Transactions of the Materials Research Society of Japan 29[4] 1085-1088 (2004)

Dielectric Film by Aerosol Deposition Method for Microwave Filter Application

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Integrating and embedding various passive components like a resistor, a capacitor, and an inductor, in one system module, is one of the attractive way to achieve down-sizing, cost-reduction and higher performance in RF wireless communication products such as a cellular phone, a personal digital assistance (PDA) and so on. Aerosol deposition (AD) method can offer the module with passive components by incorporating different materials with various electrical properties. Our tentative goal is developing the compact microwave filter around 20 GHz with low loss using AD method. Since bulk $Ba(Zn_{1/3}Ta_{2/3})O_3$ has high Q value in high frequency, it is one of the promising candidates for filter dielectrics. In this paper, we describe the experimental results and discussions regarding the microstructure and dielectric properties of $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film deposited in various conditions.

Key words: Aerosol deposition (AD) method, Microwave filter, $Ba(Zn_{1/3}Ta_{2/3})O_3$, LTCC, Room temperature, Q value, 20 GHz

1. INTRODUCTION

Currently, the network system combining information technology (IT) and communication has been developing over 1 GHz very rapidly. The key technologies to build up the network system are wireless communication, optical communication, Intelligent Transportation System (ITS) and so on. For example, over 1 GHz, a lot of applications such as cellular phone and Bluetooth, have been already applied. Around 5 GHz, Electric Toll System (ETC) and wireless Local Area Network (LAN) have been commercialized as a practical product. High speed wireless LAN application in the quasi-milliwave frequency and car-mounted milliwave radar have been studied intensively for practical use. The optical communication becomes popular and also has been researched for the higher frequency system in the future.

In order to construct the network system described above, the hardware technology in microwave range such as LSI technology, Packaging technology, electric component technology and so forth, must be supported. The requirements of the hardware are high-speed, wide-band transmission, miniaturization and multifunction. In latest cellular phone, the digital camera, GPS and Bluetooth are equipped and we can use Internet and E-mail as well as transmit the digital image easily. In the field of electric component, the compact microwave component is definitely necessary. Since the microwave filter is one of the essential components, we study this filter for the network system in the future.

The microwave filter in our research is the compact filter with low insertion loss over 10 GHz for wearable electric equipment. The expected application is short-range and high-speed wireless LAN for transmitting large information data such as Hotspot. In the Hotspot, the portable electric equipment with compact high –performance microwave filter working at high frequency range around 10 GHz, is necessary definitely. However, in current technology, the microwave filter described above cannot be developed. For example, the Surface Acoustic Wave (SAW) filter, which is widely used in cellular phone, can indicate sharp filtering. It is easy to change transmission pass-band by altering the wiring design. However, it cannot be applied in more than 10 GHz, because of the limitation of line dimension, since the pass-band of SAW is dominated in the wiring width. The dielectric resonator has high Q value in high frequency range. Thus, this filter can be applied over 20 GHz. Yet, the miniaturization is difficult, since the volume of circuit board on which the resonator is mounted, cannot be decreased. The microstrip line filter made using multilayer Low Temperature Cofired Ceramics (LTCC) technology, is effective for the miniaturization and can apply to high frequency application. The drawback of the filter is that obtaining low loss is difficult, because low-loss conductor and low-loss dielectrics cannot be applied in the same component simultaneously. That is to say, producing the filter satisfied with the above requirement is difficult.

The microstrip line filter, which has the potential for obtaining the future filter described above compared with other filters, is composed with ceramic dielectrics and conductor. In some applications, the multilayer-structure is adopted. The filter loss is determined by the dielectric loss corresponding to tan δ in ceramics, conductor loss corresponding to the conducting resistance and the radiation loss dominated by a resonator structure. The problem in current technology to develop the future microwave filter with a microstrip line structure, is that the conducting material is restricted in the firing temperature of ceramics, because the conductor is co-fired with ceramic dielectrics in LTCC. The ceramics with low dielectric loss such as alumina and $Ba(Mg_{1/3}Ta_{2/3})O_3$ are fired at high temperature around 1,500℃. Because of that, the only the metal having high melting point like tungsten and molybdenum, which has high resistivity, can be used in the conductor. When the metal with low resistivity such as copper and silver, is applied for the conductor, the firing temperature should be lowered, because of low melting point. The ceramics fired at low temperature around 1,000℃ possess high dielectric properties. Therefore, the combination of low-loss conductor and low-loss dielectrics is impossible in current LTCC system. For that reason, the process temperature of both materials: ceramics and metal, must be lowered and be same to incorporating both materials in the same body.

