77-GHz-Band Surface Mountable Ceramic Package

Kenji Kitazawa, Shinichi Koriyama, *Member, IEEE*, Hidehiro Minamiue, and Mikio Fujii

***Abstract*—The authors have developed a surface mount-type ceramic package for 77-GHz millimeter-wave application. The package has a new terminal structure for surface mount and a feedthrough of electromagnetic coupling. The authors have adopted a coplanar structure for the surface mount terminal. The structure for the electromagnetic coupling consists of microstrip line/slot/microstrip line (MSL/SLOT/MSL). Total transmission loss between the signal line on board and the RF input–output terminal inside the package was 1.0 dB at 77 GHz. Standard deviation of the insertion loss was 0.08 dB $(n = 57)$. The authors have confirmed that the surface mountable package shows high transmission characteristics as well as high reliability.**

***Index Terms*—Electromagnetic coupling, packaging, reliability testing, surface mounting.**

I. Introduction

SEVERAL millimeter-wave systems have come to play very important roles in the new markets, such as automotive radar, local multipoint distribution service, wireless LAN, etc. Packages for the monolithic microwave integrated circuit (MMIC), the key active device for such millimeter systems, are facing requirements for low cost and mass productivity, as well as high transmission performance of a high-frequency signal.

The conventional millimeter wave package is a metal package, as shown in Fig. 1. This is shaped from a metal block and has a feedthrough structure of microstrip line/stripline/microstrip line, to realize high signal performance. However, this package can only transmit the RF signal horizontally because of the structure.

To realize low cost and mass productivity, as well as high signal transmission performance for millimeter wave applications, we developed a surface mount-type ceramic package. To realize the surface mounting, the package contains an interconnection structure that can vertically transmit the RF signal.

In the range of microwave and millimeter wave, several studies have been done to get such vertical interconnection [1]–[4], by an electromagnetic coupling (MSL/SLOT/MSL) feedthrough. The electromagnetic coupling structure, illustrated in Fig. 2, has wide -band transmission in the high-frequency range. Herman *et al.* have studied and developed an electromagnetic coupling package for applications on the millimeter wave range [3]. In this work, we have adopted the coupling structure for millimeter wave package feedthrough and a coplanar structure for the surface mount interconnection. We have designed and optimized these structures for millimeter wave application, as well as the package reliability.

Manuscript received January 15, 2000; revised March 15, 2000.

K. Kitazawa, S. Koriyama, and H. Minamiue are with the R&D Center, Kagoshima, Kyocera Corporation, Kokubu-shi, Kagoshima, 899-4312 Japan.

M. Fujii is with the R&D Center, Keihanna, Kyocera Corporation, Soraku-gun, Kyoto, 619-0237 Japan.

Publisher Item Identifier S 0018-9480(00)07416-0.

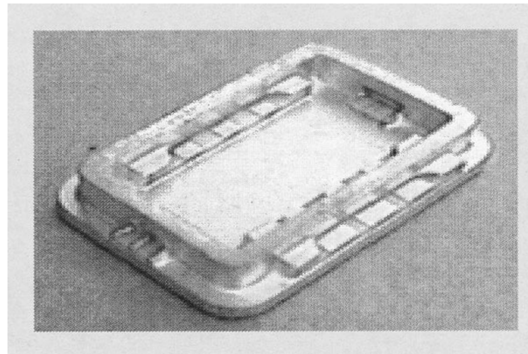

Fig. 1. Photograph of conventional package (metal wall package).

II. Transmission Characteristics of Electromagnetic Coupling Feedthrough

A test sample, a ceramic substrate containing the electromagnetic coupling, has been prepared with an alumina material (Kyocera AO473; dielectric constant =8.6, dielectric loss =0.0021; at 60 GHz). This sample has a tungsten conductor with a gold plating finish. We have optimized the stub length of microstrip line, width and length of the slot, to obtain a stable and minimized transmission loss using numerical simulations by MOMENTUM.

