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Case Study

Quality issues in hybrid microcircuits – A case study

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ABSTRACT
Indigenization of electronic components is on high thrust as per the Make In India policy. In this paper, a case study on the failure observed in an indigenously fabricated Hybrid microcircuit is presented. On the first powering of the indigenously fabricated device, the power supply fold back acted indicating short mode failure of the device. Failure Analysis of the device was carried out as per MIL STD-883 Method 5003 to identify the root cause of the failure. External examination, leak tests, and Electrical verification were carried out as part of the failure analysis. On de-capping and internal inspection, burnout was observed inside the device packaging. Further, the device was subjected to analysis through Analytical techniques: Scanning Electron Microscopy- Energy Dispersive Spectroscopy (SEM-EDS) and Raman spectroscopy. The results indicated dendrite growth inside device packaging, occurred due to Electrochemical Migration (ECM). ECM is one of the failure mechanisms seen in electronic devices. This failure mechanism is seen in non-hermetic packages and affects the quality of the device. Being an indigenously fabricated device, it is possible to have full control over the fabrication and certification of devices. Improvements suggested based on experiences will allow manufacturers to deliver quality devices.

1. Introduction

The quality of Avionics components used in Aerospace applications cannot be compromised for its targeted reliability. Aerospace Avionics components are selected based on certain criteria viz, Military class devices, reputed manufacturer, low failure rate, good usage history, etc. However, the non-availability of Military class components and the fast obsolescence of Non-Military components is of major concern.

Non-military components are procured from reputed manufacturers and the devices are subjected to in-house qualification tests to ensure their adherence to required quality levels as per military standards. However, the quick obsolescence of these devices is a major issue the Aerospace agencies face.

Indigenization is considered as the solution to all these issues. With the indigenization of Avionics components, the user can have better control on the component's quality and its obsolescence. Additional requirements to meet the Aerospace quality level in the fabrication phase can also be met with proper inspection methods and tests introduced in the manufacturing flow.

The paper presents a case study on the failure observed in one of the indigenous devices, failure analysis and suggestions to improve the quality of the device. The failure observed in the device is reported in section II, section III mentions the failure analysis carried out to identify the root cause of the failure. Suggestions for improvement in the quality of the device are discussed in section 4.

2. Observed failure

On the first powering of the indigenously fabricated MMIC power amplifier, the power supply fold back acted indicating short mode failure of the device. The failure was observed after reflow soldering on the printed circuit board (PCB). The device had successfully undergone screening tests including a burn-in test as per Military Standards before wiring. This ensures that the device was not dead on arrival and there were no die defects as it underwent a burn-in test successfully.

3. Failure analysis

Failure Analysis of the device is carried out as per MIL STD-883 Method 5003. Failure analysis is a post-mortem examination of failed devices employing, as required, electrical measurements and many of the advanced analytical techniques of physics, metallurgy, and chemistry to verify the reported failure and identify the mode or mechanism of failure as applicable. [1]

An external examination of the failed sample was carried out. This includes an optical examination at magnification to inspect the condition of the leads, plating, soldered, or welded regions, condition of external package material, seals, marking, etc. No anomaly was observed in the external examination.

External examination was followed by electrical verification procedures to confirm the failure. This includes the measurement of all electrical parameters in the applicable acquisition document. When electrically tested it was found that the device failed catastrophically with power supply shorted.

Further, the device failed in the leak test indicating poor hermiticity. The device was de-lidded and optically inspected under magnification for internal visual examination. Contamination and burnout were observed inside the device packaging as given below [2] (Figure 1).

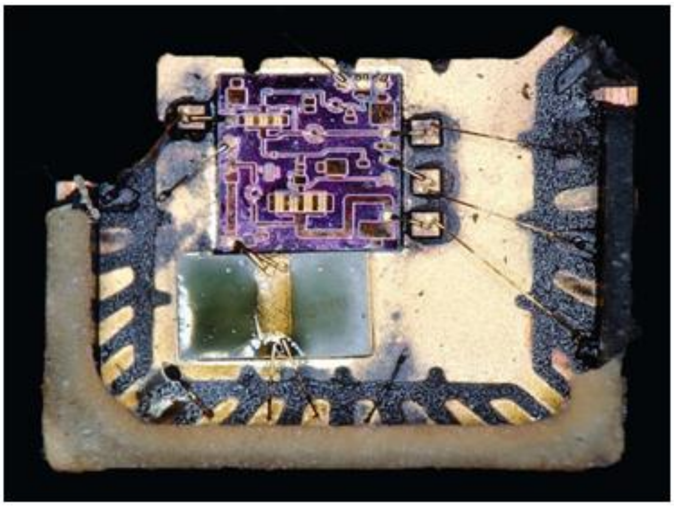

Figure 1: Failed device.

