Development of Millimeter-wave Package for Consumer Market

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1. Abstract

Semiconductor technology has made significant advancements in the past few decades. High frequency devices, including GaAs, HEMT, and HBT are driven into the market.

At the same time, the demand of packages for high frequency devices are accelerating to the market. The movement for package-less by passivation layer is occuring, however because the device yield is poor, high frequency packages are highly demanded.

These packages are currently being required for such applications in car radar and wireless LAN programs.

This paper will describe the design technologies and material options of micro- to millimeter-wave MMIC package for the consumer market to meet the demands for a small, low cost, and high performance package.

2. Metal wall package

Metal wall package is a conventional package adopted for microwave to millimeter-wave frequencies. This package consists of metal base, metal wall, and ceramic RF/DC signal I/O ports. With Au-plating finish, ground pattern is formed in package for excellent characteristics for high frequencies.

Figure (1) illustrates the characteristics of a metal wall package. At 77GHz, the return loss (S11) is -15dB and insertion loss (S21) is -0.5 dB.

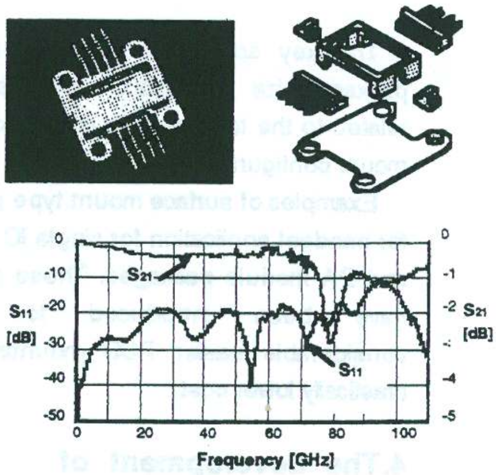


Figure (1) The characteristics of a metal wall package

Furthermore, seam welding sealing method allows protection of MMIC from external environment to ensure device integrity.

3. Package Cost

The millimeter-wave package market requires not only excellent mechanical characteristics, but also cost efficiency. A general cost comparison is shown in Figure (2). As shown, the price of conventional metal wall package is relatively high from the factors such as metal material, metal machining, and metal processing, ceramic solder attachment to metal, which results in total cost increasement.

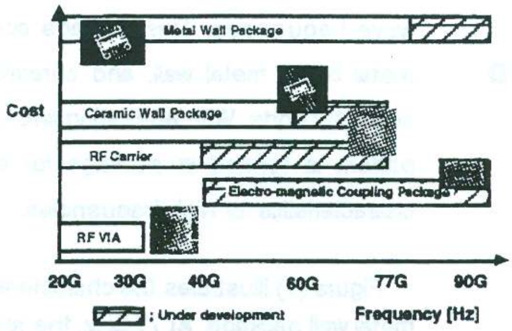


Figure (2) A general cost comparison of millimeter-wave MMIC package

The key solution for cost reduction is package size reduction, which is directly related to the total material cost, and surface mount configuration.

Examples of surface mount type packages for handset application for single IC are SAW and PA module packages. These packages have been introduced to achieve considerable easier PCB mounting by a drastically lower cost.

4.The development of feedthru type packages

Figure (3) illustrates the technology trend packaging roadmap of millimeter-wave packages through the millennium. The advantages of ceramic's packaging design flexiblity, process technology, as well as material technology is depicted.

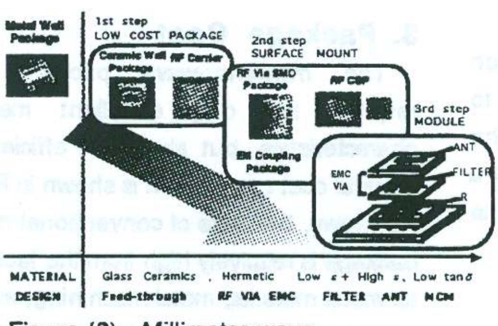


Figure (3) Millimeter-wave package roadmap

To comply with the market demands, we have developed ceramic wall packages and carrier-type packages. These packages have a feedthru structure for RF signal transmission. Ceramic material has replaced metal as an effective sollution for low cost.

