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Development of Fluxless Reflow Soldering Process for Reliable Attachment of Dice for Space Applications

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Abstract

The process of fluxless solder attachment of die is successfully developed. Reflow soldering station and Au:Sn 80:20 solders are used. The process enables realisation of high quality and reliable microwave assemblies meant for spacecraft applications. It is in tune with ongoing trend of using MMICs considering the advantages of miniaturisation, high performance, high reliability and ease of assembly. The process is designed to avoid voids or blow holes in the solder joint. A technique of evacuation of the chamber right at the time of soldering has helped obtaining best joints. Performance of the process is evaluated through visual inspection, die-shear test, EDX and SAM. Environmental stress tests like thermal cycling and constant acceleration are also performed. Using the process, HEMT MMIC is successfully attached to realise LNA at extended C-band meant for IRNSS series of spacecrafts.

Key Words : Fluxless soldering; Eutectic; MMIC attachment; EDX; SAM

1 Introduction

Soldering technique is widely used in microelectronics for electrical and mechanical connections. Dice are attached using solders to a substrate to serve the purposes of electrical connection, mechanical support, provision of power & input-output connections and dissipation of heat. Solder material is chosen based on process temperature, electrical & thermal conductivities, requirement of flux, feasibility of cleaning, ease of operation etc. Conventional soldering process demands use of flux for achieving good wettability. In that case, flux residues have to be thoroughly removed from assembly as they are corrosive and can cause long term reliability concerns.

No-clean fluxes can be used for such applications. As per literature, no-clean fluxes also leave residues after soldering which are hard to clean. These residues if not cleaned can lead to increase in leakage current and corrosion. Hence it will affect the electrical performance of the circuit [1].

Avoiding the use of flux helps not only in obviating the need of cleaning but also in improving the reliability of the module. There are two fluxless soldering techniques: The first is to use chemicals or RF plasma to remove the oxide layer that already exists. The second one is to prevent solder from oxidation by capping the solder with a barrier layer (Ag/Au) which is carried out during the coating process of solder over the bonding surface of the component to be attached. In the second technique, the capping layer will dissolve and become a part of the solder joint [2].

Among the solders, Au:Sn 80:20 is an excellent choice for a fluxless soldering process, as it contains large amount of gold that will not tarnish. Additionally, it is Pb free, has good electrical and thermal conductivities, thermal fatigue resistance and creep resistance [3].

In the present work, active atmosphere of formic acid vapours are used to remove the oxide layer from the surfaces to be bonded and ultra high pure nitrogen gas to prevent the oxidation of the molten solder during reflow. Latter helps to keep the moisture level to the bare minimum in the chamber. As an improvisation, a technique of evacuation of the chamber right at the time of soldering is found to be very effective.

Formic acid vapour is active at typical soldering temperature while Formic acid decomposes at the reflow temperatures so that it does not contaminate the devices [4].

The reaction of formic acid with metal oxide is:

When temperature is more than $150°C$,

$2HCOOH + MeO = Me(COOH)_2 + H_2O$; (Me stands for metal)

When temperature is more than $200°C$,

$Me(COOH)_2 = Me + CO_2 + H_2$

$H_2 + MeO = Me + H_2O$

When the temperature is between 150 C and 200 C, formic acid reacts with solder oxide to form a carboxyl compound. When the temperature is higher than 200 C, the compound further decomposes into carbon dioxide and hydrogen and is excluded from the chamber by nitrogen purging.

2 Experimental Design

ATV make solder reflow system SRO-704 is used in this work. Soldering operation is carried out in a controlled atmosphere. Controlled atmosphere typically comprises of two components: protective and activating. Protective component consists of pure nitrogen which is inert towards the solder and the other activating component is formic acid. Protective component is intended to protect the metallic surfaces from further oxidation during the heating process while activating component removes pre-existing metal oxides.