A fresh good device was de-lidded for reference and optically inspected under magnification. No such signature was observed as seen in the failed device (Figure 2).

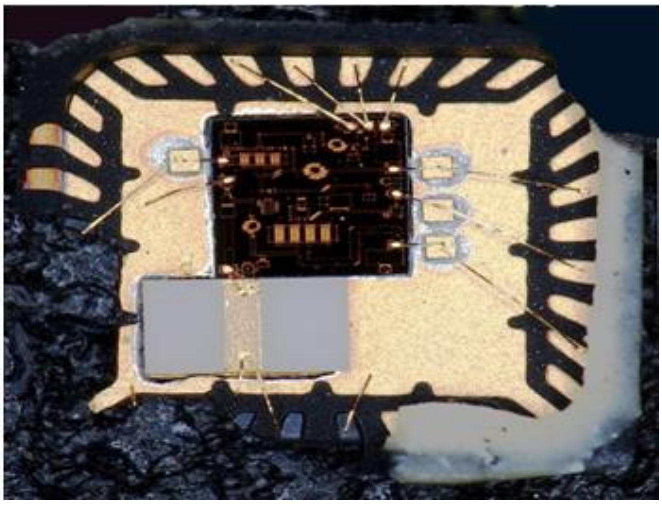

Figure 2: Reference device.

It was evident from the above figures that there was contamination for the failed device which had resulted in the failure. Also, the hermeticity of the device was poor as it failed in both fine leak and gross leak tests as per MIL STD 883 [1].

These devices were subjected to analysis through Analytical techniques: Scanning Electron Microscopy- Energy Dispersive Spectroscopy (SEM-EDS) and Raman spectroscopy [3].

Morphological analysis of the failed device revealed the presence of dendrites-like growth between the circuit components and EDS analysis confirmed the presence of copper in these dendrites-like structures (Figure 3). In addition to that carbon was observed throughout the interfaces of the circuit components in the failed device. However, the reference device was lacking any of such features (Figure 4).

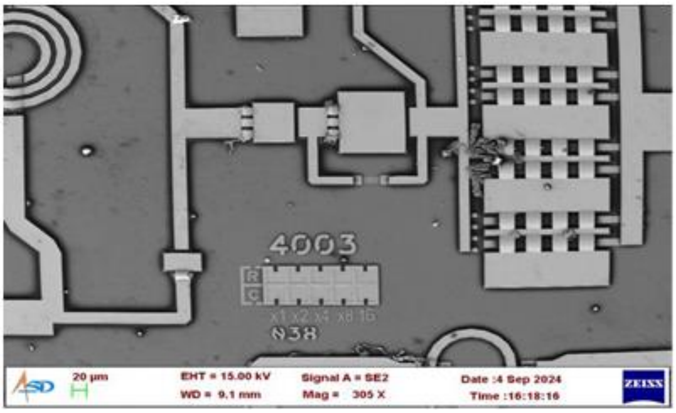

Figure 3: SEM image of Failed device.

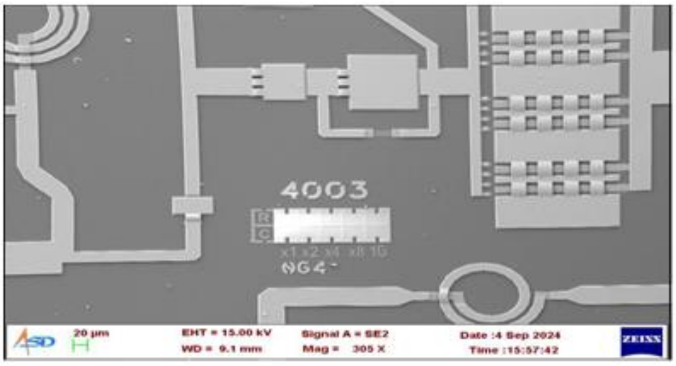

Figure 4: SEM image of Reference device.

