environmental conditions as well as the possibility of coupling if they are put together such as in multi-layer coatings. A number of cases, the material use in PCBA applications can be viewed with a focus on corrosion reliability, however it is beyond the scope of this paper. Therefore few examples are provided below to show the importance of material choice.

It is important to know the user environment in critical cases before selection of PCB surface finish for example. In a sulphur containing environment such as in pig farm, a silver finish PCBA can easily fail due to the higher sensitivity of silver towards sulphur. Ozone containing environment is also not good for the silver. Although high levels of ozone is not found in the atmosphere, its level can be easily increased in a closed electronic box due to the switching devices generating electric sparks, which could convert atmospheric oxygen to ozone.

Another aspect related to the material choice is the multi-layer coatings used for contact and connectors. Typical example is ENIG with 50-100 nm layer of gold, which is insufficient to avoid porosity and exposure of underlying nickel to cause galvanic corrosion. Therefore when the connectors are made with a top noble layer such as gold, it is important to optimize the gold thickness for better performance. Similarly if new coating combinations are selected, it is important to know the relative electrochemical potential difference between them defining the galvanic coupling possibility.

There are other adverse material combinations in electronic applications such as Al-Au, Cu-Al etc., which can also form galvanic coupling. Typical example is the bond pad corrosion between Al-Au, sometime also in connection with release of species such as iodine from associated polymer products.

Good component selection is also imperative for good corrosion reliability. Typical example is the corrosion of chip resistors reported under sulphur conditions due to the non-coverage of the silver underlayer by the glass passivation layer. A number of other examples also could be found in the literature.

PCBA design

Today PCBA design is based more on other reliability aspects such as mechanical, electrical, and electronics, and it is clear that it is not easy to change many of these design aspects, however consideration of corrosion issues during the PCBA design sometimes can lead to simple changes that could enhance the corrosion reliability. Some level of predictability on the susceptibility of the PCBA design to corrosion is possible by simulating the drift in component properties by knowing the leak current/SIR levels.

Important aspects which could be considered during PCBA design for improved corrosion reliability are:

1. Avoid short distances where it is not necessary.
3. Variation of thermal mass of the PCBA surface due to variation in the distribution of copper can introduce temperature variation on the PCBA surface during soldering resulting in increased flux residues at low temperature area.
4. PCBAs get heated up during working and therefore drive away humidity. PCBA designs with uniform temperature distribution perform better than designs showing hot and cold areas.
5. Knowledge on local flux contamination in critical areas in connection with design is more important than the overall flux residue content as leak current and corrosion effects are highly localized.
6. Know your laminate and plastics before use. Glass epoxy laminate structure is important in driving water inside of the laminate, while type of fire retardant used is important in connection with application.

Cleanliness of PCBA

While it is important to start with a clean PCB for mounting, selection of flux system is important in achieving higher corrosion reliability. Although other considerations are needed for flux selection such as wettability and solder joint integrity, following are the factors if possible could take care from the corrosion point of view:

1. Halide flux residues in general are more aggressive towards leak current and corrosion due to the strong ionic nature.
2. Acid content and acid type of the flux is important as it could influence the hygroscopicity, leak current, and the corrosion effects.
3. Localized content of flux residue is more important than the overall residue content. Fast and reliable techniques are available for the localized testing of critical areas for residue levels in additions to the IPC-TM-650 2.3.25 ROSE test.
4. It is also important to know the distribution of ions in residues at least to the level of whether it is weak or strong ions as the behaviour towards them to the leak current and corrosion is different.

Use of conformal coating

Conformal coating can be used as protective layer against corrosion on the PCBAs. Number conformal coatings types are available for example acrylic, silicone, polyurethane, epoxy etc. However, irrespective of the coating, it is difficult achieve a uniform defect free coating on the PCBA surface due to the inhomogenity of the surface.

Therefore presence of any localized contamination on the board prior to coating can have an adverse effect on adhesion under the humid conditions. Presence of flux residue at the coating – PCBA interface cause corrosion failures within a short time interval compared to a clean surface. Corrosion is more severe in this case than without coating due to the localized chemistry of the solution generated underneath of the coating. It is very important therefore to achieve more cleanliness levels before introducing the conformal coatings.

Enclosure and device design

Proper enclosure design is an important aspect in reducing the effect humidity on electronic devices. Figure 3 shows some of the design strategies to reduce water induced corrosion. Careful design of enclosure to avoid entry of contamination from outside and regulating humidity inside is most important as even a highly reliable PCBA will not survive under severe condensing conditions.

