Failure Analysis of Substrate of Carrier Plate of Electromechanical Package for Space Payloads

Dhaval A. Vartak
Mtech CAD/CAM (IVth Sem),
Indus University,
Ahmedabad, India.

Prof. VK Manglik
HOD Automobile Engineering
Indus University,
Ahmedabad, India.

***Abstract* - Electromechanical packages are used for electrical interfaces between the components in the spacecraft system. These are designed to operate over the wide range of microwave frequencies and also with stand the stringent space and launch environment. The purpose of such a microwave package is to integrate all the components of a sub-system in such a way to minimize the size & mass and ease in accessibility of all component during testing . It provides electrical interfaces between the components in the spacecraft system and has to ensure high reliability. A typical package consists of alumina substrate mounted carrier plates, stepped cover, electronic devices which are mounted on substrates as well on base surface. Carrier plate is used as metallic carrier to support to alumina substrate on which microwave circuit is etched . Alumina substrate is of 25mil-0.635 mm thick, fragile material which is bonded by preform to carrier plate. Stress developed at various stages like manufacturing, assembly, testing (due to static, dynamic & thermal loading) in carrier plate results in cracking of alumina substrate in some cases. It may ultimately fails the electromechanical package and that may lead to failure of payload and even mission may be effected. Efforts are made in the paper to analyze various stages & causes of failures of substrate which are mounted on the carrier plate.**

Keywords – Electromechanical packages, kovar carrier plate, Alumina Substrate, perform, failure, causes

I. INTRODUCTION

Housing of microwave electronic components is carried out in well designed enclosure which is known as electromechanical packages. These packages (Fig 1) are designed to operate over wide band of microwave frequencies and with stand stringent space & launch environments. The package includes a substrate mounted carrier plate, stepped cover, electronic devices which are also mounted on alumina substrates of 25 mil - 0.635 mm thick. These substrates are made of alumina and mounted on carrier plate which is made of kovar material. The linear co-efficient of thermal expansion. of kovar material and alumina substrate matches well.

The purpose of a microwave package is to integrate all the components of a sub-system in such a way to minimize size, mass & complexity, ease in accessibility and withstand the space and launch environments. It should also provide electrical interfaces between the components of the spacecraft system and ensure high reliability.

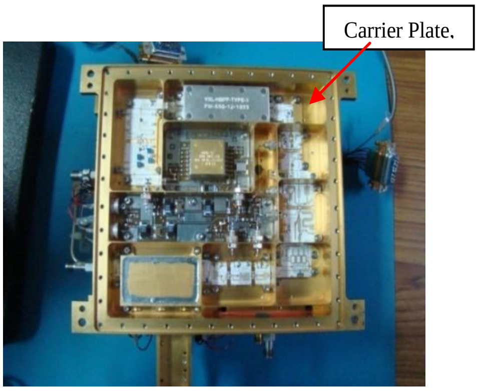

Fig:1 Electromechanical Package with Carrier Plate

Electromechanical packages are designed to house microwave integrated circuits(MIC) and printed circuit boards (PCB) with interface components in the separate compartment having partition wall in one unit. MIC is etched on the alumina substrate which is soldered with carrier plate to house them in one compartment. The substrate may also have electronic component and electrically connected to RF connectors, feed through to provide electrical input and output. The compartment has stepped cover to avoid RF leakage. Details of these mountings are shown in the fig.1.

Carrier plates are used in different sizes & shapes so that MIC substrate are properly soldered on them. The Carrier plates are firmly secured with the enclosure on their extension which is known as mounting lugs. Carrier plates are made of kovar material with high cobalt & nickel content to have low coefficient of linear thermal extension. Different sizes and various topology of carrier plates are used for electromechanical package as shown in "Fig 2". Thickness of this carrier plate is 0.8 mm at functional area (alumina substrate mounting area) and mounting lugs have thickness of 1.5 mm.

Kovar material is poor in corrosion resistance and therefore gold plated in the range of 4 to 6 micron. Gold provides an excellent corrosion resistance due to noble in nature, good electrical conductivity and good solder ability for attaching gold plated alumina substrate.