SEM images indicate undesired dendrite growth and carbon deposits between the circuit components [3] (Figure 5).

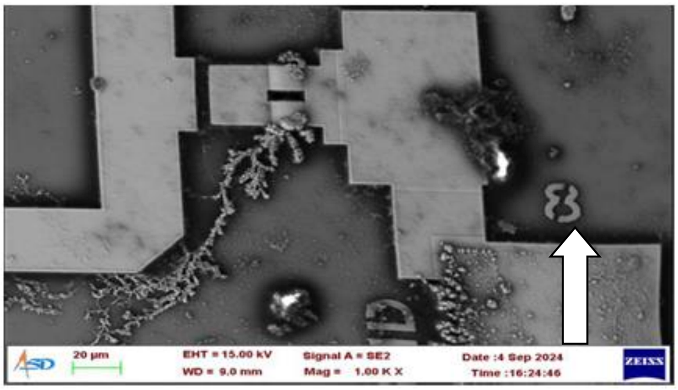

Figure 5: Dendrites and carbon deposits.

Dendrite growth is the result of electrochemical migration (ECM) processes. ECM occurs when moisture adheres between electrodes made of materials such as copper, solder or silver. When the bias voltage is applied, metal from the anode gets ionized and moves towards the cathode. Metal ions are formed by ionic dissolution of the anode [4].

$$\mathrm{Me} \rightarrow \mathrm{Me}^{n+} + \mathrm{n.e}^{-}$$

and are deposited at the cathode

$$\mathrm{Me}^{n+} + \mathrm{n.e}^{-} \rightarrow \mathrm{Me}$$

forming dendrites or dendrite-like filaments (Figure 6).

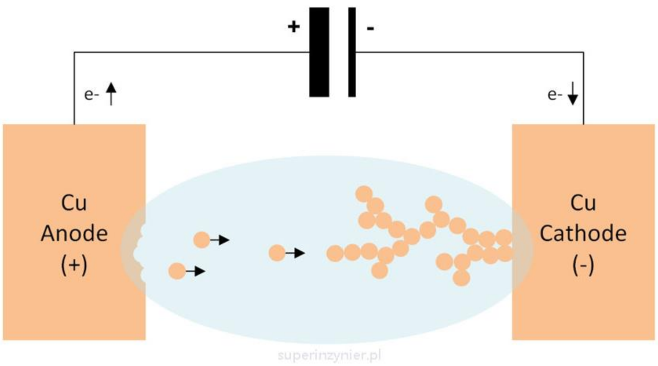

Figure 6: ECM process.

Major factors causing dendrite growth are:

- Metals used in fabrication;
- Contaminants like flux residues;
- Electric field parameters like potential difference and electrodes spacing;
- Environmental factors like humidity.

ECM occurs with the application of electrical potential between metal tracks in the presence of metal ions. Sources of ions are flux residues, salt, non-distilled water or sweat from fingerprints [4]. These contaminants can enter into the device during Printed circuit board wiring process, where the device is subjected to chemical exposure as part of cleaning and reflow soldering. Unqualified sealing process can cause presence of moisture inside the device packaging leading to metal ion formation.

During the formation of dendrite, the surface resistance between the anode and the cathode decreases. Eventually, the dendrite will electrically connect the two electrodes i.e., metal tracks and short them. Here the metal that migrated between tracks is Copper, whose source is identified in the lead frame which is part of device packaging.

Elemental mapping also shows copper and carbon distribution between inter digitated circuits (Figure 7).