Samples & Preparation

Three samples, differing in their composition are chosen for study: Si IC, GaAs MMIC and patterned alumina substrates. ICs have Au as back metallisation and alumina substrate is metallised with Cr/Cu/Au on either sides. Au:Sn 80:20 solder in the form of thin-sheets (called pre-forms) of 0.025 mm thick supplied by Indium Corporation is used as solder. Pre-form is cut to match the size of die. ICs, substrate and cut pre-forms are all cleaned thoroughly with isopropyl alcohol. They are kept in oven at 150C for 30 minutes for removal of moisture.

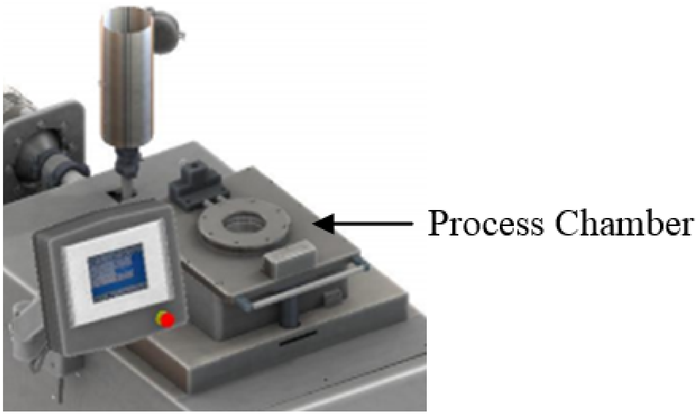


Figure 1. ATV Solder Reflow Station (SRO-704)

Solder Attachment Process

The above samples are kept in the process chamber. Soldering profile is loaded to the equipment. Optimised profile is shown in figure 2. Chamber is evacuated and backfilled with Nitrogen. This sequence is performed twice to ensure the moisture level in the chamber is bare minimum. The temperature is raised from ambient to $200°C$. Formic acid is let in which acts as reducing agent and removes pre-existing metal oxides on the surface of the samples. Then the temperature is raised to the reflow temperature ($280^{\underline{o}}C + 30^{\underline{o}}C$) of the solder. At the reflow temperature, Nitrogen is let in to remove the reactive gases and to avoid further oxidation of the samples during heating process. In this step, soldering would take place. During this period, chamber is evacuated. Trapped gases from the molten solder at the soldering interface are moved out of the chamber. This improvisation helps to avoid the formation of voids in the solder joint. Then cooling is done with the flow of nitrogen. That completes the reflow soldering run.

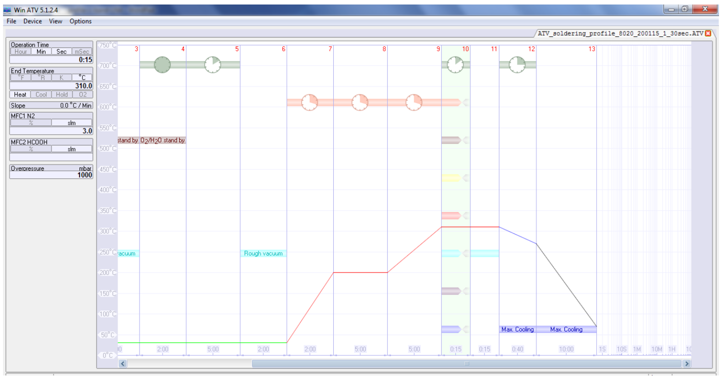


Figure 2. Solder Profile for die attachment with vacuum

2.1 Characterization, results and analysis

Visual inspection is carried out at 100 x using a trinocular microscope from where the images are captured. Images of solder attached samples are shown in figure 3.

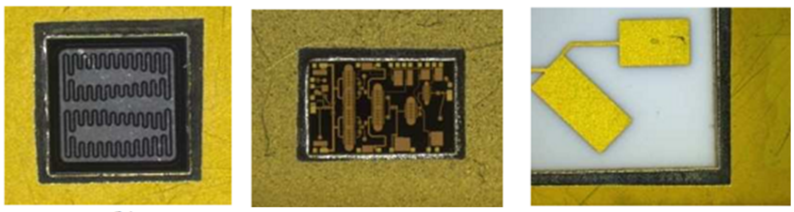


Figure 3. Images of solder attached Si IC, GaAs IC and Alumina substrate

Images of solder joints without the use of evacuation technique are shown in figure 4. As seen, blow holes appear in the joints.