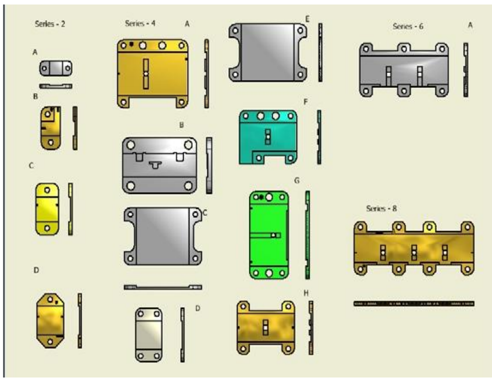

Fig. 2 Different types Carrier plates

Alumina (Al_2O_3) is an extremely brittle ceramic having hexagonal close packed crystal structure [1]. The dislocations are immobile, grain boundary sliding does not occur, and the material exhibits an isotropic behavior. Substrate made of Aluminum oxide (Al_2O_3) is having more than 99.6 % purity. It is available from the size of 6.35 x 6.35 mm to 76.2 x 76.2 mm with 0.635 mm thickness and shown in "Fig 3".

Alumina is electrical insulator & having good thermal conductivity and therefore used for high power, high frequency RF circuit. Microwave components such as capacitor, resistor are formed by etching and other substrate mounted component s are used in microwave frequency range of the order of 10 Ghz. Alumina have wide variety of applications in thin film and thick film technology.

Fig : 3 Various Carrier Plates, Alumina Substrate, Carrier Plate Assembly

TABLE 1
Material List for Electromechanical Packages

Material	***Composition (%)***	***Density ρ (gm/cm³)***	***CTE × 10⁻⁶ α (m/m/K) (25⁰ to 150⁰C)***	***Poisson Ratio μ***	***Young's Modulus E (GPa)***
Aluminium	Alloy 6061 Al+0.6Mg+1Si	2.7	23.6		70
Kovar	Fe+28Ni+18Co	8.2	5.2	0.3	140
Alumina Substrate.	Al_2O_3	3.6	6.1	0.22	300
Preform	(Au-Sn) 80%-20%	1.5	16	0.405	68

The carrier plate assembly shown in "Fig 3" has alumina substrate having engraved MIC and bonded to Kovar carrier plate. Bonding is carried out by using Au-Sn (80%-20%) solder. Assemblies consisting of solder perform on the carrier plate and substrate kept on top is prepared. The assembly is heated to 280 deg. C which is melting temperature of the perform. Subsequently, it is slowly cooled to solidify perform and making a perfect joint [2] between substrate and carrier plate. The substrates have engraved microwave circuit to perform specific functions as required by payload.

It is found in some cases that component start malfunctioning which is very serious problem for satellite pay loads. Such failures may lead to the non functionality of subsystem and may jeopardize the mission. Failure analysis is therefore very important for such a carrier plate assembly to improve quality and reduce failures. An attempt is made to analyze various causes of substrate failure which could lead to mission failure in extreme case.

II. FAILURES DUE TO MECHANICAL STRESSES DEVELOPED ON THE CARRIER PLATE

These stresses are developed in kovar carrier plates during various stages of development and also during mountings. Variation in these stresses causes substrate to experience them and since substrate is made of highly fragile material it gets cracked.

A. Manufacturing Stage

- The carrier plates are normally mounted by the screws during machining operations. These operation causes surface stresses and also mounting stress on the carrier plate. The release of mounting screws causes the stresses embedded in the material also get released and cause deformation or undulation or warpage of the surface.
- These carrier plates and housing are fabricated by using milling operation on CNC machines or otherwise. In milling operation , the end-mill cutter used is not providing sharp corners. Hence one will not get a zero radii at corner due to process limitation. More over the cutter may worn out due to frequent use and produces larger radii, which creates mounting stresses in the assembly.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 3, March - 2014

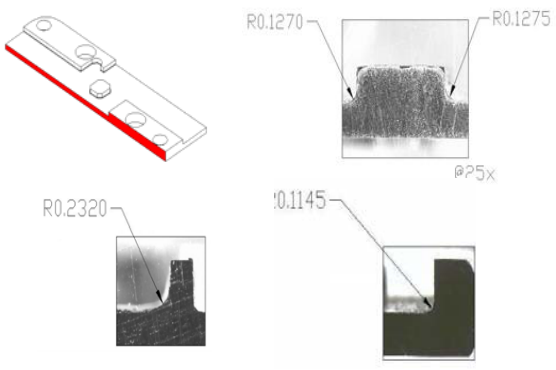

Fig 4. Sectioned Sample of CP (a) Image of CP @ 25X
(b) Image of CP @ 40X

Fig.4 shows the typical radius (in mm) at the corner of carrier plate. The image was taken by an optical microscope under 25X zoom. The typical radius at the corner is about 127 micron, which is more than 50 micron, the thickness of solder pre form. The variation in radius causes carrier plates to experience stresses during attachment. This will generate additional stress on bottom layer of MIC. The image under 40X zoom is shown.

