MILLIMETER-WAVE IC PACKAGING TECHNOLOGY
- STATE OF THE ART AND FUTURE TRENDS -

Keiichi Ohata

Photonic and Wireless Devices Research Laboratories
System Devices and Fundamental Research, NEC Corporation

2-9-1 Seiran, Otsu, Shiga 520-0833, Japan
Tel: +81-77-537-7683, Fax: +81-77-537-7689, E-mail: k-ohata@ab.jp.nec.com

ABSTRACT

This paper presents an overview of recent state of the art technologies and future trends in millimeter-wave MMIC packaging in the aspects of low cost, high productivity and high functionality. Developments of ceramic packages up to W-band have been progressed by design innovation. LTCC Technology with thick film printing has realized low-cost packages and 60GHz-band antenna integrated MCMs. Multi-junctional integrated modules have been proposed utilizing Si micromachining technologies.

INTRODUCTION

Demands for high capacity multimedia communications are increasing. Various terminals with over subGbps transmission interfaces such as IEEE 1394 (100, 200, 400Mbps), Gigabit Ethernet and so on are spreading. Millimeter-waves, especially 60GHz-band are suitable for such high-speed transmissions in wireless link scheme. A 60GHz-band S400 (400Mbps) IEEE1394 wireless adapter has been realized for the first time as Ohata et al (1), (2). For such commercial applications, packaging technologies become important more and more. Compactness, low-cost and high productivity with high performance and function are required. Technology developments are mainly focused on high producible flip-chip bonding of CPW MMICs and low-cost multi-layer ceramic packages. Although the package is primarily important, the technology is also covering multi-functional integrated modules such as RF front-ends integrating MMICs, antennas and filters adopting innovative technologies such as Si micromachining and so on.

This paper describes state of the art technologies and future trends in packages and modules for millimeter-wave MMICs applicable up to W-band.

MILLIMETER-WAVE PACKAGING TECHNOLOGY

Progresses on the electromagnetic simulation enable the design of high performance millimeter-wave packages and MMIC assembling. The flip-chip bonding with low loss and high producible interconnect has already been applied to 60/76GHz modules for automotive radars etc as Ohashi et al (3), Ito et al (4) and Kerssenbrock et al (5). Low-cost ceramic packages have been developed up to W-band. Developments of a surface mount type of package with a couple of electromagnetic (EM) coupling feed-through are progressing as Koriyama et al (6). Figure 1 shows the package concept. The EM coupling was designed so as to obtain the largest margin for the production of ceramic lamination technology. The terminal structure on a mother-board such' as an alumina substrate adopting solder reflow has also been optimized. Both MSLs on board and package are transformed to CPW and connected by solder to each other. The photograph of surface mount assembly is shown in Fig. 2. The net insertion loss is 1.0dB with 0.08dB standard deviation at 77GHz.

Conventional LTCC (Low-Temperature Co-Fired Ceramic) technologies, which have been used for the mass production of packages and modules below K-band so far, can be applied up to W-band by design innovation. Figure 3 shows the package concept (a) and feed-through structure (b) utilizing multi-layer LTCC technology with thick film printing for wiring as Maruhashi et al (7) and Ito et al (8). Coplanar MMICs are flip-chip assembled into cavities formed in the multi-layer LTCC substrate. Grounded via-holes are incorporated to suppress unwanted parallel-plate mode in the CPW. Embedded coplanar waveguide (E-CPW) with a thin dielectric film on the CPW is adopted for interconnection among MMICs. Its 50Ω line has line/space of 0.122mm/0.114mm satisfying the minimum design rule of 0.1mm for low-cost thick film printing and exhibits small frequency dispersion up to 100GHz. In contrast, the conventional CPW shows significant frequency dispersion above 40GHz with the line/space of 0.162mm/0.094mm. Another feature of the package is the side via hole (SVH) at the interface of the feed-through in order to suppress the radiation outside the signal line. Transmission characteristics of a feed-through with and without SVH are shown in Fig.4. The package is usable up to 90GHz with a feed-through loss of 1.1dB at 76GHz. The return loss is better than 17dB from DC to 95GHz. A packaged 76GHz-band amplifier has exhibited better than 15dB gain and 33dB isolation from 71 to 80GHz without instability.

