Millimeter-wave IC Components using Fine Grained Alumina Substrate

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Abstract

To investigate the feasibility of millimeter-wave ICs using Fine Grained Alumina substrate, the propagation loss and effective dielectric constant of the microstrip lines were measured at 50 GHz and millimeter-wave IC components were successfully developed.

Introduction

At present, millimeter-wave circuit technique is successfully applied in communication systems, motoronics and various sensers, in which the waveguide circuits are mainly used.

Althouth, millimeter-wave Integrated Circuits (ICs) have been developed to minimize system sizes among this decade years (1) (2) (3), the ICs were not applied to the actual systems, because quartz, which was mainly used as substrates of the ICs for the patterning accuracy depending on the good surface roughness, has the fatal weak point, such as weaker flexural strength.

We developed the several millimeter-wave passive IC components, such as a branch type 3 dB hybrid, a backward-wave type 10 dB directional coupler, a coupled line for DC blocking and a waveguide to microstrip line transition. In the ICs, Fine Grained Alumina (FGA) substrates developed at Fujitsu were used. (4)

The propagation loss and the effective dielectric constant, which were basic parameters of a dielectric substrate, were measured and these values were sufficient to be applied in the millimeter-wave ICs.

Fine Grained Alumina Substrate

Fine Grained Alumina (FGA) is an alumina of Al_2O_3- MgO-Cr_2O_3 system which is cast by the doctor-blading method.

Table 1 shows the comparison between the FGA substrate and others.

From this table, the cost and the flexural strength are superior to those of the quartz and the FGA has same surface roughness compared with the quartz.

By these reason, we chose the FGA substrate.

In order to investigate the electrical characteristics of the FGA in the millimeter-wave region, we measured the propagation loss and the effective dielectric constant of microstrip line.

To measure the loss, the special waveguide to microstrip transition shown at the top of Fig. 1 was developed. The important items are that the microstrip line length can be accurately measured and the connection between a waveguide and a microstrip line is easy and that this transition has a good VSWR over the wide band.

The configuration, the VSWR and the dead loss of the transition are shown in Fig. 1.

Table 1. Substrate Properties

	98percent alumina	Fine grained alumina	Quartz	Sapphire
ε_r	9.7	9.8	3.8~4.0	9.3~11.7
tan δ (10 GHz)	2 x 10^{-4}	0.5 x 10^{-4} (at 1 MHz)	1 x 10^{-4}	0.5 to 1 x 10^{-4}
Flexual strength (kg/cm^2)	3,100	6,500	700	7,000
Thermal conductivity (cal/cm·sec·°C)	0.06	0.09	0.003	0.09
Surface roughness CLA (μm)	0.4	0.05	0.03	0.03
Relative price	1	2	0.1 ~ 0.5	20~100

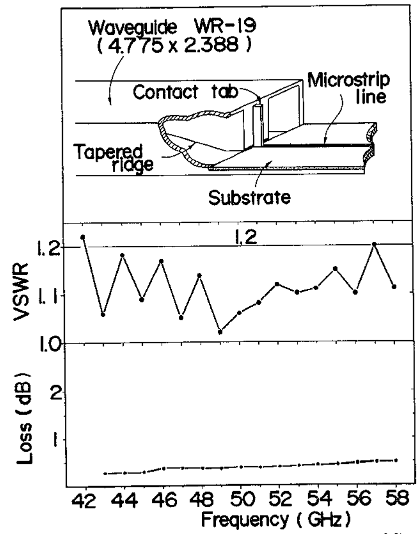

Fig. 1 Frequency Responses of Waveguide to Microstrip Transition

We selected the 0.2 millimeters thick substrate because of the higher cutoff frequency of TE spurious mode and the stronger flexural strength. The cutoff frequency of this thickness is 127 GHz, which is sufficiently higher than the operating frequency range of 40 to 60 GHz.

The measured and calculated results of the propagation loss of the FGA including the transition loss are shown in Fig. 2. The loss at line length 0 is that of the transitions at the both line ends.

The propagation loss of the microstrip line with 0.2 millimeters thick substrate was measured for various line length at three different frequencies. The loss per length can be obtained from the gradient, because the measured losses increase in proportion to the line length. The calculated results computed by the equation in the refference (5). The measured and calculated results are shown in Fig. 2. The measured loss was 5.68 dB per 100 millimeters at 50 GHz.