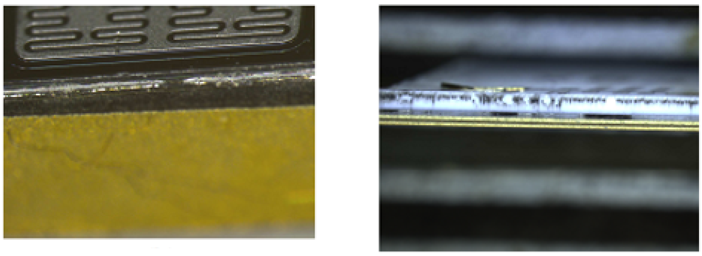


Figure 4. Images of blow holes in Si IC and Alumina substrate

3 Energy-dispersive X-ray Spectroscopy (EDX)

Microsectioning is carried out in one of the sample to measure thickness and to ascertain the composition of the solder attachment layer (figure 7 & 8 (a)). Thickness of the solder layer is found to be 26.819 m, which is equivalent to that of solder perform thickness used during attachment. EDX analysis reveals that no impurity got added to the solder joint (figure 8 (b)).

Energy-dispersive X-ray Spectroscopy (EDX) and Scanning Electron Microscopy (SEM) are carried out on solder joint after it is microsectioned. Composition and the microscopic structure of solder preform before attachment and molten solder interface are shown in figure 8 (a) & 8 (b).

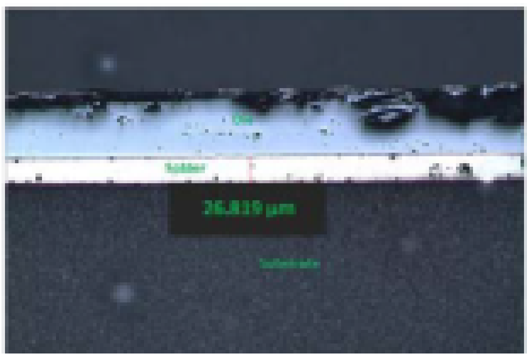
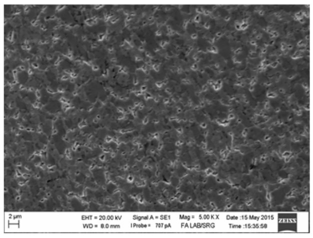
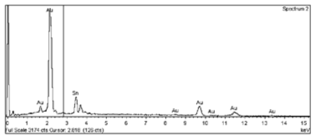


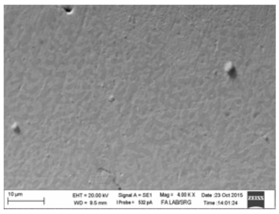
Figure 7. Optical Image Microsectioned sample (100 x)

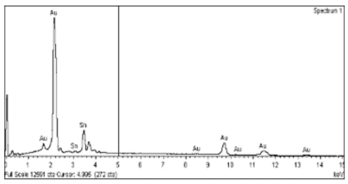




Element	Weight%	Atomic%
Sn L	20.19	29.57
Au M	79.81	70.43
Totals	100.00	100.00

(a)





Element	Weight%	Atomic%
Sn L	20.93	30.52
Au M	79.07	69.48
Totals	100.00	100.00

(b)

Figure 8. (a) SEM image & EDX Spectrum for Solder perform before attachment; (b) SEM image & EDX Spectrum of molten solder interface

4 Scanning Acoustic Microscopy (SAM)

SAM analysis is performed to detect voids and cracks within solder joints. SAM images are shown in figure 9 & 10. For comparison SAM image of the sample where evacuation technique is not adopted is shown in figure 9 (b). It can be observed that this sample had few voids.

