A GHz-Band Ceramic Multi-Layer Substrate and Its Application to a Hybrid IC

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ABSTRACT

A novel ceramic multi-layer substrate for mobile communication using alumina-glass composite ceramics and co-fired copper conductors are presented. Electrical characteristics in GHz frequencies of the substrate, copper conductor, transmission line, and via hole were evaluated. Hybrid integrated circuits such as an antenna switch were also demonstrated using the substrate. The results showed that the ceramic multi-layer substrate had good electrical characteristics enough for GHz-band applications. Using the ceramic multi-layer substrates, one can drastically reduce the size of RF circuit boards for mobile communication equipment.

1. INTRODUCTION

In communication electronics, few multi-layer substrates have been used. It is partly because the needs for the multi-layer substrates were not so much as the VCRs or computers and is partly because the microwave characteristics of the multi-layer substrates have not yet been well-known. However, also in communication electronics, the needs for reducing size and weight of the RF circuits have been rapidly increasing.

In conventional RF circuits of mobile portable telephones, resin single layer substrates have been usually used. In order to reduce the size and weight of the RF circuits, some multi-layer structures have been investigated and reported(1)(2). We considered to apply the ceramic multi-layer substrates(3) using alumina(Al_2O_3)-glass dielectric materials and copper(Cu) conductors to microwave circuits, especially for mobile communication equipment.

In this paper, we present the fabrication process, basic microwave electrical characteristics of the ceramics multi-layer substrate having transmission lines, via holes, and its application to GHz frequency circuits.

2. MATERIALS OF THE CERAMIC MULTI-LAYER SUBSTRATES

Copper is one of the best materials for conductors in the multi-layered structure, because it has the lowest resistance next to silver(Ag) and much less electro-migration than Ag, and is cheaper. However, the melting point of Cu is relatively low(1083°C) and easy to oxidize. We used an alumina(55%)-glass(45%) composite for the dielectric substrate, because the firing temperature could be lowered by controlling the amount of glass and could be co-fired in reducing atmosphere without loosing alumina's excellent dielectric properties such as a small dielectric loss at high frequencies. The details of the ceramic multi-layer substrate were described in Ref.(3).

3. BASIC ELECTRICAL CHARACTERISTICS OF THE SUBSTRATE

The basic electrical characteristics in GHz frequencies of the ceramic multi-layer substrate were evaluated from the resonant characteristics of triplate structure resonators. The resonator basically consisted of a 1/2 wavelength stripline sandwiched between two ground planes. The relationship among the resonator length, resonant frequency and Qu (unloaded Q) is shown in **Fig.1**. As a reference, we measured the resonant characteristics of resonators having same dimensions with Ag conductors. The Qu values using Ag conductors and resonant frequencies are also shown in **Fig.1**. The resonant frequencies using Ag conductors were same as those using Cu conductors. Silver has less resistivity than copper, so the Qu using silver conductors was slightly better than that using copper conductors.

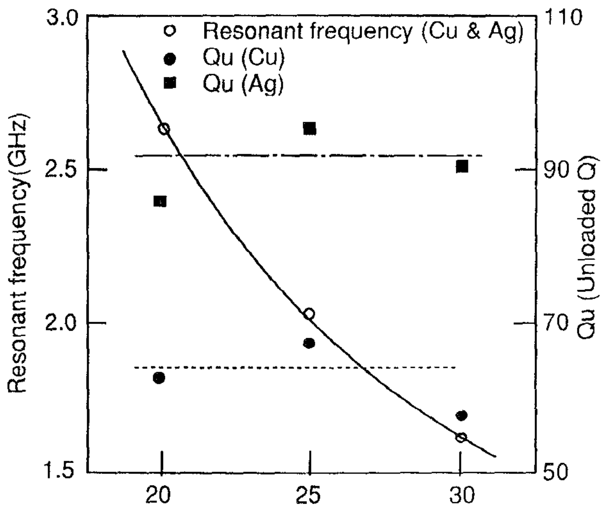


Fig.1 Relationship among resonator length, resonant frequency and Qu

Table 1 Basic characteristics of the substrate materials

Dielectric materials	Alumina with glass composite
Dielectric constant	7.55 (at 2GHz)
Loss tangent	0.005 (at 2GHz)
Conductor	Cu (Reduction from CuO)
Resistivity	4.0 x $10^{-6}\Omega$ cm
Conductor thickness	10 μm

According to the simulation by HP85150 Microwave Design System (MDS) using these values, the basic electrical characteristics of the substrate materials at 2 GHz were estimated and summarized in **Table.1**.