The sample has two electromagnetic coupling structures and two microstrip line/grounded coplanar wave-guide structures for probing the vector-type network analyzer (HP 85109C). The schematic diagram of this sample is shown in Fig. 3. The full size of the sample is 2.6 mm in length. Measured results are shown in Fig. 4 as functions of signal frequency. The bold line shows the transmission coefficient (S21), and the fine line shows reflection coefficient (S11). The test sample has shown a very low loss at 77 GHz. The loss of the electromagnetic coupling has been estimated to be 0.4 dB, compared with a single microstrip line measurement.

This electromagnetic coupling structure has a very efficient wide-band transmission and low transmission loss. The coupling structure is, therefore, useful for vertical transmissions to realize a surface mountable package.

III. Interconnection Designing

The RF signal often reflects and radiates from the interconnection on a transmission line, between the mounting board and the package. The interconnection design has been studied for high transmission performance to establish a surface-mountable package.

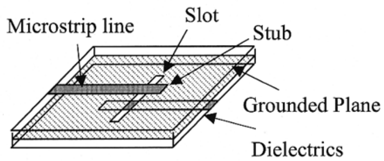

Fig. 2. Schematic drawing of electromagnetic coupling feedthrough.

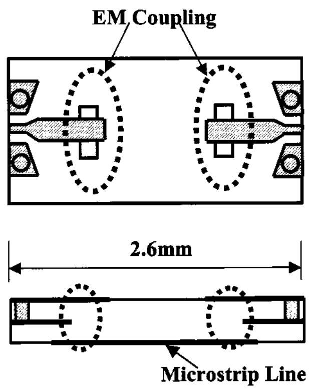

Fig. 3. Schematic diagram of electromagnetic coupling designed for 77 GHz. MSL width =0.24 mm, MSL stub =0.2 mm, SLOT length =0.6 mm, SLOT width =0.2 mm, alumina sheet thickness =0.2 mm (between MSL and SLOT).

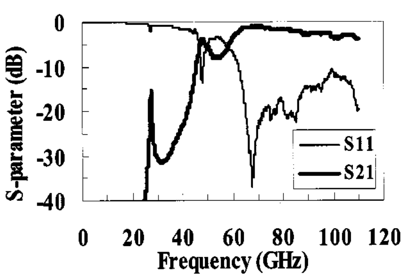

Fig. 4. Measured transmission characteristics of the electromagnetic coupling structure designed for 77 GHz.

Fig. 5 illustrates electromagnetic modes on each side of the interconnection [Fig. 5(a) and (c)]. The electromagnetic mode at the signal line on the board should be transferred to the mode inside the package. Low loss signal transformation between these areas has been realized by adopting a coplanar structure at the interconnection [Fig. 5(b)].

We optimized the interconnection structure by numerical simulations of HFSS (HP), including the coplanar line structures and solder for the coplanar lines connection. For the optimization, solder height and ground pattern at the interconnection is the main concern. The ground pattern and gaps between solders were designed to minimize radiation from the interconnection. The solder height was varied from 30 to 80 μm to find the best height. Since no significant dependence was obtained, we have fixed the height to 50 μm. Fig. 6 shows the model of the optimized structure. Fig. 7 shows calculated transmission characteristics of the interconnection. The model is constructed with alumina ceramics of 150 μm thickness, assuming no dielectric loss and the perfect conductor. The optimized structure has shown the transmission loss of 0.4 dB at 77 GHz, as can be seen in Fig. 7.

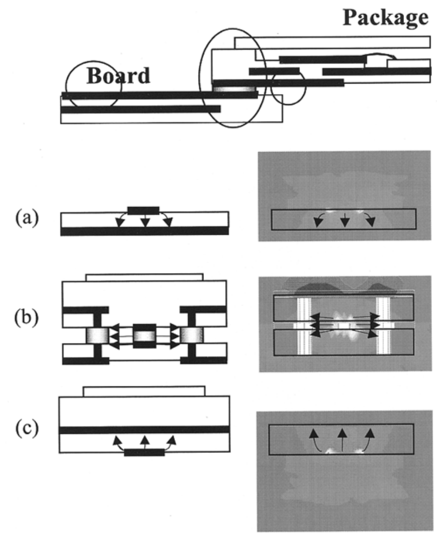

Fig. 5. Schematic diagram and electromagnetic mode at each part of the interconnection: (a) mounting board, (b) coplanar line connection, and (c) package.