MULTI-FUNCTIONAL MULTI-CHIP MODULE TECHNOLOGY

State of the art technologies on millimeter-wave multi-chip modules are covering total RF front-ends including antennas and passive components. Low-cost 60GHz-band antenna-integrated transmitter/receiver modules utilizing multi-layer LTCC technology described above have been proposed and demonstrated as Maruhashi et al (7). Figures 5 shows the photograph and structure of the module. A double slot antenna is printed on the LTCC substrate. The transmitter MCM consists of a upconverter and an output amplifier. The receiver MCM consists of an LNA and a downconverter. Performance summary is shown in Table 1.

It is also noted that Si micromachining technology is being applied to multifunction millimeter-wave modules. This technology has high potential of making precise components and high-density circuits. A 25GHz-band receiver front-end IC has been proposed and demonstrated, in which a micromachined filter and flip-chip MMICs are integrated on a Si substrate as Takahashi et al (9). In Fig.6, the module structure is shown. Filter patterns and matching circuits are built into multi-layered BCB on a Si substrate. A micromachined Si cover with a metal plated cavity was used to cover the filter pattern. Figure 7 shows photograph of a fabricated receiver front-end IC with its block-diagram. Overall conversion gain was obtained up to 24.2dB with the noise figure of less than 4.0dB at 25.0 ± 0.25GHz. The filter displayed sufficient suppression of above 28dB at 23GHz.

A W-band power module consisting of flip-chip MMICs and Si micromachined distribution networks and patch antenna array are proposed as Henderson et al (10). The concept is shown in Fig.8. The distribution networks have been developed based on a finite ground coplanar (FGC) waveguide interconnect architecture. The packaged FGC line with a shielding cavity as shown in Fig.9 exhibits low loss performance. A 1x4 distribution network has demonstrated the insertion loss of approximately 0.7dB around 94GHz. These Si micromachining technology has also realized a 110 μm deep cavity for a flip-chip with low loss access FGC lines as Becker and Katehi (11).

FUTURE TRENDS

Mass commercial use of millimeter wave systems such as multimedia home networks, automotive radars and so on is spreading. Therefore, further works on the package, component and assembling will be conducted aiming at optimized integrated modules with compactness, reduced cost and high productivity. Especially, developments of highly functional RF front-end modules will be enhanced utilizing state of the art design based on electromagnetic simulation and fabrication technologies.

SUMMARY

State of the art technologies on millimeter wave IC packaging are reviewed. For spreading of millimeter-wave commercial systems, low-cost, high producible and high functional modules are required. Low-cost ceramic packages usable up to W-band and antenna and passive integrated modules have been proposed and demonstrated.

ACKNOWLEDGEMENT

The author wishes to thank to researchers and engineers contributing to these developments, especially to Drs. S.Koriyama (Kyocera Corp.), K.Takahashi (Matsushita Research Inst.) and Prof. L.P.B.Katehi (Univ. Michigan).

REFERENCES

(1) K.Ohata et al; "Ultra high speed 60GHz-band ASK transceiver," 2000 Topical Symp. Millimeter Waves Dig., pp.173-176.

(2) K.Ohata et al; "A 500Mbps 60GHz-band transceiver for IEEE 1394 wireless home networks," to be presented at 2000 European Microwave Conf.

(3) Y.Ohashi et al; "76GHz flip-chip MMICs in through-hole packages," 1998 European Microwave Conf. Proc., pp.433-438.

(4) M.Ito et al; "Analysis of flip-chip MMIC structure for 60- and 76-GHz-band low noise amplifiers," 1998 Asia-Pacific Microwave Conf. Proc, pp.299-302.

(5) T.v.Kerssenbrock et al; "Novel 77GHz low-cost automotive radar module with fractional-PLL frequency linearizer," 1999 European Microwave Conf. Proc., vol.2, pp.5-8.

(6) S.Koriyama et al; "Millimeter-wave ceramic package for a surface mount," 2000 IEEE MTT-S Int. Microwave Symp. Dig., pp.61-63.

(7) K.Maruhashi et al; "Low-cost 60-GHz-band antenna integrated transmitter/receiver modules utilizing multi-layer low-temperature co-fired ceramic technology," 2000 IEEE Int. Solid State Circuits Conf. Dig., pp.324-325.

(8) M. Ito et al; "Low cost multi-layer ceramic package for flip-chip MMIC up to W-band," 2000 IEEE MTT-S Int. Microwave Symp. Dig., pp.57-60.