The key solution in designing these packages are to achieve low loss results by introducing multilayer ceramic technology, where metal feedthrough has been used conventionally.

The characteristics of carrier-type packages are shown in Figure (4).

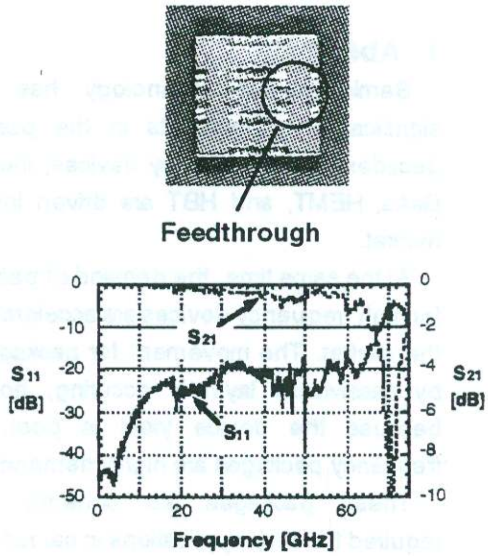


Figure (4) The characteristics of carrier-type packages

We have optimized the feedthru structure to improve the performance in RF feedthru of the package.

First, we studied the mechanism of RF signal transmission in feedthru.

Figure (5) illustrates the simulation and actual measurement results. At 40GHz to 50GHz, a resonance frequency occurs.

As shown, the actual measurement and simulation are similar.

This shows that the simulation technology is reliable for design optimizated package measurements for the required frequency bands.

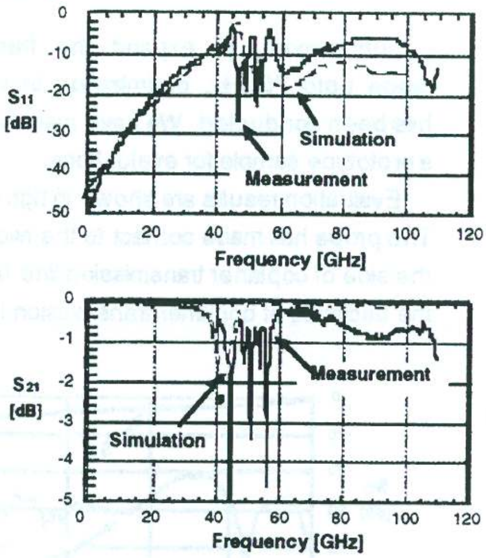


Figure (5) The simulation and actual measurement results

Figure (6) shows the mechanism of resonance frequency from our studies.

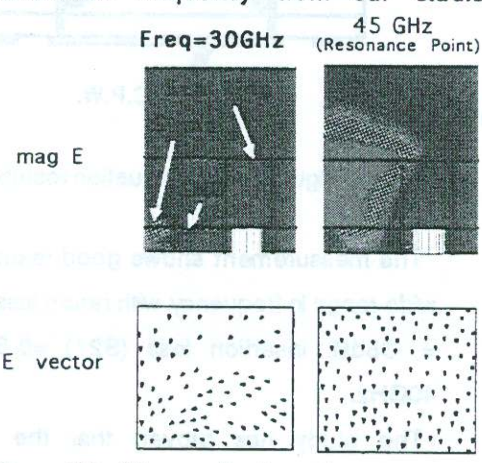


Figure (6) The mechanism of resonance frequency

At 30GHz, the E vector from signal to ground is equally distributed and shows that signal transmission is smooth.

At 45GHz, the distribution of E-vector is in vertical direction. This is TE01 mode, which means top of seal ring area to ground is connected in the signal line of feedthru. And the cross section is very similar to that of the waveguide.