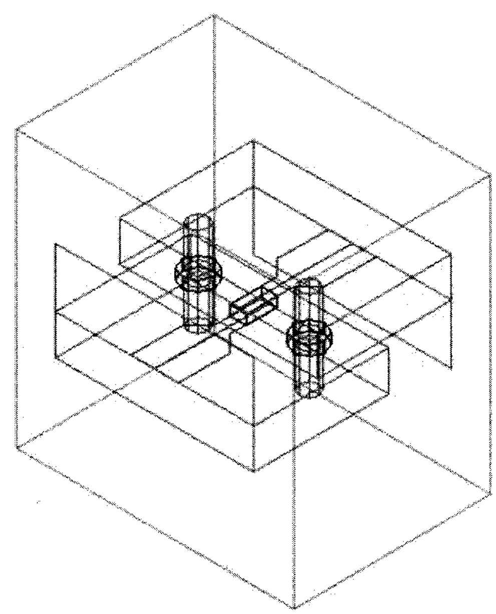

Fig. 6. Model for HFSS of interconnection, composed of two MSL substrates and coplanar line connection.

IV. Performance of the Surface Mountable Package

We prepared a test sample of the package and mounting board, for performance evaluation of the newly designed electromagnetic coupling and surface mountable interconnection structures. The package size is 5.8 $\times$ 5.8 $\times$ 0.7 mm^3, the dimension for MMIC 2.0$\times$2.0 mm^2 [Fig. 8(a)]. The circuit board has a hole at the mounting area of the package, for avoiding a disturbance on the electromagnetic coupling [see Fig. 8(b)]. After solder paste was printed on the board, the package was mounted on the paste and put in a solder reflowing furnace under a nitrogen atmosphere. We used the solder of tin–silver–copper.

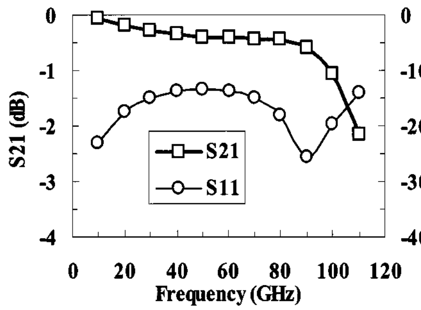

Fig. 7. Calculated transmission characteristics of interconnection. Optimized dimension: alumina sheet thickness =0.15 mm, MSL width =0.16 mm, signal solder 0.08 mm square × 0.05 mm, ground solder 0.16 mm $\phi \times 0.05$ mm.

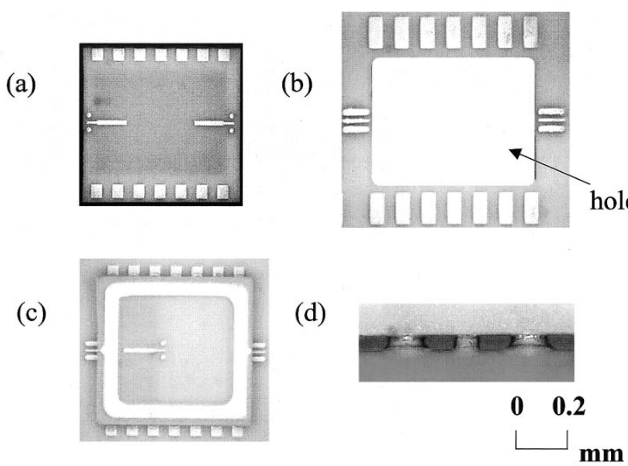

Fig. 8. Photograph of prepared samples. (a) The bottom view of the package. The package size is 5.8 mm square× 0.7 mm. (b) The mounting board. This board has a hole at the center. (c) The top of the surface mounted sample. The center pattern is a probing terminal. (d) The cross section of the interconnection. The gap between the package and the board is 0.05 mm.