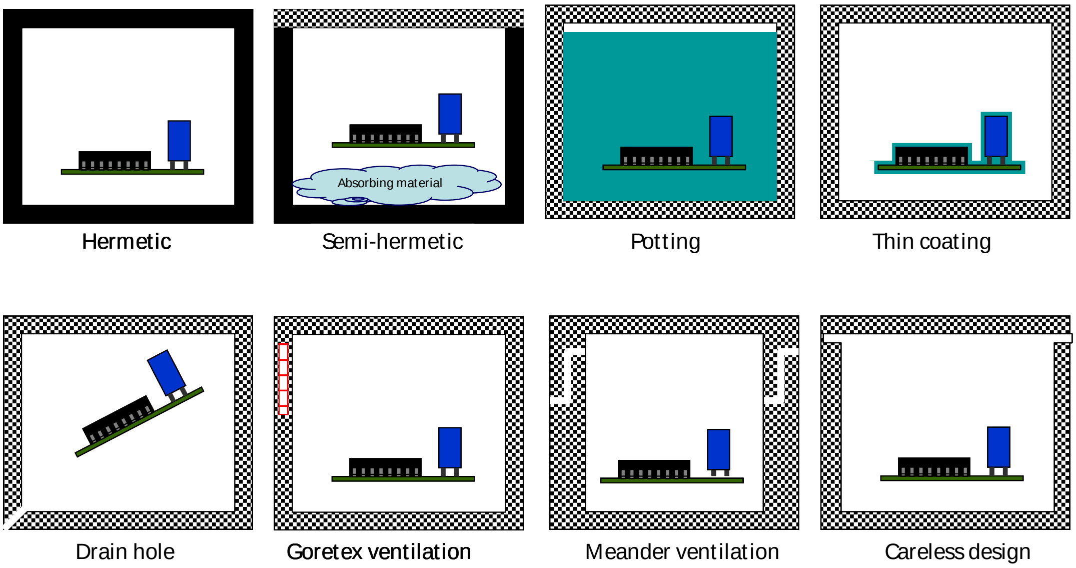

Figure 3. Some simple design strategies to avoid water induced corrosion [21]

Centre for electronic corrosion (www.celcorr.com) at Department of Mechanical Engineering, Technical University of Denmark has extensive research and development activities in the area of climatic reliability of electronics. Various activities at the centre are in close collaboration with Industries internationally including the activities within the CreCon industrial consortium. Following list provides a glimpse of some of major activities at the centre:

- PCBA materials and component issues in relation to climatic reliability
- PCBA cleanliness aspects and ways to reduce contamination
- Proper flux selection and optimized process control for better reliability
- PCBA design aspects for improving climatic reliability
- Various corrosion failure mechanisms due to humidity and corrosive gases
- Conformal coating of PCBAs and related issues
- Predicting possible climatic reliability issues at PCBA design stage
- Device design, enclosure design, and local climatic control
- Failure analysis and advice for climatic reliability
- Education services in climatic reliability of electronics

References

1. D. Minzari, PhD Thesis, Technical University of Denmark, 2010.
2. M. Yunovich, Appendix Z – Electronics, pp. Z1-Z7, www.corrosioncost.com/pdf/electronics.pdf
3. H. Risto et al., "Corrosion and climatic effects in electronics", Published by VTT Automation, Finland, 2000.
4. G. Di Giacomo, "Reliability of electronic packages and semiconductor devices", McGarw-Hill, USA, 1996.
5. M.S. Jellesen, P. Westermann, D. Minzari, P. Møller, and R. Ambat, "Corrosion in electronics, Corrosion Management", Sept/Oct (2008) p. 17.
6. Conseil, H.; Jellesen, M.S.; Verdingovas, V.; Ambat, R., Proceedings of EU-ROCORR 2013, 2013.
7. Verdingovas, V.; Jellesen, M.S.; Ambat, R., *Corrosion Engineering, Science and Technology*, **2013**, *48*, 6, p. 426-435
8. Verdingovas, V.; Jellesen, M.S.; Ambat, R., *Proceedings of EUROCORR 2012*.
9. D. Minzari, M.S. Jellesen, P. Møller, R. Ambat, "On the mechanism of electro-chemical migration of tin", Corrosion Science, 53 (2011) p. 3366.
10. M.S. Jellesen, D. Minzari, U. Rathinavelu, P. Møller, and R. Ambat, "Investigation of electronic corrosion at devices level", ECS Transactions, 25 (2010) p.1-14.
11. M.S. Jellesen, D. Minzari, U. Rathinavelu, P. Møller, and R. Ambat, "Solder flux residue induced corrosion failure of an electronic add-on device", Engineering Failure Analysis, 17 (2010) 1263.
12. H.C. Ling and A.M. Jackson, "Correlation of silver migration with temperature-humidity-bias (THB) failures in multilayer ceramic capacitors, IEEE Trans. On components, hybrids, and manuf. Techn., 12 (1980) p.130.
13. L. Yang and J. B. Bernstein, "Failure rate estimation of known failures mecha-nisms of electronic packages", Microelectronics Reliability, 49 (2009) p. 1563.
14. Luo and C.P. Wong, "Fundamental study on moisture absorption in epoxy for electronic application", Proc. Of 2001 International Symposium on Advanced Packaging Materials, P. 293.
15. H. Qi, S. Ganesan, M. Pecht, "No-fault-found and intermittent failures in electron-ics products", Microelectronics Reliability, 48 (2008) p. 663S.
16. M. Meinhardt, V. Leonavicius, J. Flannery, S.C. OA Mathuna, "Impact of power electronics packaging on the reliability of grid connected photovoltaic converters for outdoor", Microelectronics Reliability, 39 (1999) p. 1461.
17. J.D. Sinclair, L.A. Psota-kelty, G. Peins, "Indoor/Outdoor relationships of airborne ionic substances: comparison of electronic equipment room and factory environ-ments", Atmos. Environ., 26A (1992) p.871.
18. M. Tencer, "Deposition of aerosol ("hydroscopic dust") on electronics – mecha-nism and risk", Microelectronics Reliability, 48 (2008) p. 584.
19. M. Tencer and J.S. Moss, "Humidity management of outdoor electronic equip-ment: Methods, pitfalls, and Recommendations", IEEE Transactions of compo-nents and packaging technologies, 25 (2002) p. 66.
20. H. Gil, J.A. Calderon, C.P. Buitrago, A. Echavarria, F. Echverria, "Indoor atmos-pheric corrosion of electronic materials in tropical-mountain environments", Corro-sion Science, 52 (2010) p. 327.
21. Poster on enclosure design, Grundfos, Denmark, 2011.

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