A Novel Microstrip Antenna Using Alumina-ceramic/Polyimide Multilayer Dielectric Substrate

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ABSTRACT

A novel microstrip antenna using an alumina-ceramic/polyimide multilayer dielectric substrate is presented. This configuration in which two different multilayer materials with much different permittivities and thicknesses are stacked together, can be used for designing antenna with selective substrate thickness, thus providing the optimum substrate thickness for operation frequencies. We fabricated prototypes of a 10-GHz-band antenna and an 18-GHz-band antenna, that achieve good return loss of less than -30 dB and a general bandwidth of 2.8 %.

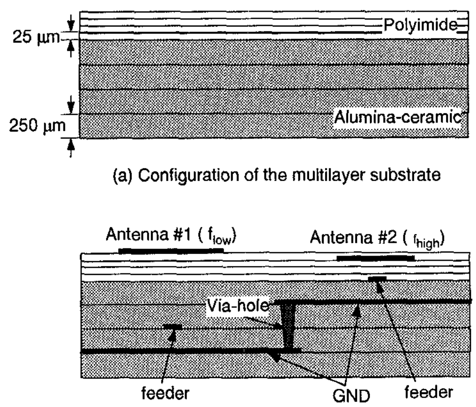
INTRODUCTION

Millimeter-wave systems are becoming important for many application, e.g., wireless LAN, mobile satellite communication systems and radar systems. In millimeter-wave communication systems, many serious problems such as multipass interference and shadowing requires antennas performance of narrow-beam and angle diversity, which make lowering costs and stabilizing systems difficult. The dual-frequency communication system, in which information signals are propagated by millimeter-wave frequencies and control signals are propagated by microwave frequencies, is thought to be an effective solution to these problems. However, conventional microstrip antennas cannot be used with this system because their substrates are manufactured for fixed frequency band operation only. Therefore, we have developed a new microstrip antenna configuration using an alumina-ceramic/polyimide multilayer dielectric substrate that can operate in selective frequency bands.

The significant advantage of these substrates for antenna design is that the effective substrate thickness changes according to the operation frequencies, thus providing the optimum antenna performance. This is because the multilayer substrate consists of two dielectric materials, alumina-ceramic and polyimide, which have much different permittivities and thicknesses. The primary design issue was to confirm weather this configuration, which incorporates the multilayer dielectric substrate, is flexible for designing antennas with the optimum substrate thickness for the broadband frequency range.

CONFIGURATION

Figure 1 (a) shows the four alumina-ceramic and four polyimide layers stacked in the multilayer dielectric



(a) Configuration of the multilayer substrate

(b) Antenna configuration for multifrequency systems

Fig.1 Configuration of the multilayer alumina-ceramic/polyimide dielectric substrate and antenna configuration for multifrequency systems.

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TABLE I

Multilayer dielectric properties

	Alumina-ceramic	Polyimide
Permittivity (@10GHz)	9.0	3.2
Loss tangent (@10GHz)	0.001	0.002
Thermal expansion (x 10^{-5} ℃)	6.8	20 - 70
Metallization material	W (tungsten)	Au (gold)

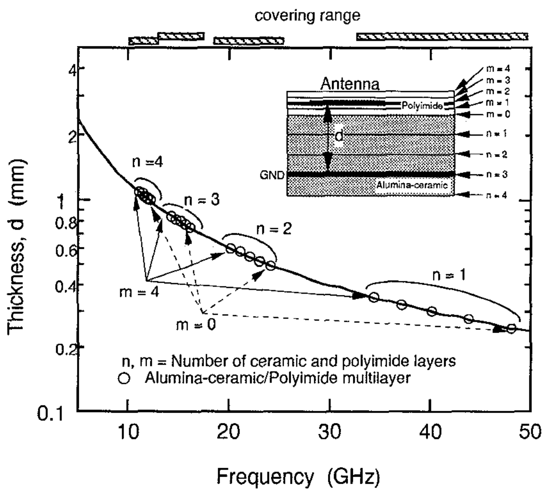


Fig.2 Substrate thickness for suitable microstrip antenna design as a function of frequency. The circles show the frequencies at which 4-layer alumina-ceramic and 4-layer polyimide dielectric substrate can be used.