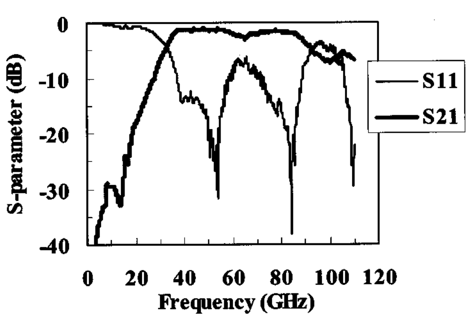

Fig. 9. Measured transmission characteristics of surface mounting sample.

The transmission characteristics were measured between the signal line on the board and the probing terminal inside the package [see Fig. 8(c)]. The measured results are shown in Fig. 9. The bold line shows the transmission coefficient (S21), and the fine line for reflection coefficient (S11). We can see clearly that the insertion loss is very small at 77 GHz. We obtained the average insertion loss of 1.0 dB and the standard deviation to be 0.08 dB by measuring 57 samples. These results confirm that the highly reliable interconnection has been established (Fig. 10).

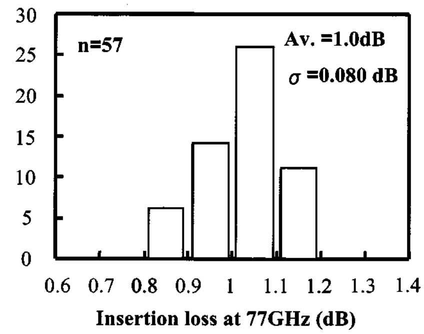

Fig. 10. Histogram of insertion loss between MMIC RF input–output and the signal line on the board. The loss dose not include loss of the probing terminal. The total number of samples is 57, the average of insertion loss is 1.0 dB, and the standard deviation 0.08 dB.

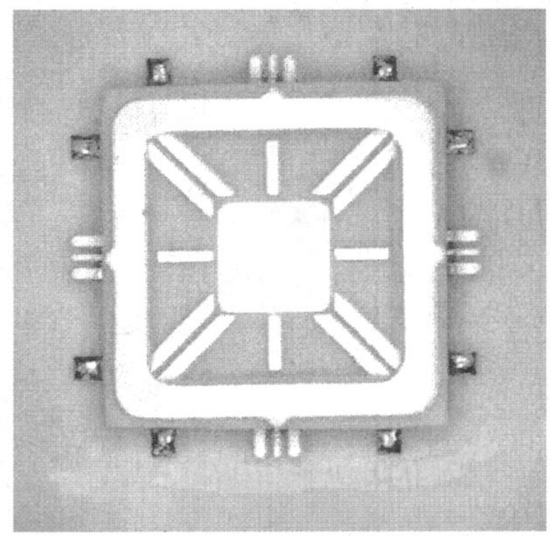

Fig. 11. Photograph of isolation sample. Vertical and horizontal lines are MMIC RF input–output. Diagonal lines are dc bias. A metal lid was attached on this sample for isolation measurement. The package size is 5.8 mm square×0.7 mm.

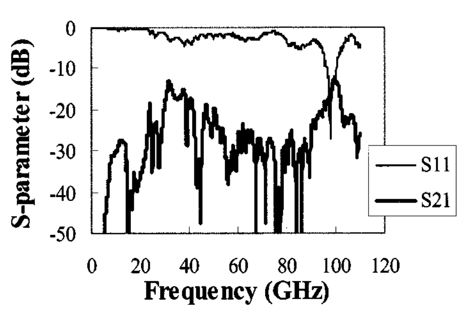

Fig. 12. Measured transmission characteristics of isolation sample.