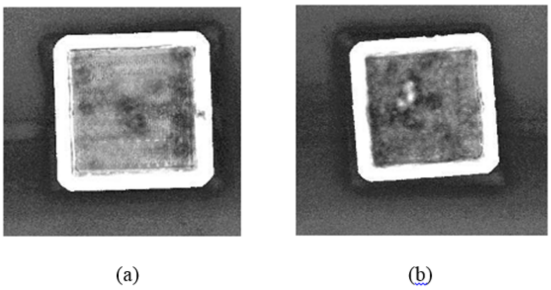


Fig. 9. (a) Si IC Sample with vacuum; (b) Si IC Sample

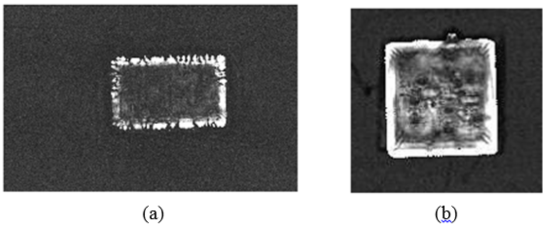


Fig. 10. GaAs MMICs attached with

5 Die Shear Test

Die shear test is carried out on all three samples and mechanical strength of the solder attachment is assessed. Results are provided in table-1.

#	Sample Area	Minimum force Die shall withstand at 2X as per MIL-STD-883	Die shear test result (as per Method 2019.7 in MIL-STD-883)
1	Substrate: 2 x2 mm^2	2.4 kgforce	5.468 kgforce, No effect
2	Si IC: 3.5 x3.5 mm^2	3.2 kgforce	5.470 kgforce, No effect
3	GaAs MMIC: 1.18 x 1.23 mm^2	1.9 kgforce	2.4 kgforce, Die broken

6 Environmental Stress Screening (ESS)

Temperature Cycling and Constant Acceleration:

As part of evaluation of the process for space applications, ESS tests are performed on the samples. Thermal cycling is carried between -55°C to +125°C with 10 min dwell time for 100 cycles. No crack is observed after the cycling in visual inspection at 100 x magnification. Constant acceleration test is performed on the same samples at 5000 g, 10000 g and 15000 g for 1 minute each. No detachment is observed in visual inspection at 100 x magnification. Samples are subjected to die shear test. No degradation in mechanical strength is observed after ESS tests.

7 Induction of the process in realization of the module

The process is inducted in realization of LNA at extended C-band. This module, shown in figure 11 is based on Microwave Integrated Circuit Technology. Transmission lines are realized on Cr/Cu/Au thin film metallised 99.6% purity alumina substrate with thicknesses of 0.254 mm and 0.625 mm. The module consists of two HEMTs: one in bare MMIC form and one in packaged form. Photolithography and sequential etching are used for pattern generation. Laser scribed substrates, passive & active components and pedestals are attached using fluxless reflow soldering technique developed. The module is tested in ambient and hot & cold. The performance is satisfactory. The module is identified for use in TTC Receiver systems of IRNSS and GEOSAT series of spacecrafts.

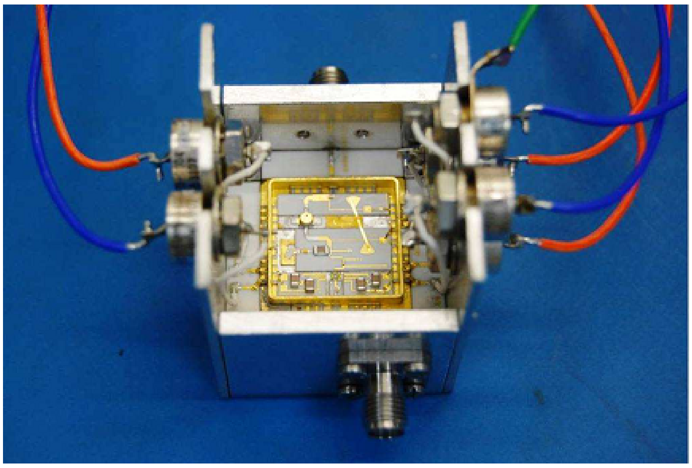


Figure 11. C-band LNA Module realized using fluxless soldering

8 Conclusion

Fluxless soldering process is developed and optimized. The process performance is characterized and samples have been subjected to environmental stress screening tests. A technique to evaluate the chamber during the soldering process is found to result in avoiding the voids. An MMIC based module is realised using these processes and performance is found satisfactory.

9 Acknowledgements

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