The reduction of dielectric constant and increase of the dielectric loss are due to the addition of the glass material and due to the fabrication process fired at 900°C in reducing atmosphere.The resistivity of the Cu conductor was 4.0X10^{-6} ohm-cm. This value was about twice as that of pure Cu. This is due to the residue of the copper oxide and the roughness of the Cu electrode surface. The resistivity of the Cu conductor was about twice as that of pure Cu.

4. TRANSMISSION LINE

We evaluated the characteristic impedance and transmission line losses of the multi-layered stripline changing the line width(W) and substrate thickness(B).

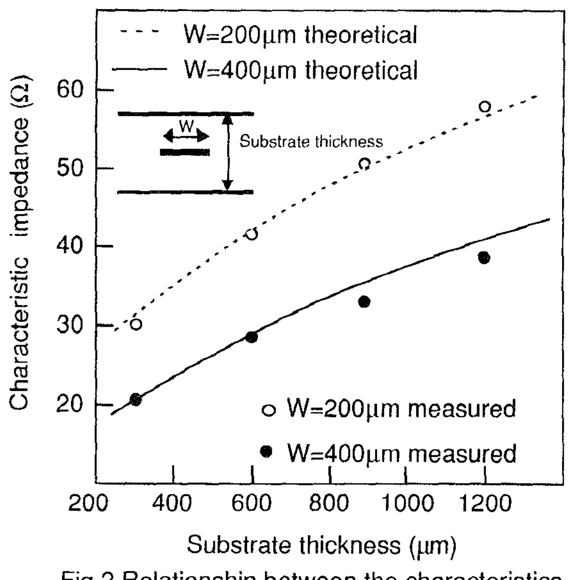


Fig.2 Relationship between the characteristics impedance and the substrate thickness

Figure 2 shows the relationship between the characteristic impedance of the transmission line and substrate thickness. The theoretical values shown by the lines, were obtained from the MDS using the electrical characteristics shown in **Table.1**. The measured values were in good agreement with the theoretical values.

Figure 3 shows the relationship between the transmission line loss and frequency. The line width was 200 μm, the substrate thickness was 910 μm and the characteristics impedance was 50 Ω. As a reference, the transmission losses of the microstrip line consisting of Au thick film (10 μm) on 99.6% alumina substrates are also shown. The linewidth of the microstrip line was 600 μm and the substrate thickness was 635 μm. The characteristic impedance of the microstrip line was 50 Ω. Although the transmission loss was slightly worse than that of the Au conductors on the high purity alumina substrate, it is still good enough for mobile communication application operating in the frequency range from 800MHz to 1.9 GHz.

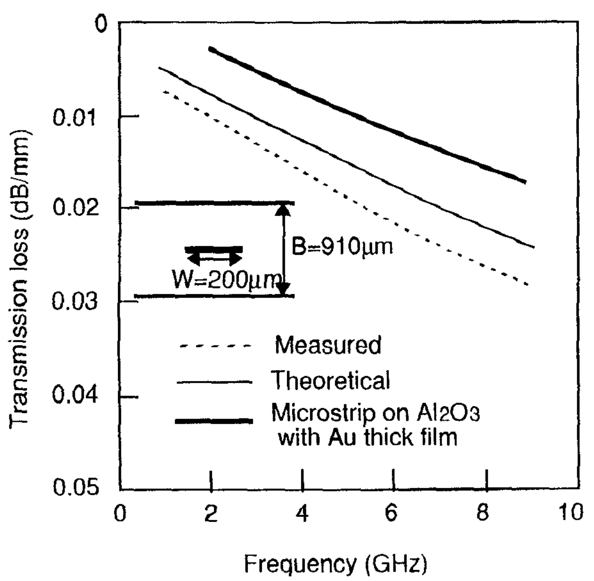


Fig.3 Relationship between the transmission loss and frequency

5. VIA HOLE

Figure 4 shows the relationship between the loss and the frequency of the via hole. The loss was estimated to be 0.012 dB for one via hole at 2GHz. The loss of via hole was small enough.

