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MULTILAYER MICROWAVE DEVICES EMPLOYING Bi-BASED DIELECTRIC CERAMICS WITH COPPER INTERNAL CONDUCTORS

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We have developed a multilayer microwave resonator employing bismuth-based dielectric ceramics with copper internal conductors. The dielectric ceramics mainly consisting of $BiNbO_4$ and a small amount of CuO and V_2O_5 could be sintered at 875 °C in N_2 atmosphere. This ceramics have a excellent dielectric properties at microwave frequencies. The method of multilayer resonator employs copper oxide paste as conductive materials. In this fabrication method , the organic binder was burned-out in air, followed by reduction of copper oxide and sintering. This resonator has good electrical characteristics at microwave frequencies.

1.Introduction

Recently, with the progress in microwave telecommunication and satellite broadcasting, equipment is required to miniaturize. To realize this, multilayer microwave devices were proposed.[1] The microwave dielectric ceramics for this use needs to co-fire with high conductors. Furthermore, the characteristics required for these ceramics are a high dielectric constant (ε_r), a low dielectric loss (a high Q value) and a small temperature coefficient of resonant frequencies (τ_f).

Copper is one of the most promising electrode material for the microwave devices because of its high conductivity and reliability. Copper must be fired in reducing atmosphere because it is easily oxidized in air. On the other hand, a green sheet technique has been used in manufacturing multilayer devices. The green sheet contains a large amount of organic binders. Therefore, it is necessary to remove these organic binders completely by heat treatment in air as the carbonaceous residue doesn't prevent the densification of the dielectric ceramics. The multilayer microwave devices with copper internal conductors couldn't be realized because it was difficult to burn out the binder without the oxidation of copper.

In this paper, we report the dielectric properties of $BiNbO_4$ system at microwave frequencies and the performance of multilayer resonators employing above ceramics and copper oxide paste.

2.Dielectric Materials

2.1.Experimental Procedures

Starting materials were high-purity Bi_2O_3, Nb_2O_5, CuO and V_2O_5 (over 99% purity). They were mixed in a ball mill with pure water, then dried and calcined at 750 to 850°C . The calcined powders were milled again, then dried. After adding an organic binder, they pressed into rods of 6mm in height and 13mm in diameter. The rods were fired at 875 - 975°C for 2 h in N_2. The dielectric constant was measured using Hakki and Coleman's method.[2] The Q value was measured using cavity method with a $TE_{01\delta}$ resonant peak.[3] The temperature coefficient of resonant frequency was obtained by measuring $TE_{01\delta}$ resonant frequencies in the temperature range of -30 to +90°C . Here, τ_f was determined by the resonant frequencies at -25 and 85°C. Furthermore, τ_{fL} was determined by resonant frequencies of -25 and 20°C, and τ_{fH} was determined by the resonant frequencies of 20 and 85°C.

Table 1. Microwave dielectric properties of $BiNbO_4$ system

Additive (wt%)		S.T. (°C)	ε	Q (f₀) (GHz)	τ_{fL} (ppm/°C)	τ_{fH} (ppm/°C)
nothing		1000	35	1270 (4.7)	+33	-4
nothing		1050	30	1085 (5.0)	-279	-272
CuO	0.074	975	44	2240 (4.3)	+21	-21
CuO V_2O_5	0.043 0.050	875	43	4260 (4.3)	+38	+3

2.2.Dielectric Properties

$BiNbO_4$ is known to have a low-temperature phase below 1020°C and a high-temperature phase over 1020°C.[4] According to the XRD pattern, the crystalline phase with sintering temperature 1000°C was the low-temperature phase and it was the high-temperature phase when sintered at 1050°C. The former ceramic has a nonlinear small τ_f value as shown in figure 1 but the latter has a large value. The difference of τ_f by sintering temperature is due to the difference of these phases. Figure 2 shows the change of the Q value by X in $(Bi_2O_3)_x(Nb_2O_5)_{1-x}$. The Q values changed extremely by a little difference of X in the vicinity of X=0.5.

The $BiNbO_4$ without additives had excellent dielectric properties when the crystalline phase was the low-temperature phase, however, dense ceramics couldn't be obtained. Therefore, various additives were investigated. With the addition of CuO or V_2O_5, the ceramics became dense even if fired below 1000°C. Table 1 shows the dielectric properties of these ceramics. They had a high dielectric constant (ε_r>43), a high Q value (Q>2000) and a small τ_f ($|\tau_f|$<40ppm/°C). Particularly, when both were added, the sintering temperature became 875°C and the Q value became high exceeding 4000 (at 4.3GHz).