To determine the exact circuit dimensions in the design of millimeter-wave ICs, it is necessary to know the accurate value of a effective dielectric constant.

In order to measure the effective dielectric constant, the ring type resonator shown at the bottom of Fig. 2 was used and the frequency response was measured. From these results, the effective dielectric constant was calculated by the following equation,

$$\varepsilon_{eff}(fn)=\left\{\frac{n\ C_o}{\pi(2r+W)fn}\right\}^2, \quad \text{----------(1)}$$

where n is the resonant number, C_o the velocity of light, fn the resonant frequency of resonant number n, r the inner radius of the resonator and W the width of the line.

Figure 2 shows these results and calculated results mentioned following. The effective dielectric constant gets higher and higher as frequency increase by frequency dispersion.

The equation by which the effective dielectric constant was calculated was reported by Chudobiak (6),

$$\varepsilon_{eff}(f)=m(f-f_d)+\varepsilon_{eff}(0), \quad \text{--------(2)}$$

where m is the coefficient determined by the dimension of the line, fd the lowest frequency value below which the frequency dependence can be ignored, and $\varepsilon_{eff}(0)$ the static dielectric constant.

In this figure, the measured result curve agrees well with the calculated one. Equation (2) was the exprimental one which was obtained in microwave region. But, from these results, it is validated that this equation was also sufficiently applied in millimeter-wave.

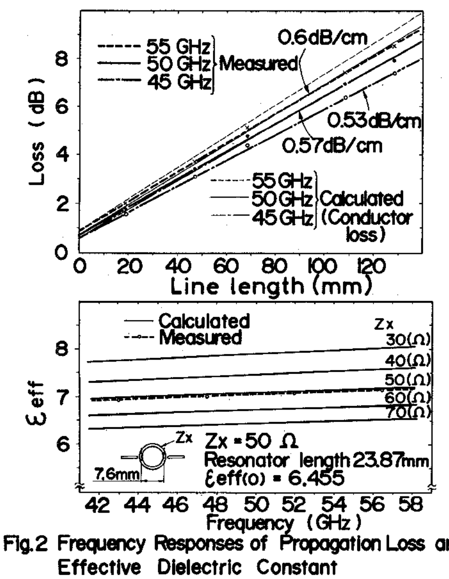

Fig.2 Frequency Responses of Propagation Loss and Effective Dielectric Constant

Passive millimeter-wave IC Components

A branch type 3 dB hybrid was developed in consideration of following problem. As the line width and the diameter of the circle are very small and same order dimension, it is anticipated that the interraction between the lines was occured and that the effective line impedance was different from the calculated one. So, the hybrid was designed using the previously determined values. From the characteristic results, the line width was corrected by computer simulation. Figure 3 shows the characteristics of the 3dB hybrid. The pattern is shown in Fig. 4. The diameter and the line width of the hybrid are around 1 millimeter and around 0.4 millimeters, respectively. The VSWR, the directivity and the dead loss are less than 1.22, more than 20 dB and 0.6 dB over the frequency range from 45.5 to 52.5 GHz, respectively.

Backward-wave type 10 dB directional coupler was developed. The important items of this circuit design is that the 50 ohms line width becomes 1/8 wave length at 50 GHz and that the characteristics of even mode and odd