(9) K.Takahashi et. al; "K-band receiver front-end IC integrating micromachined filter and flip-chip assembled active devices," 1999 IEEE MTT-S Int. Microwave Symp.Dig., pp.229-232.

(10) R.Henderson et al; "Three-dimensional, W-band circuits using Si micromachining," ibid, pp.44 l-444.

(11) J.P.Becker and L.P.B.Katehi; "Multilevel finite ground coplanar line transitions for high-density packaging using silicon micromachining," 2000 IEEE MTT-S Int. Microwave Symp. Dig., pp.303-306.

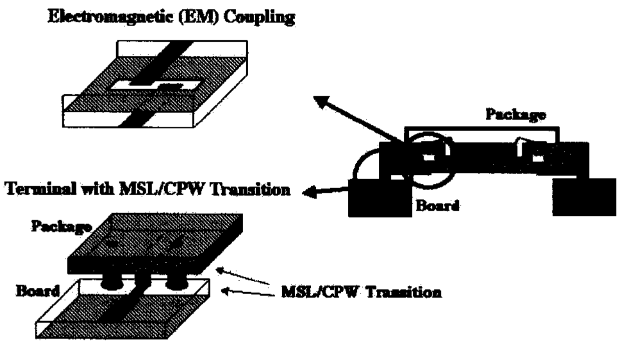

Fig. 1. EM coupling package concept (6).

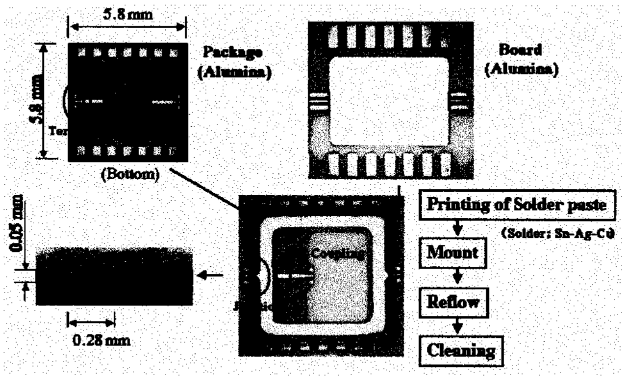

Fig. 2 Surface mount assembly of the EM coupling package (6).

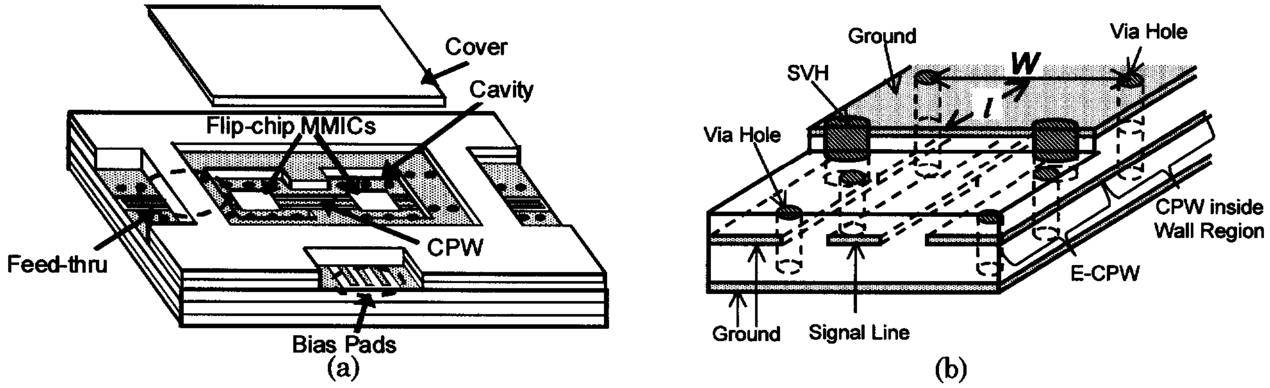

Fig. 3 Ceramic package utilizing multi-layer LTCC technology. (a) Concept (b) Structure of E-CPW and feed-thru (8). SVH at the interface of the feed-thru suppresses the radiation which is considerable in the case without SVH when 1 is longer than λ/4. W is designed to cut off parasitic waveguide modes up to 80GHz.