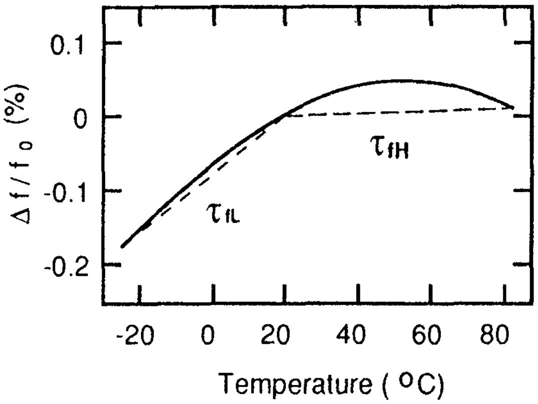

Fig.1 Temperature dependence of resonant frequency change rate of $BiNbO_4$ ($\Delta f / f_0$) with low-temperature phase

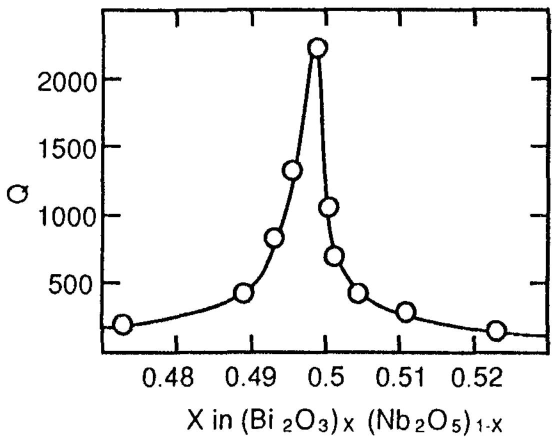

Fig.2 The Q values by $(Bi_2O_3)_X(Nb_2O_5)_{1-X}$

3.Multilayer Devices

3.1.Manufacturing Process

Figure 3 shows the manufacturing process of multilayer devices with copper internal conductors. Multilayered green chips were fabricated by a conventional method from the dielectric green sheets and the copper oxide paste.[5] The green chips were fired in air for burned out the binder. Then they were heated in hydrogen atmosphere for reducing copper oxide. Finally, they were sinterd in nitrogen atmosphere to obtain the multilayer devices with copper internal conductors.

3.2.Results and Discussion

We discussed the performance of the multilayer resonators of 8mm X 4mm X 2mm, as shown in figure 4, concerned with the manufacturing process.

Figure 5 shows the Q values of the multilayer resonators made of the different powders in calcining temperature. The resonators had a high Q value when the calcining temperature was over 800°C although the Q value become below 100 and the conductors look like melting when the calcining temperature was at 750°C. According to XRD pattern, Bi_2O_3 still remained by 750°C calcination. We considered that the remained Bi_2O_3 was reduced to Bi-metal in the

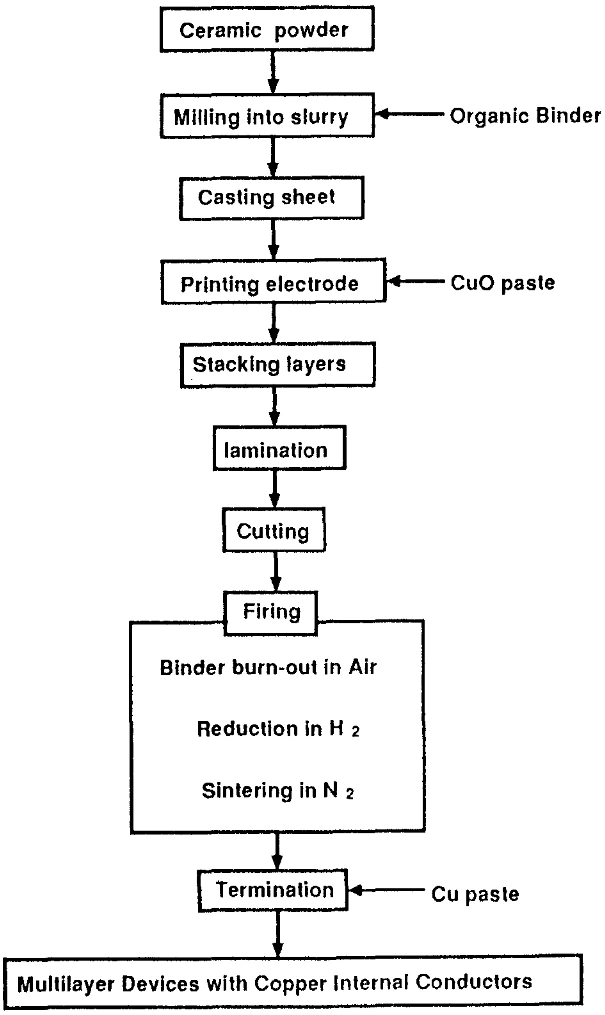

Fig. 3 Manufacturing process of multilayer devices with copper intrnal conductors