Therefore, the control of the width of castellation allows the change in resonance frequency.

Figure (7) shows the relationship of resonanace frequency and width change of castellation.

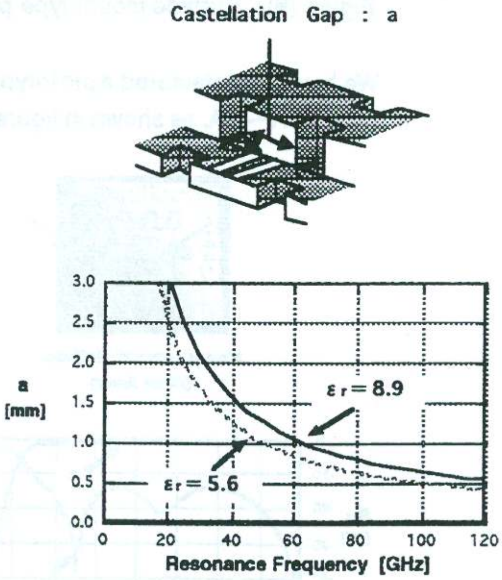


Figure (7) The relationship of resonanace frequency and width change of castellation

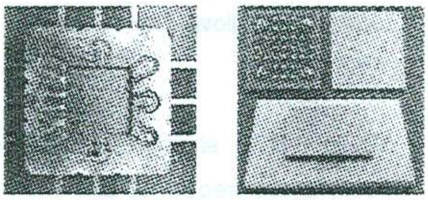
For alumina material with $\varepsilon_r = 8.9$, the optimized design is for gap of 0.7mm or thinner.(upto 60 GHz level) And low temperature cofired ceramics(glass ceramics) material with $\varepsilon_r = 5.6$, a=0.77mm gap will achieve frequency range of 90GHz.

5. Development of surface mount type packages

A surface mount type package where RF signal line is transmitted through via is under development.

The advantage of surface mount type packages that it achieves hermetic sealing.

There are two concepts for surface mount type packages, shown in Figure (8). Type A is RF-VIA type, type B is RF-CSP type.



A ; RF-VIA B ; RF-CSP

Figure (8) Surface mount type packages

We have manufactured a prototype sample of Type A, RF-VIA, as shown in figure (9).

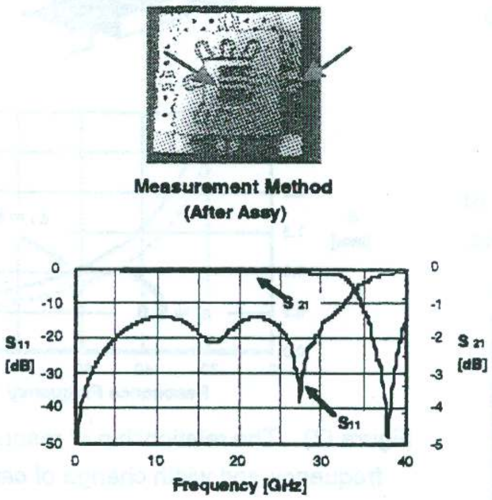


Figure (9) The characteristics of RF-VIA

The measurement of high frequency characteristics of package is made by mounting a thin film substrate on package, to enable the probe to contact with cavity area. Package itself is mounted on alumina ceramic substrate. The measurement are made from package side and substrate side.

The characteristics is measured at the via. Here the package characteristics is measured after mounting, instead of package itself. The result show that return loss (S11) ≦10dB and insertion loss (S21) ≦0.8dB at 32GHz.

Furthermore, to expand the frequency range upto 70GHz, optimization in via-hole has been conducted. We have manufactured a prototype sample for evaluations.

Evaluation results are shown in figure (10). The probe has made contact to the two via on the side of coplaner transmission line through the backside of coplaner transmission line.