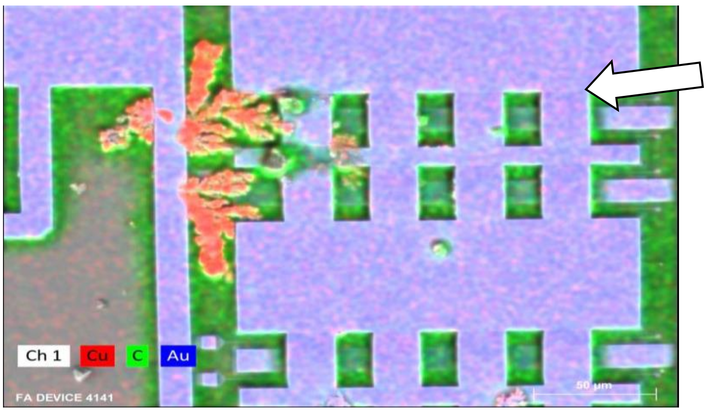

Figure 7: Elemental Analysis indicating Cu growth between metal tracks.

Carbon species observed on the failed device were further analyzed by Raman spectroscopy and characteristic spectral features of ordered carbon (due to high-temperature burning) were obtained (Figure 8).

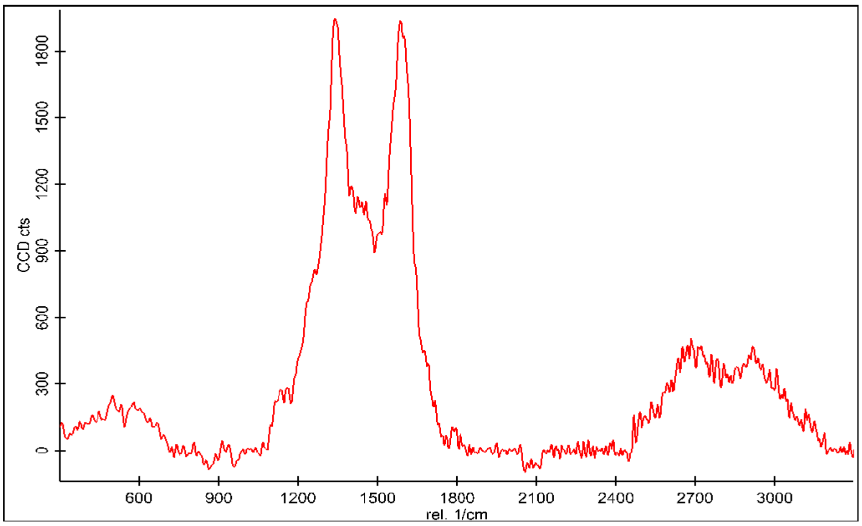

Figure 8: Raman spectrum from the failed device showing characteristic carbon peaks.

All the above analyses indicate that the device was contaminated, which caused ECM resulting in Cu dendrite growth between metal tracks with the application of electrical power. The low resistance path between the tracks resulted in device short mode failure, burning, and carbon deposition.

4. Suggestions

Hermeticity is one of the required qualities for a device to meet the reliability of the system in which it is used. Seeping of contaminants due to poor hermeticity is a major concern.

To avoid the failure under study:

1. Improvements can be made in the fabrication process by adopting better device packaging procedures as those used for military class devices.
2. Ceramic casing with laser welding shall be adopted to ensure hermeticity.
3. A Nitrogen (inert) atmospheric pre-seal bake followed by Nitrogen atmosphere lid seal will avoid moisture entrapment in device packaging.[8]
4. Biased HAST (BHAST) can be part of the qualification for evaluating the reliability of non-hermetic packaged devices in humid environments. When devices are subjected to HAST, moisture penetrates the packaging and when voltage bias is applied, metal from the anode is ionized and

moves towards the cathode resulting in dendrite growth. [4-7]
5. 100 % Pre-Cap inspection on all devices fabricated to bring out deviations in the material used, fabrication, and construction [1].

5. Conclusions

The existence of a failure mechanism has a tremendous impact on product reliability, process control, and reliability prediction of the system.

Through the Indigenization of electronic components, it is possible to have full control over the fabrication and certification of devices. The cause of failure studied is due to poor packaging quality of the device leading to ionic contamination and ECM.

Steps have to be adopted to improve the quality of the device during the fabrication phase. Procedures as per MIL standards are to be followed to detect defects at an early stage. Screening and qualification tests have to be devised to bring out inherent failures and weed out weak parts before inducting into the system.

Authors' contributions

The author read and approved the final manuscript.

Conflicts of interest

The author declares no conflict of interest.

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Data availability

No new data were created.

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