- Kovar is hard material and machining is carried out in couples of steps. High pressure developed during machining of carrier plate produces hardening effect that retards further machining and causes distortion in thin sections. Internal stress in carrier plates can be developed after machining in some cases.
- Sometimes one may not achieve proper clearance due to variations in tolerance of bought out electronics components or dimensions of carrier plate. Surface finish on functional area is provided on box and carrier plate surface to avoid the stress generation. Geometrical tolerances are important factor for stress generation. Dimensional variation and geometrical tolerances on centre distance of mounting holes of CP and its diameter with ovality, cylindricity also create mismatch in assembly and that causes stress generation . A proper tolerance on CP dimensions give to maintain the proper gap and ease in assembly.

TABLE 2
Tolerances on carrier plate

Roughness	Flatness tolerance	Center hole tolerances	Defects-Pits, bumps, scratches, tool marks
1.6–8 micron - CP 8-25 micron -Box	50 microns	0.4 mm at hole center to center	Less than 100 microns (allowable)

- Due to fabrication constrains, the carrier plates are fabricated with 50 microns surface flatness. This gap will is bridged by applying a tightening torque which results into carrier plate deformation and hence the stress generation in the substrates.
- The mounting lug undulation may generate deformation in the carrier plate, which results in cracking of substrate. In addition, this results into improper RF grounding which leads to degradation of intended performance of the package. It also generates anomalies during thermal cycles due to differential thermal expansion of Aluminium package and Kovar carrier plate.

B. Substrate Attachment with carrier plate

The carrier plate is bonded to substrate by solder. A thin layers of pre form is formed between the carrier plate and substrate. The difference in the coefficient of thermal expansion (CTE) between Kovar and Alumina is not significant. However the coefficient of thermal expansion between preforms & substrate differs by more than 10 times and that results in thermo-mechanical strains on substrates and pre form. The strain gradient creates stresses on substrate.

Fig: 5 Substrate Attachment on Kovar Carrier plate

During handling & cleaning operation, there are chances (workmanship error) that minor scratch on substrate are developed. It may propagate cracks due to stress concentration over the period of time.

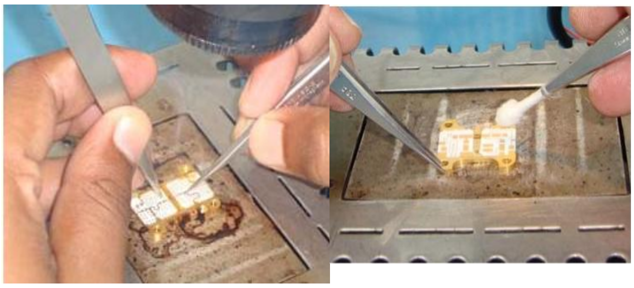

Fig : 6 Adjusting Substrate before bonding & Cleaning of CP after bonding
Assembly of Carrier plate with box

C. Assembly of Carrier plate with box

- Warpage or undulation developed in career plate during manufacturing as discussed in previous paras. Even though bottom surface flatness of carrier plate is within tolerance limit (less than 50 microns)[3] the stresses are generated at the lugs of carrier plate during the mounting with boxes. It is transferred from CP to substrate by virtue of integral nature of carrier plate and substrate and that also causes cracking of substrate. Crack can occur if the top surface of the substrate goes in tension. This tension can be due to distortion of the substrate while tightening it with the boxes.

- The situation can also arise due to either one or both of the mating surfaces (box and carrier plate) are not flat and result in loading the substrate surface. This loading can be tensile for some combinations of flatness.
- For electromechanical assemblies, critical requirement is to get 30 to 100 micron clearance between adjacent parts. If it is more than 100 micron it creates electrical problems, and if it is less than 30 microns, it may short during low temperature contraction. Sometimes one may not achieve proper clearance due to wider tolerance of bought out components or higher side dimensions of carrier plate.

Stresses on substrate is also transferred during mounting of carrier plate with the enclose. Though the mounting torque is well identified and all the care is taken during mounting still the rigidity of kovar carrier plates transfer the stresses on the substrates which is mounted on the carrier plate.