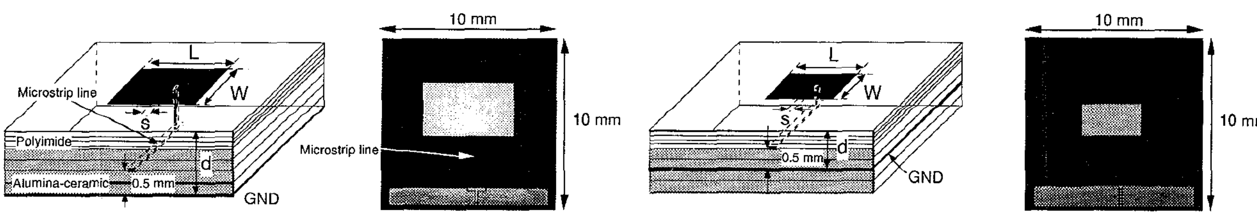
TABLE II

Parameters of patch antennas

	10 GHz-band	18 GHz-band
Length of patch, L	5 mm	3.2 mm
Width of patch, W	3 mm	1.8 mm
Thickness, d	1.1 mm	0.5 mm
Offset, s	0.45 mm	0.37 mm

substrate [1], [2]. Each layer of polyimide is 25 μm, and each layer of alumina-ceramic is 250 μm. The characteristics of these materials are presented in Table I. Antennas and circuits manufactured on alumina-ceramic/polyimide dielectric substrates are highly stable and reliable under 150℃, 85 % r.h. (1.7 atm.), 1000-hour pressure cooker test (PCT) and 1000-times, -65 - 150℃ thermal cycle test (TCT). The substrate thickness giving the best antenna characteristics for operation frequency is shown in Fig. 2. The circles show the frequency at which the multilayer substrate shown in Fig. 1 can be used. The solid line indicates substrate thicknesses typically used for conventional antenna design (e.g. 1/25 free space wave-length). Alumina-ceramic/polyimide multilayer dielectric substrate can be used for designing antenna with optimum performance for selective frequency band, resulting in posibility of antenna design for multi-frequency systems utlilizing the same process as shown in Fig. 1 (b). The continuity of substrate thickness can be improved by increasing the number of layers and making each layer thinner.

Figure 3 shows a schematic diagram and photographs of a 10-GHz-band and an 18-GHz-band microstrip antenna prototype, both 10 x 10 mm² in size. These antennas are directly fed by a 50-μm-radius via-hole connecting a 0.45 mm-wide microstrip line, which is joined to a coplanar waveguide (CPW) at the other terminal for on-wafer measurement. Feeding point is off-set from the center of the patch to match the 50-Ω microstrip line. The 10 GHz-band and the 18 GHz-band patches are respectively 5.0 mm and 3.2 mm long (L; resonant length), 3.0 mm and 1.8 mm wide (w). The off-set lengths s, from the center are 0.45 mm and 0.37 mm as shown in Table II. The ground plane is formed at



(a) Schematic and a photograph of a 10-GHz-band Antenna.

(b) Schematic and a photograph of a 18-GHz-band Antenna.

Fig. 3 Patch antennas using Alumina-ceramic/Polyimide dielectric substrate.

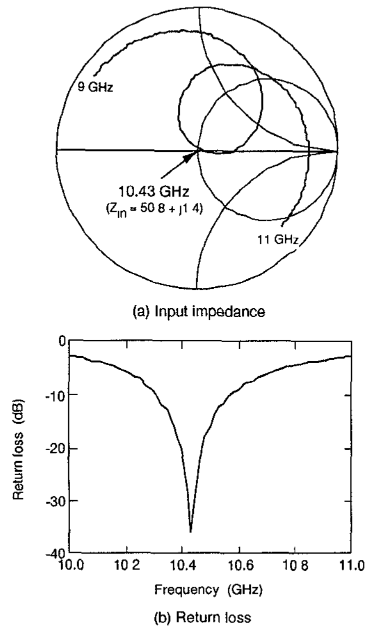


Fig. 4 Smith chart plot of the input impedance and return loss of the 10-GHz-band antenna.

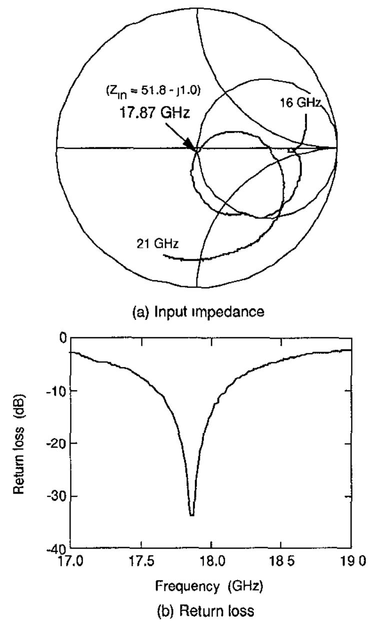


Fig. 5 Smith chart plot of the input impedance and return loss of the 18-GHz-band antenna.

TABLE III

Performance of patch antennas

	10 GHz-band	18 GHz-band
Resonant frequency	10 43 GHz	17.87 GHz
Return loss	- 36 2 dB	- 34 dB
Bandwidth (< VSWR2)	2 8 %	2.9 %
Equivalent permittivity	8 27	6.66

the bottom of ceramic substrate for the 10 GHz-band antenna (substrate thickness: 1.1 mm), and at the middle of ceramicfor the 18 GHz-band antenna (substrate thickness: 0.6 mm).