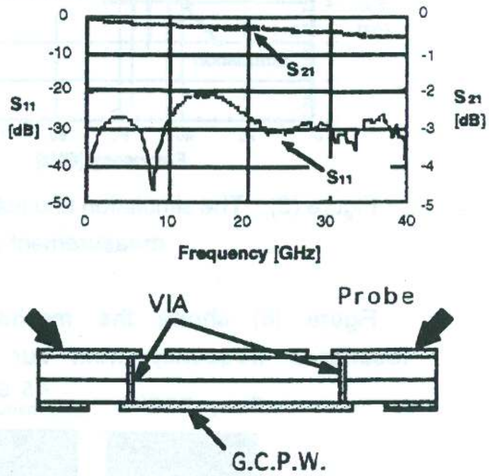


Figure (10) Evaluation results

The measurement shows good results in a wide range in frequency with return loss (S11) = -38dB, insertion loss (S21) =0.5dB at 40GHz.

The study has proven that the newly developed packages are adoptable for high frequency use.

Type B is under development. We call this simple structure package, RF-CSP.

6. Material Options

Until recently, studies for alumina ceramics has been in the main stream for millimeter-wave packages material. However, to achieve a lower loss, we must consider improvement of dielectric loss of package material together with loss of conductor material. To comply with requirement for lower loss, we have studied low temperature cofired ceramic (glass ceramic).

Table 1 illustrates the material properties of alumina and newly developed glass ceramic. With Cu-conductor, a dielectric loss of 8 x 10^{-4} at 60GHz is achieved.

Table 1 The material properties of alumina and newly developed glass ceramic.

Material Property * Preliminary Data

ITEM	UNIT	CERAMIC: Alumina A493	Alumina A473	Glass Ceramics GL550	Glass Ceramic GL660	Glass* Ceramics A	Glass* Ceramics B
Bulk Density	—	3.9	3.6	2.8	3.1	2.6	2.8
<ELECTRICAL> Dielectric Constant (1MHz)	—	9.8	9.0	5.7	9.5	4.8	6.0
Tan δ (1MHz)	(1×10^{-4})	2	8~12	5	16	8	—
Tan δ (10GHz)	(1×10^{-4})	1	12	13	27	8	29 (30GHz)
Tan δ (60GHz)	(1×10^{-4})	2.2	27~37	29	—	8	—
Conductor Material	—	W, Mo	W, Mo	Cu	Cu	Cu	Cu
Sheet Resistance	mΩ/□	8 to 10	8 to 10	2 to 3	2 to 3	2 to 3	2 to 3
<THERMAL> Thermal Expansion (40–400 °C)	1/°C (1×10^{-6})	7.4	7.0	5.5	6.3	5.5	7.5
Thermal Conductivity	W/mK	34.0	17	2.5	1.5	2.0	1.5
Specific Heat	J/gK	0.78	0.79	0.73	0.66	0.7	0.66
<MECHANICAL> Flexural Strength	MPa	400	314	200	200	170~200	AVE.200
Young's Modulus of Elasticity	GPa	—	265	110	100	90	90

Note Material characteristics mentioned above are typical values. These values may change based upon further improvement or modification of these materials and processes

Although, package reliablity and mechanical characteristics must be further studied, there is anticipation for this newly developed glass ceramic material to be adopted in next generation multilayer millimter-wave packages.

7. Summary

To respond to the technology shift, we have proposed surface mount packages as an attractive option for millimeter-wave MMIC packages. And optimization of vias design is major factor to achieve high frequency range in CSP type packages.

The design of vias must be considered together with process technology.

Therefore, we will continue to develop vias for high frequencies from both design and process technology. Furthermore, to achive a high second level board level reliability,the surface mount type packages will continue to be considered.

As the function of device improves, the movement for development of RF-MCM concept will be sure to arrive. In any case, the key factor is package, device, and system side must be mutually considered simulataneously to meet the market requirements for further miniturized, high performance, and low cost.

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