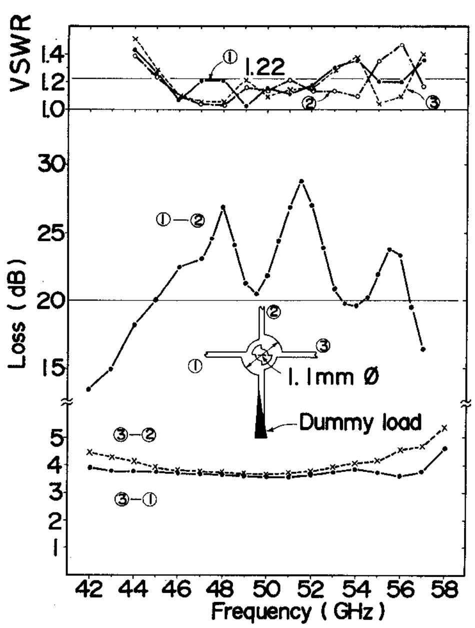

Fig.3 Frequency Responses of 3dB Hybrid

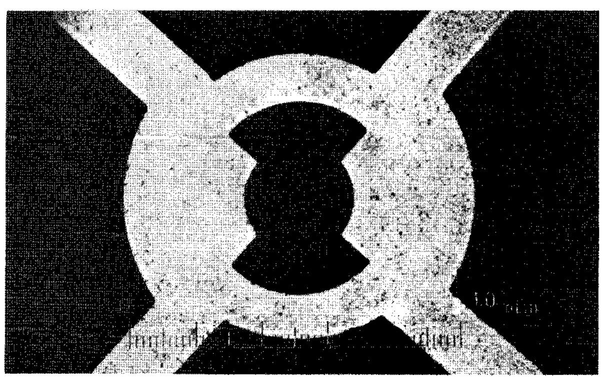

Fig. 4, 3 dB Hybrid Circuit Pattern

mode are different from those in microwave region. From these reasons, the effective coupling coefficient is larger than the calculated, and the correction becomes necessary.

Figure 5 shows the characteristics of the 10 dB directional coupler, Figure 6 shows the characteristics of the coupled line for DC blocking and the dummy load and Figure 7 shows the pattern of the DC blocking. These components have good performances which are sufficiently applied in millimeter-wave ICs.

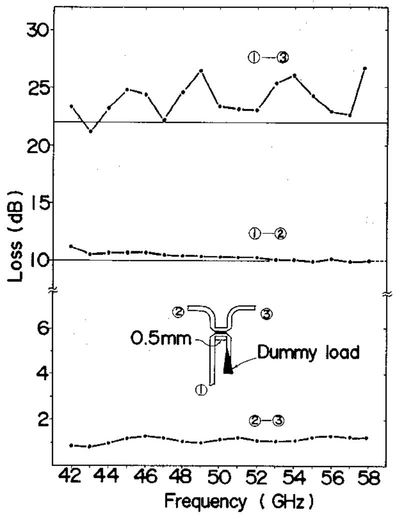

Fig.5 Frequency Responses of 10dB Directional Coupler

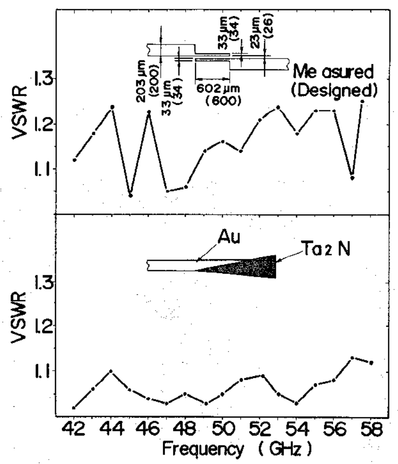

Fig.6 Frequency Responses of Coupled Line and Dummy Load

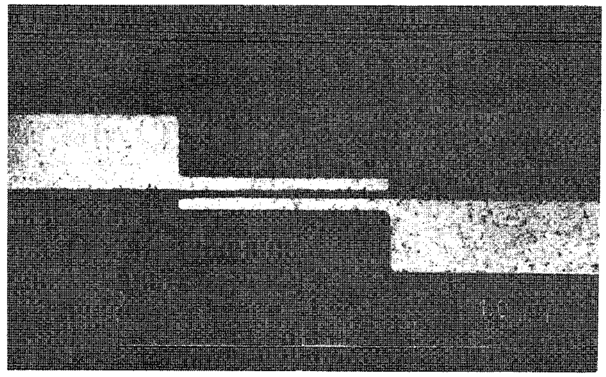

Fig. 7, DC Blocking Circuit Pattern

Conclusion

To validate the feasibility of millimeter-wave ICs using Fine Grained Alumina substrate, the propagation loss and the effective dielectric constant of microstrip line were measured. As the result, the loss and the constant were 5.68 dB per 100 millimeters and 7 at 50 GHz, respectively. These values are sufficiently applied in the millimeter-wave ICs.

The millimeter-wave passive IC components using the FGA such as a branch type 3 dB hybrid, a backward-wave type 10 dB directional coupler, a coupled line for DC blocking and a dummy load were successfully developed.

Acknowledgment

The authors gratefully acknowledge Youichi Arai of Fujitsu for valuable discussion relating to this work and preparing the manuscript.

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