To overcome the problem, we adopt the aerosol deposition (AD) method to develop the ceramics with low dielectric loss. In this method, the film is formed by bombarding the aerosol ceramics generated in the vibration unit, is transferred through tube and injected from nozzle located in the chamber under the vacuum pressure. The greatest feature of this method is that dense ceramics film can be deposited at room temperature [1, 2]. Since the ceramic raw powder is used as a starting material, it can control the complicated composition and the electrical properties like bulk ceramics. As for conductor, we adopt plating method of which process temperature less than 100 ℃ for developing low-loss wiring. As a result, it is thought that the filter component can be produced at low temperature below 100℃ by applying AD method and plating method.

To develop the compact microwave filter with low loss, we have been studying ceramic film with high Q value by AD method at room temperature, and copper wiring technology by plating method. In this study, we examine the microstructure of ceramic film deposited in various conditions by AD method, and the dielectric properties in AD films, to clarify the correlation between deposition condition, microstructure and dielectric properties.

2. EXPERIMENTAL PROCEDURE

The raw powders used in this study are $Ba(Zn_{1/3}Ta_{2/3})O_3$ (average particle size: 0.5 μm) produced in solid state reaction method shown in Fig. 1, and Al_2O_3 coated TiO_2 powder (average particle size: 0.3 μm), shown in Fig. 2. From SEM observation result, both raw powders have almost spherical shape. Two vol%-α alumina (average particle size: 0.2 μm) was added in some of $Ba(Zn_{1/3}Ta_{2/3})O_3$ powders.

The aerosol deposition was carried out in the equipment shown in Fig. 3, under the following condition (Deposition time: 10 min., Gas pressure: 2 kg/cm2, Gas flow: 4 l/ min., Base pressure in chamber < 10 Pa). The carrier gases used in this study are O_2, N_2 and He. The deposition rate is almost 1 μm/min. After depositing AD film, the microstructure of the film was observed using Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM). The dielectric constant and dielectric loss at 10 kHz was measured using capacitance-bridge method.

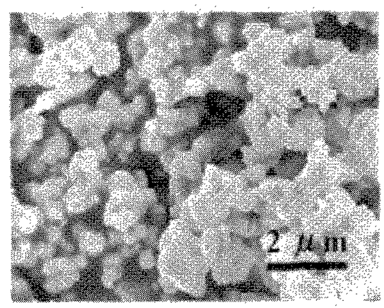


Figure 1 Raw $Ba(Zn_{1/3}Ta_{2/3})O_3$ powder used in this study

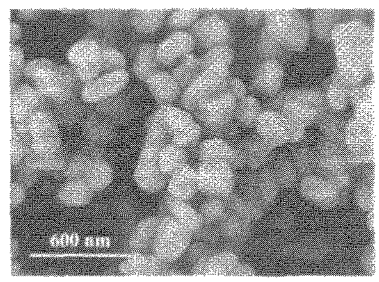


Figure 2 Al_2O_3 coated TiO_2- mixture powder used in this study (x 20,000)

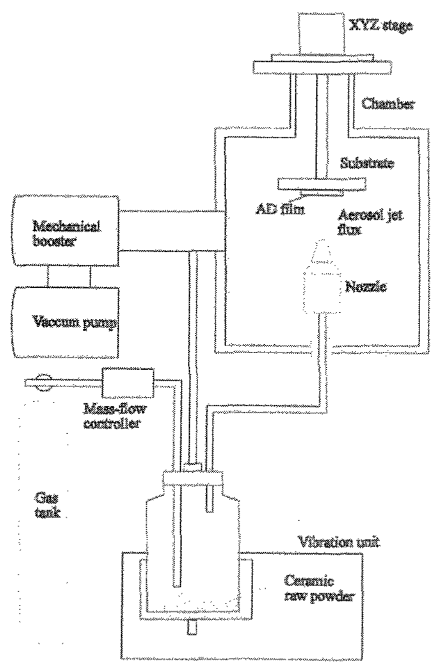
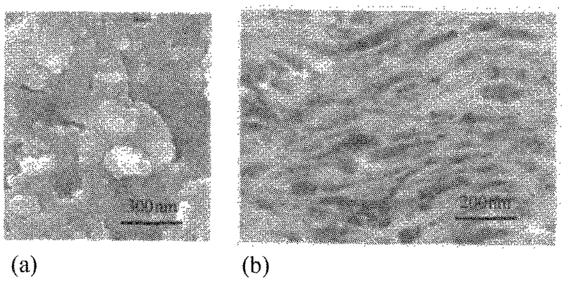


Figure 3 Schematics of the equipment of AD method.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

In order to understand the deposition mechanism of AD film, the microstructure of AD film was observed with a SEM and TEM. Figure 4 (a) and (b) show the surface view and the cross-sectional view of the microstructure of TiO_2/Al_2O_3 AD film deposited in N_2. In Fig. 4 (a) (Top view), the round shape particles around 30 nm are observed. In contrast, the lamellar structure with TiO_2/Al_2O_3 is observed in the cross-sectional view. Since the raw powder is spherical shape, it is thought that the ceramic particles are collapsed and are adhered with the substrate. It seems that the lamellar structure is formed for the reason that the collapsed particles are pilled and stacked, as shown in Fig. 5.