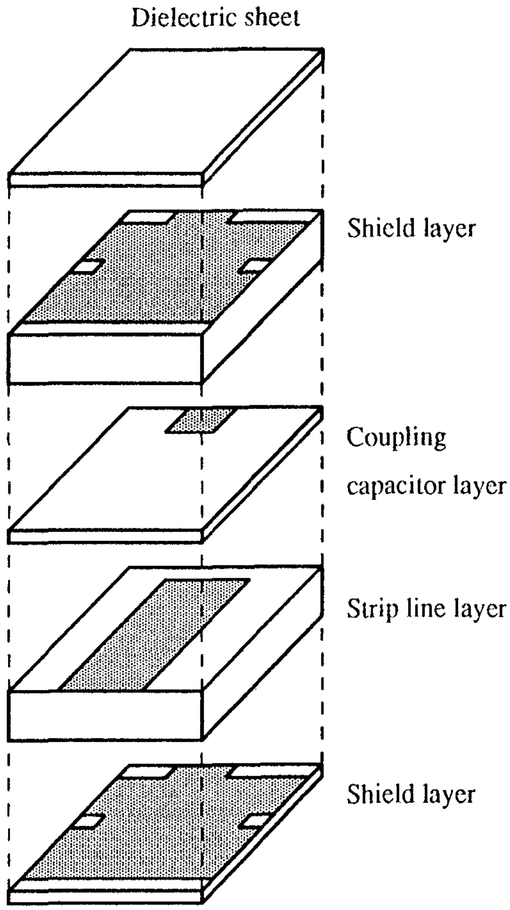

Fig. 4 Structure of multilayer resonator

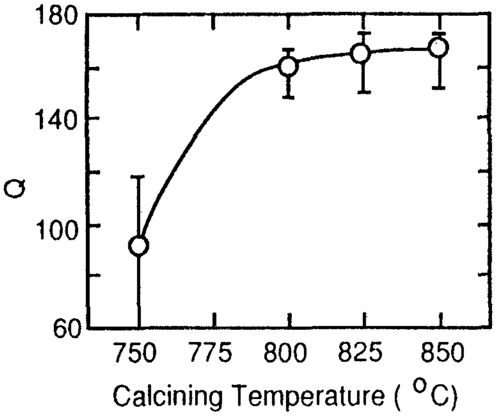

Fig.5 The Q values of multilayer resonators made of different powder in calcining temperature

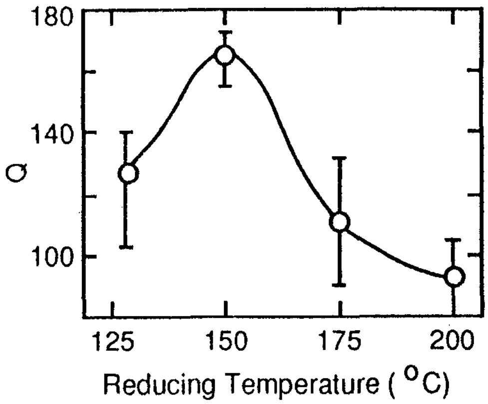

Fig.6 The Q values of multilayer resonators by difference in reducing temperature

reduction process and made a Cu-Bi alloy of low melting point. Therefore, the Q value decreased with increasing of conductor's resistivity.

Figure 6 shows the Q values of mutilayer resonators by difference in reducing temperature. When the reducing temperature was below 130°C, the copper oxide was not enough reduced to copper metal and the Q value decreased. When the reducing temperature was over 175°C, the Q value decreased also. We considered that bismuth oxide in $BiNbO_4$ was reduced to Bi-metal, and a Cu-Bi alloy was made.

When the calcining temperature was at 850°C and the reducing temperature was at 150°C, the excellent multilayer resonator with copper internal conductors, having the Q value of 170 at 1.4GHz, was obtained.

4. Conclusions

We found that the low-fire ceramics in the system of $BiNbO_4$ have excellent dielectric properties at microwave frequencies. Employing the ceramics and the reducing of CuO process, we realized multilayer microwave resonators with copper internal conductors. The miniaturize resonator had high Q value (Q=170) at 1.4GHz.

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