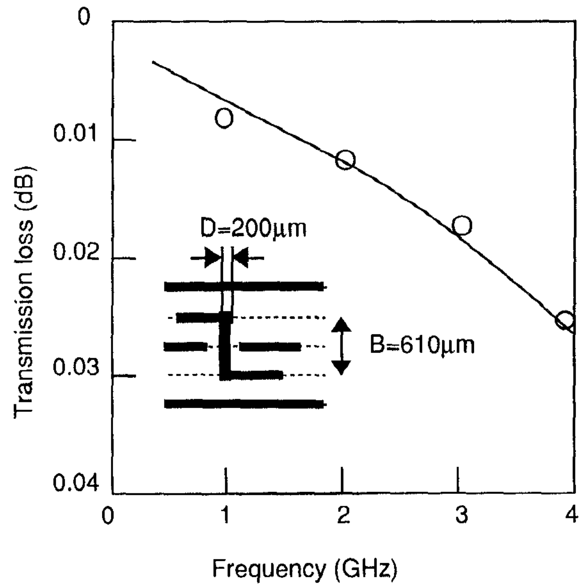
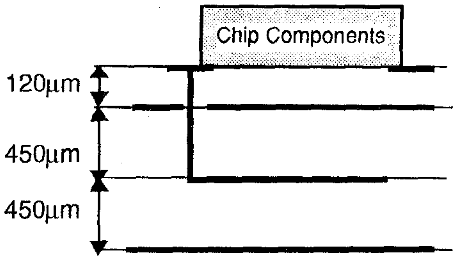


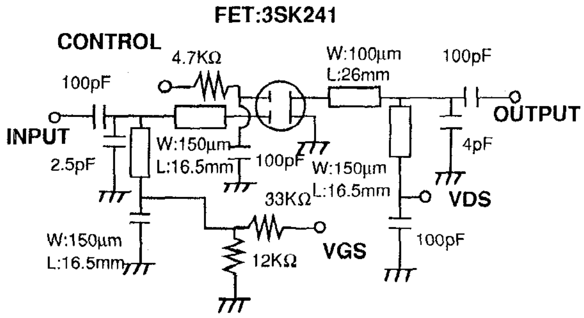
Fig.4 Relationship between the loss and frequency of the via hole

6. APPLICATION

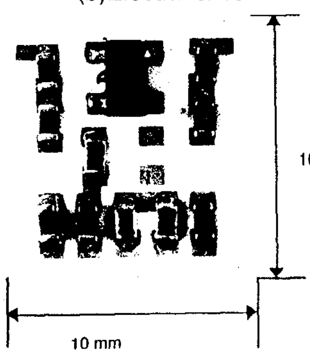
Figure5 shows an RF antenna switch circuit for mobile portable telephones operating at 1.5GHz. It consisted of 3 dielectric layers and 4 electrode layers. It had 3 chip resistors, 7 chip capacitors, and 1 GaAs FET on the top layer. The chip component size was 1.6mmX0.8mm. The S-parameter characteristics are shown in **Fig.6.** As shown in **Fig.6**, the input and output impedance matchings were good enough. The theoretical gain was 13.8 dB by the MDS, and actually obtained gain was 13.0 dB including the input and output connector losses. They were in good agreement. The ON/OFF ratio was 47dB. This value was much better than that made by a monolayer microstrip line circuit. We could reduce the area by 50% using the multi-layer substrate.



(a) Vertical cross sectional view of the substrate



(b)Electric circuit



(c) Photograph

Fig.5 Application to an antenna switch circuit for potable telephones

7. CONCLUSIONS

We evaluated the basic electrical characteristics such as the dielectric constant and dielectric loss of the ceramic multi-layer substrate consisting of the alumina-glass composite and Cu conductors in GHz frequencies. We also evaluated the electrical characteristics of the basic electrical elements using the substrates. We also demonstrated the antenna switch circuit for mobile portable telephones operating at 1.5GHz using the substrate.

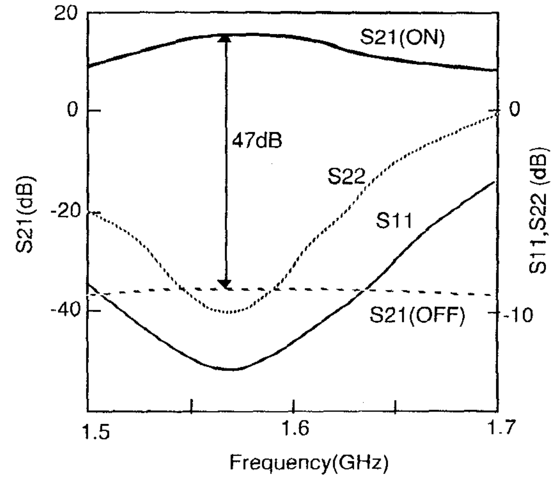


Fig.6 S parameter characteristics of antenna switch circuit

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