(a) (b)
Fig. 4 Microstuctre of TiO_2/Al_2O_3 AD film deposited in N_2 (a) (Top view),
(b) (Cross-sectional view).

Figure 6 and 7 show the microstructure of $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film deposited in O_2 and He atmosphere, respectively. In the AD film deposited in O_2 (Fig. 6), large pores are not observed and the lamellar structure is formed in the same morphology of Fig.4. In contrast, large pores and large particles more than 500 nm are observed in the film deposited in He (Fig.6).

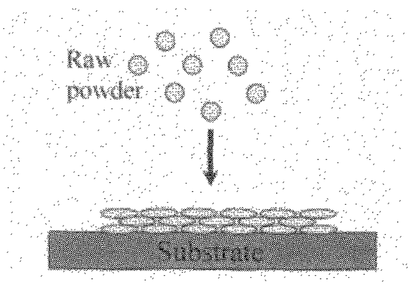


Fig. 5 Schematics of the mechanism model of AD deposition.

The small particles less than 50 nm, are located between large particles. It seems that the small particles play a role of bonding agent between large particles, as shown in Fig. 8. Table 1 lists the speed of sound of gas at room temperature. The speed of sound of He is more than twice as much as other gases such as N_2 and O_2. It is thought that the He gas carries much larger particles, taking into account this speed of sound. It seems that these large particles prevent the homogenous lamellar structure, and make large pores introduce in AD film.

In high purity gas used in this study, some of the oxygen is included as a contamination. As shown in Table 2, three ppm oxygen was in He, and 50 ppm oxygen was in supplied N_2. Table 2 shows the relationship between the carrier gas for deposition and the dielectric properties of $Ba(Zn_{1/3}Ta_{2/3})O_3$ film deposited.

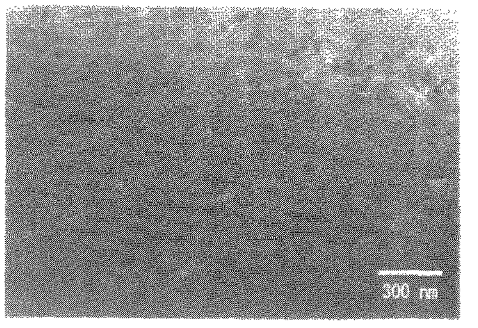


Fig. 6 Microstuctre of $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film deposited in O_2

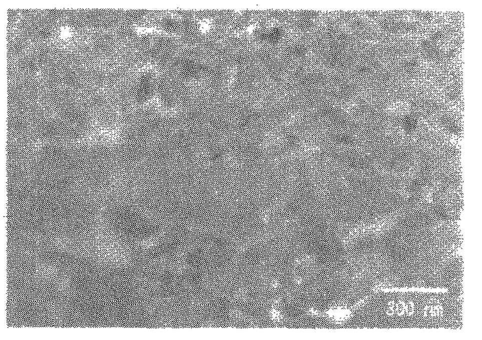


Fig. 7 Microstuctre of $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film deposited in He.

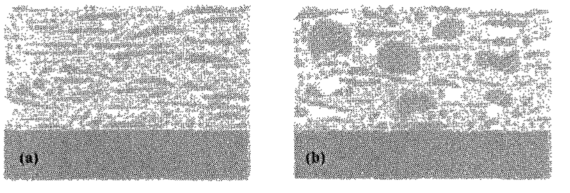


Fig. 8 Schematic model of the microstructure of AD film (a)O_2 deposition, (b)He deposition.

Table 1 Speed of sound of gas at RT

Carrier gas	Speed of sound (m/sec)
He	965
N_2	353
O_2	330

Table 2 Dielectric properties of $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film deposited in various carrier gas.