MEASURED RESULTS

Figures 4 and 5 show a Smith chart plot of the input impedance and return loss of the 10-GHz-band and the 18-GHz-band antennas. Both of them achieve a perfect match at 10.43 GHz and 17.87 GHz respectively, while their return losses are less than -30 dB. Measurement results are summarized in Table III. The bandwidth of the 18-GHz-band antena is wider than that of the 10-GHz-band antenna since the equivalent dielectric constant is lower. Measured far-field patterns of the 10-GHz-band antenna are shown in Fig. 6. The antenna chip is mounted on 10 x 10 cm^2 copper plate. The measured pattern is in good agreement with the pattern calculated by moment analysis considering infinite substrate [3],[4]. A 4-dB

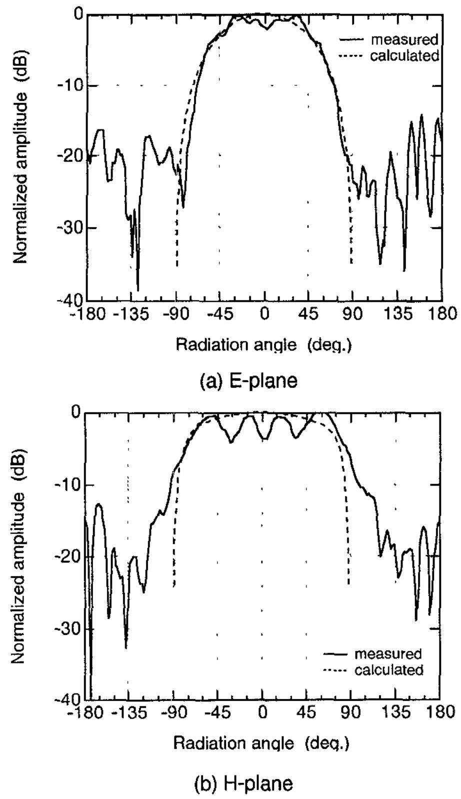


Fig. 6 Radiation patern of the 10-GHz-band antenna.

ripple in the E-plane pattern is generated more by the edge effect of the two ground metals for CPW, rather than by the copper ground plane.

The antennas using multilayer dielectric substrates have many other features, as shown in Fig. 7, such as

(i) The fabricated antenna on multilayer substrate is smaller for a lower frequency, and improves its characteristics at higher frequencies because the equivalent dielectric-constant is decreased by the reduction of the number of ceramic layers.

(ii) This configuration is suitable for integration with active devices and MMICs, since the thermal expansion coefficiency of alumina-ceramic is similar to those of semiconductors such as GaAs and Si.

(iii) The alumina-ceramic bending strength of 350 MPa, which is three and half times stronger than Si substrate, and thus supports array antennas with a number of elements.

(iv) Owing to the multilayer characteristics, the layout of the power combining circuits and bias circuits is more flexible.

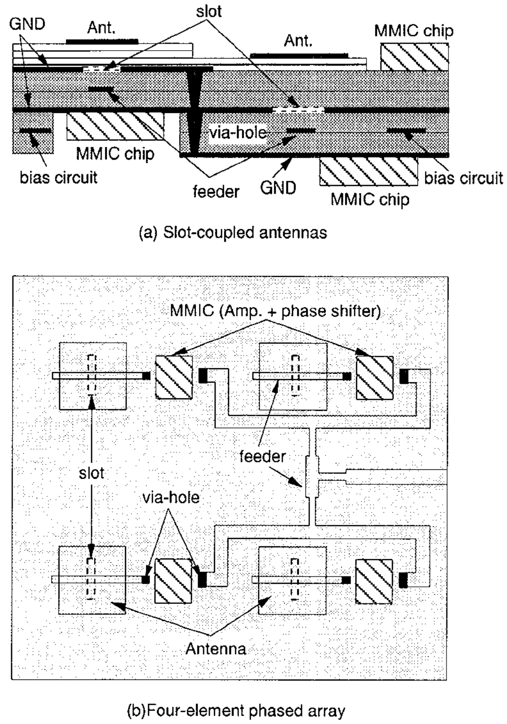


Fig. 7 Antenna configuration of integration with active devices.

CONCLUSION

We presented a microstrip antenna using an alumina-ceramic/polyimide multilayer dielectric substrate and demonstrated prototypes of a 10-GHz-band and an 18-GHz-band antenna. The prototypes performed well, indicating that this multilayer configuration is useful for antenna design for selective frequency band. Thus, multi-frequency communication systems using monolithic multilayer substrate can be achieved. Furthermore, the multilayer configuration can be easily used for designing slot-coupled microstrip antennas [5], and is suitable for active antenna arrays and phased arrays integrated with active devices and MMIC's.

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