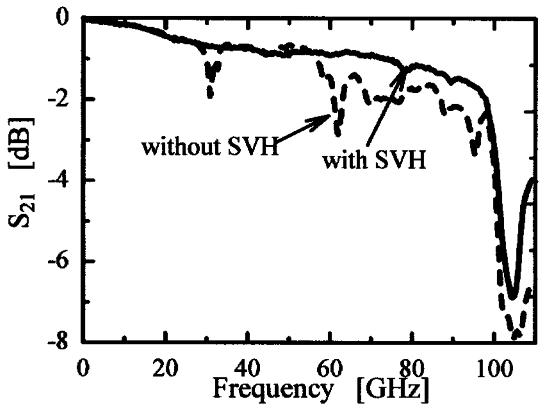

Fig. 4 Transmission characteristics of a feed-thru (8). (Including 1mmx2 input/output lines)

Table 1 LTCC MCM performance summary (7).

MCM:	Frequency	59 - 60 GHz
	Output Power (TX)	10 mW (10 dBm)
	Conversion Gain (RX)	10 dB
PA:	Output Power (P1dB)	12 dBm
	Linear Gain	13 dB
LNA:	Gain	18 dB
	Noise Figure	5 dB
Upconv.	Conversion Gain	-5 dB @ IF freq. = 1 GHz
Downconv.:	Conversion Gain	-8 dB @ IF freq. = 1 GHz
Antenna:	Gain	4 dBi
	Port Return Loss	10 dB
E-CPW:	Transmission Loss	0.22 dB/mm @ 60 GHz
	Interconnect Loss	0.9 dB (between MMICs)

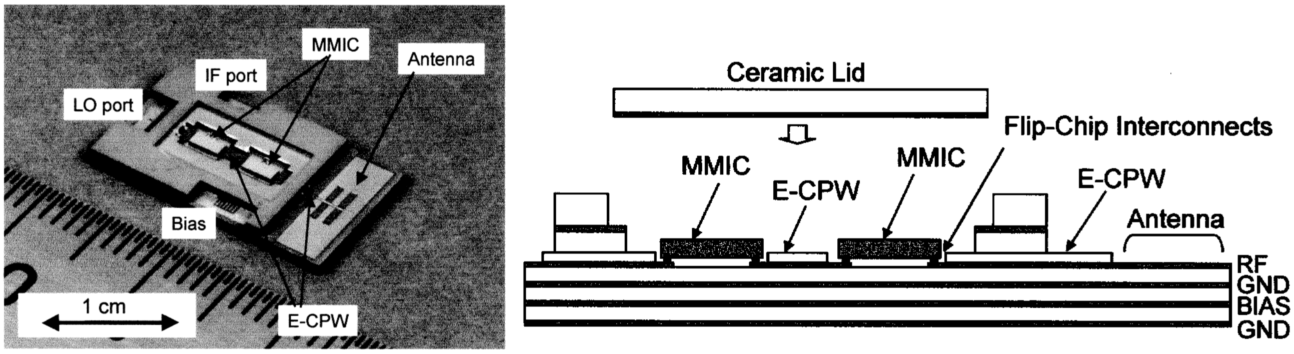

Fig. 5 60GHz-band antenna-integrated MCM using multi-layer LTCC technology (7).