Carrier gas [O_2 content]	Dielectric constant [@10kHz]	Q value (1/tan δ) [@10kHz]
He [3 ppm]	77	104
N_2 [50 ppm]	57	240
O_2 [100%]	50	500

*Bulk $Ba(Zn_{1/3}Ta_{2/3})O_3$: 30 (Dielectric constant), 5,000 (Q value)

From these results, it seems that the dielectric properties are dependent on the oxygen content in carrier gas. The dielectric constant is decreased by increasing the oxygen content. On the contrary, Q value is increased with increasing the oxygen content. When conventional oxide ceramics are fired at low-oxygen partial pressure, the oxygen point defect is formed by reduction, depending on the enthalpy of defect formation, band gap Eg, the mobility of electron and so on.

$$O_O \rightarrow 1/2\, V_O^{\cdot\cdot} + e^-$$

When the oxygen defect is introduced in dielectrics, the surface color is changed from white to black and the properties like n-type semiconductor is expressed. As a result, high dielectric constant and low Q value are obtained when fired in low oxygen partial pressure. It is thought that similar phenomenon takes place in this aerosol deposition, like the bulk ceramics fired in low oxygen partial pressure. Compared with the dielectric properties of bulk $Ba(Zn_{1/3}Ta_{2/3})O_3$, the dielectric constant of $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film is higher. Therefore, it is considered that some of the semiconductor layer is still formed in $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film. Further study should be done to better understand these experimental results.

Figure 9 shows the cross-sectional view of the microstructure of $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film deposited in N_2. Lamellar structure is observed and layer-shaped macro pores are observed. As listed in Table 2, Q value of the AD film is 240. It is considered that this low Q value results from large amounts of pores in the AD film.

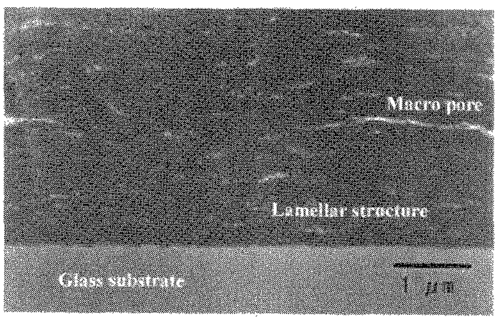
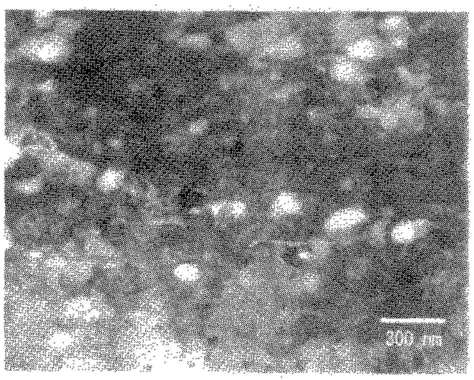
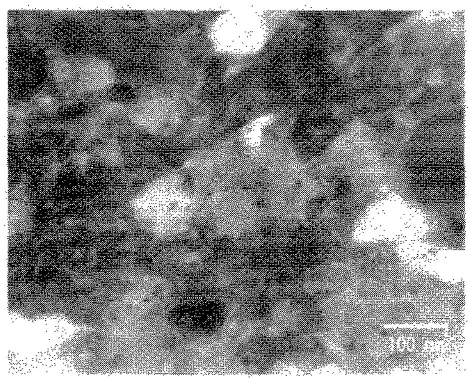


Fig. 9 Microstuctre of $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film deposited in N_2.



(a)



(b)

Fig. 10 (a), (b) Microstuctre of alumina added $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film deposited in N_2. [white part: Alumina]

Since alumina has high Q value, high $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film can be expected by adding alumina. The Q value of AD film using the $Ba(Zn_{1/3}Ta_{2/3})O_3$ powder adding alumina powder by 2 vol.%, is increased (Q value: 470), following our expectation. Added alumina is incorporated in the pore, which is formed in the $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film without additive, as shown in Fig. 10.

4. CONCLUSIONS

We examine the microstructure of ceramic film deposited in various conditions by AD method using SEM and TEM, and dielectric properties in AD film using capacitance-bridge method. As a result, the following conclusion is obtained.

(1) Ceramic particles are collapsed and lamellar structure is observed in AD film (TiO_2/Al_2O_3).

(2) Large pores and particles exists in $Ba(Zn_{1/3}Ta_{2/3})O_3$ AD film deposited in He atmosphere with high speed of sound.

(3) Small particles play a role of adhering with large particles.

(4) Oxygen partial pressure in carrier gas, and additive of raw powder affect Q value.

Acknowledgement

This research was partially supported by NEDO projects of "Nano Structure Forming for Advanced Ceramic Integration Technology in Japan nano technology program".

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(Received October 11, 2003; Accepted March 10, 2004)