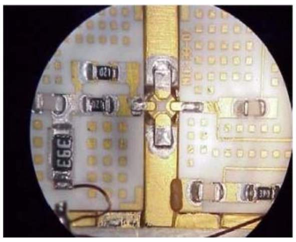

Fig 7. Clearance between Devices and Substrate

D. Testing of payload:

- Electromechanical boxes along with carrier plates undergo rigorous environmental tests to meet launch & space environmental . In thermal cycling testing electromechanical package are tested in the range of limit is -60 to +100 deg C. It gives thermal loading on the carrier plate assembly. Stresses produced due to difference in CTE between materials are added to stress developed during assembly of CP along with box also causes failures of the substrate.
- Electromechanical boxes are also tested under vibration loading which is of the order 20 g and the frequency range is 5 to 2000 Hz. Substrate mounted on carrier plate should withstand against that load without failure. All the package designed need to with stand loading at the resonance frequency of assembly & the loading on substrate may increase beyond acceptance limit.
- Alumina substrate is cut by laser machining and the edge of surface depends on accuracy/sharpness of laser beam. Alumina substrate is subjected to tensile stress; it fails at the boundaries because of its weaker atomic bonding.

The stress increases with temperature in thermal cycling from the fact that the surface energy increases with temperature. The cracks observe in alumina substrate has been examined under optical microscope to locate the precise point of fracture initiation, which turned out to be surface cracks resulting from localized stress concentration. Cracks in attached substrate were sharp. partly trans-crystalline and partly inter crystalline fracture was observed.

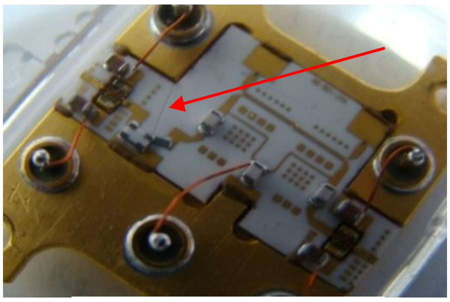

Fig 8 Crack on Substrate

CONCLUSIONS

The strain transfer to substrate may develop a hairline crack in MIC which will result in a failure of performance of the circuit. One of the important cause of such a strain transfer is due to the warpage developed in carrier plate. Since substrate is made of a very fragile material even the stress relieving in the carrier plate could lead to crack development in the substrate which will lead to failure of assembly. Development of Warpage in the career plates are due to machining operation of hard material like invar, stress relieving of mounting during fabrication and also tolerance mismatching during assembly of the system.

Sustained stress developed in carrier plate may cause development of Creep in career plates. It will also get transferred to substrate which will also be a cause of its failure.

Thermal stress also gets developed in the substrate due to mismatch of coefficient of thermal expansion between substrate and perform made of solder. It provide significant amount of stresses on substrate particularly during thermal cycling testing of pay load.

Substrate cracking could also occur due to wide range of frequency testing where resonance frequency of package is difficult to avoid.

The analysis provides that stresses are developed at various stage of developmental activities. These stresses at each stage may not be significant but cumulative effect and may lead to development of significant stresses which may lead to failures of substrate.

ACKNOWLEDGMENT

We are thankful to Shri. AR Srinivas, Sci/Eng SG, Space Applications Centre-ISRO for guidance and valuable suggestions. we would also like to extend my thanks to Shri. KB Vyas Group Head, QACMG for offering the resources and for encouragement. we would like to thank Shri RM Shah Eng SG QAMD, we would also like to offer our gratitude to Deputy Director SRA and Director Space Application Centre.

REFERENCES

1. ASM Handbook, Volume 2, *"Non-ferrous Metals & Alloys"*, American Society of Metals, (1997).
2. ISRO Pax-300 - workmanship guideline.
3. Quality Assurance Mechanical Division, SAC ISRO "Drawing guidelines and tolerances on critical dimensions for active & passive mechanical Hardware subsystem(FM) for GEOSAT/RISAT/MET payload".
4. MIL-STD-883 Evaluation and acceptance procedure for polymeric adhesive.
5. Compressive failure analysis of alumina nano particles dispersed shart Glass/ carban fiber reinforce epoxy hybrid composites by Akash Mohanty & VK Srivastava, Internation journal of scientific & engineering research, volume 3, issue II, Nov 2012

Author :

Dhaval A. Vartak is pursuing Mtech (CAD/CAM) from Indus University, Ahmadabad.

Prof. V.K.Manglik is working as professor for last 10 years in engineering colleges. He has total of 20 years of teaching experience to graduate and post graduate students in mechanical engineering. He guided PhD student and several post graduate student for their dissertation work. He has more than 30 research papers in various journals and national & international conferences.