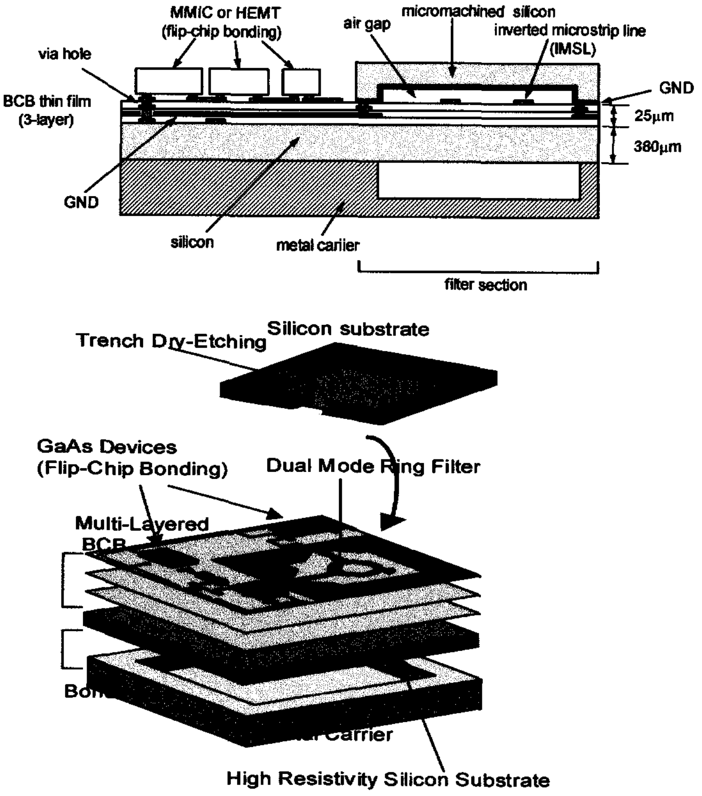

Fig. 6 Structure of front-end IC with a micromachined filter (9).

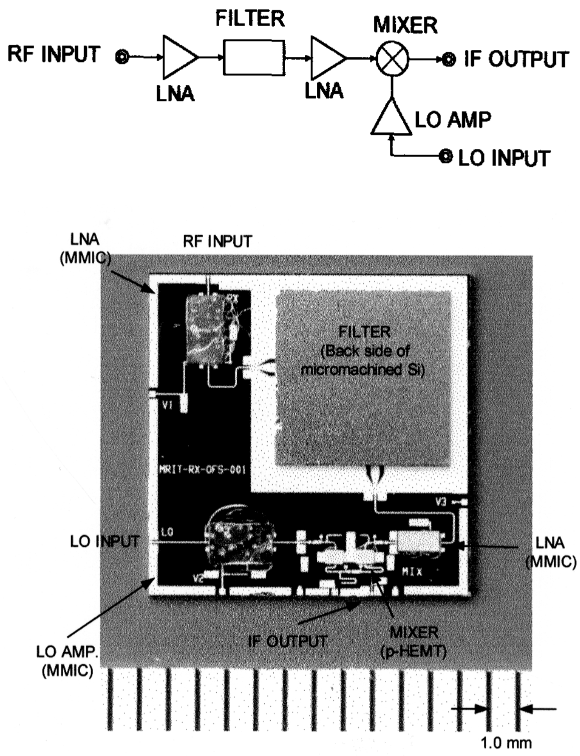

Fig. 7 25GHz-band receiver front-end IC (9).

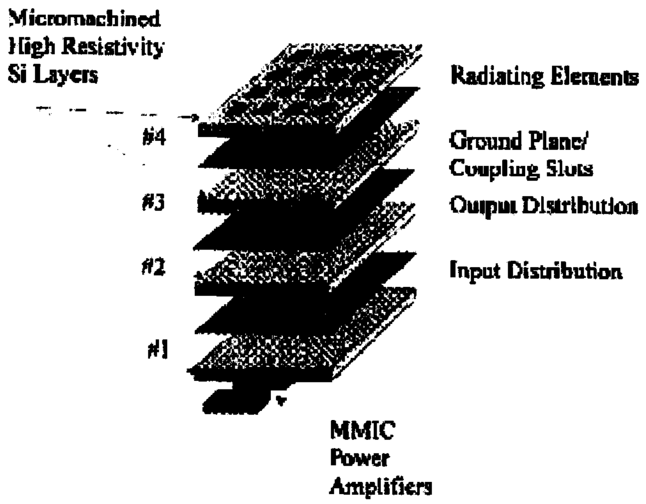

Fig. 8 Concept of Si micromachined power module (10).

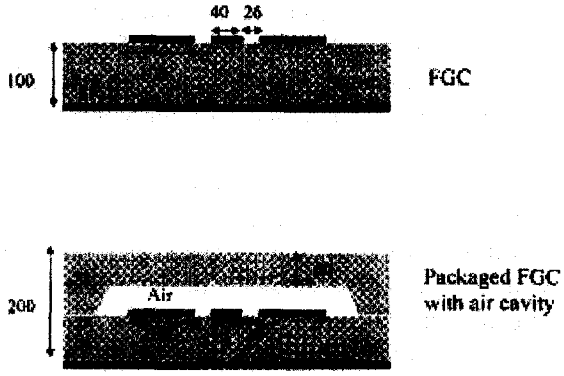

Fig. 9 Cross-section of unpackaged and Packaged FGC line (10).