V. Isolation

We prepared a test sample of surface mounting package, which contains a die attached area for MMIC to check an isolation performance. The package size is $5.8 \times 5.8 \times 0.7$ mm^3. The internal terminal for the MMIC input–output was not connected. This package was shielded by a metal lid (Fig. 11).

TABLE I
RELIABILITY TEST RESULTS

Item	Condition	Evaluation Results
Temperature cycle	-40deg.C(30min)/125deg.C(30min) Air (3000cycle)	0/56
Thermal shock	0deg.C(5min)/100deg.C(5min) Water(3000cycle)	0/14
Mechanical Vibration	10G, 10～500Hz, 2hours/direction direction (X,Y,Z)	0/14
Mechanical shock	500G, 1ms, 3times/direction direction (X1,X2,Y1,Y2,Z1,Z2)	0/14

The package was mounted on an alumina board. Isolation between one RF input line and another RF output line on the board was about −35 dB at the 77-GHz band (see Fig. 12). This isolation is good enough for a standard MMIC. Above 95 GHz, reflection and transmission loss is increased. This comes from the resonance inside the package.

VI. Reliability in Thermal and Mechanical Tests

Reliability tests of the package and interconnection have been conducted, concerning characteristics other than the transmission performance, such as temperature cycle, thermal shock, vibration, and mechanical shock tests. For these tests, the package was shielded with an Alloy 42 lid by gold-tin eutectic alloy. Test conditions and measured failure rates are summarized in Table I. The helium leak rate of the packages was less then 1.0×10^{-8} atm cc/s and showed no increase after the tests. We see that the package and surface mounting interconnection have fairly high reliability.

VII. Conclusion

We developed a new millimeter wave ceramic package, surface mountable with high signal transmission performance and reliability. This package has a feedthrough structure of electromagnetic coupling and coplanar interconnection for surface mount. Transmission loss between the signal line on board and the MMIC RF-input–output in a package was 1.0 dB at 77 GHz, with standard deviation of 0.08 dB. We confirmed that the thermal and mechanical reliability is also very high. This surface mountable package has low cost productivity and mountability.

References

[1] N. Vandenberg and L. Katehi, "Broadband vertical interconnects using slot-coupled shielded microstrip lines," *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 81–88, Jan. 1992.

[2] M. Herman *et al.*, "Novel techniques for millimeter-wave packages," *IEEE Trans. Microwave Theory Tech.*, vol. 43, pp. 1516–1523, July 1995.

[3] G. Strauss and W. Menzel, "Millimeter-wave monolithic integrated circuit interconnects using electromagnetic field coupling," *IEEE Trans. Compon., Packaging, Manuf. Technol. B*, vol. 19, pp. 278–282, May 1996.

[4] S. Koriyama, K. Kitazawa, and M. Fujii, "Development of a package utilizing an electromagnetic coupling structure," *1998 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1087–1090.

Kenji Kitazawa was born in Shiga, Japan, in 1967. He received the B.S. and M.S. degrees in science from the University of Okayama, Okayama, Japan in 1990 and 1992, respectively.

In 1992, he joined Kyocera Corporation R&D Center, Kokubu-shi, Japan. He has been engaged in research and development of microwave and millimeter wave package.

Mr. Kitazawa is a member of the Institute of Electronics, Information and Communication Engineers (IEICE), Japan.

Shinichi Koriyama (M'98) received the B.S. and M.S. degrees in electric engineering from Nagaoka University of Technology in 1983 and 1985, respectively.

He is currently with Kyocera Corporation, Kagoshima, Japan.

Mr. Koriyama is a member of the Institute of Electronics, Information and Communication Engineers (IEICE), Japan.

Hidehiro Minamiue received the B.S. degree in chemical engineering from Kyusyu University in 1980.

He is currently with Kyocera Corporation, Kagoshima, Japan.

Mikio Fujii received the B.S. and M.S. degrees in material science from University of Tokyo, Tokyo, Japan in 1975 and 1977, respectively.

He is currently with Kyocera Corporation, Kyoto, Japan.