Low loss Z-type barium ferrite (Co_2Z) for terrestrial digital multimedia broadcasting antenna application

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(Presented 11 November 2008; received 25 September 2008; accepted 3 December 2008; published online 4 March 2009)

Magnetic properties of sol-gel and conventional ceramic processed $Ba_3Co_2Fe_2O_{41}$ hexaferrite were investigated and compared for terrestrial digital multimedia broadcasting (T-DMB) antenna application. All of the synthesized powder and sintered body showed almost single Z-phase. The loss tan δ of sol-gel processed and sintered Co_2Z hexaferrite was 0.010 at 200 MHz, while conventional ceramic processed and sintered Co_2Z showed 0.068. The ω_d (resonance frequency of domain wall) and ω_s (resonance frequency of spin components) of sol-gel and ceramic processed hexaferrites were estimated to be 10 and 1160 MHz and 17 and 1025 MHz, respectively. The frequency difference between ω_d and ω_s (1150 MHz) for the sol-gel processed hexaferrite is wider than that (1008 MHz) for the ceramic processed hexaferrite. The permeabilities of sol-gel and ceramic processed hexaferrites were 6.91 and 9.23 at 200 MHz, respectively. Both permeabilities are higher than 6.88 and 7.64 of corresponding permittivities at the same frequency, respectively. It is found that the sol-gel processed and sintered Z-type hexaferrite meet desired low-loss tan δ and broadband for T-DMB antenna. © *2009 American Institute of Physics*. [DOI: 10.1063/1.3073940]

I. INTRODUCTION

Antenna miniaturization is demanded for terrestrial digital multimedia broadcasting (T-DMB) antenna, where the center frequency is 200 MHz. It has been known that antenna size can be reduced by use of ferrite having permeability (μ) and permittivity (ε).[1,2] In order to realize the ferrite antenna application, low loss tan δ, less than 3%, is desired for high electromagnetic radiation. Furthermore, the $\mu > \varepsilon$ property of the ferrite enhances broadband performance of the antenna.[1]

Hexagonal Z-type $Ba_3Co_2Fe_2O_{41}$ (Co_2Z) hexaferrite has high permeability and low loss property in the range of T-DMB frequency. Most recently, Zn doped Co_2Z,[3] Z-type Ba–Sr ferrite,[4] thermal stability of Co_2Z,[5] and Co_2Z-epoxy composite[6] have been intensively studied. Synthetic mechanisms of Co_2Z and static magnetic properties have been reported but the high frequency loss mechanism of sintered Co_2Z hexaferrite has not been sufficiently studied.

In this paper, we report Co_2Z hexaferrite having 0.01 of loss tan δ at 200 MHz and its static and dynamic magnetic properties for T-DMB antenna applications. The sol-gel process (SGP) and conventional ceramic process (CCP) were used for the synthesis of Co_2Z precursors.

II. EXPERIMENTAL

Starting materials such as $Ba(NO_3)_2$, $Co(NO_3)_2 \cdot 6H_2O$, and $Fe(NO_3)_3 \cdot 9H_2O$ were used for SGP and $BaCO_3$, CoO, and α-Fe_2O_3 used for CCP according to Fe/Ba mole ratio of 7.2 and 8.0, respectively. A mixture of starting materials was shake milled for 10 h with hardened-steel balls in a jar, which had a balls-to-powder weight ratio of 10:1. The shake milled precursors were subjected to two-step calcinations. The first-step calcination was performed at 1000 °C for 4 h and followed by the second-step calcination at 1300 °C with ambient O_2 pressure to obtain pure Z-type phase. In order to prepare sintered ring for dynamic magnetic property measurements, the second-step calcined Co_2Z powder was mixed with polyvinyl alcohol binder (1 wt %) and pressed with a steel mold (inner diameter 3 mm and outer diameter 7 mm). Green bodies were then sintered in O_2 at 1300 °C for 2 h.

Crystal phase of the second-step calcined Co_2Z particles and sintered body were characterized by an x-ray diffractometer using Cu $K\alpha$ radiation. Vibrating sample magnetometer was used to characterize static magnetic properties of the second-step calcined Co_2Z particles and sintered body. Network analyzer (Agilent N5230A) and coaxial air line fixture (Agilent 85051-60007) were used to measure permeability spectra of sintered Co_2Z rings.

III. RESULTS AND DISCUSSION

Precursors of Co_2Z processed by SGP and CCP contain both M-($BaFe_{12}O_{19}$) and Y-type ($Ba_2Co_2Fe_{12}O_{22}$) phases after the first-step calcination at 1000 °C. During the second-step calcination at 1300 °C, M- and Y-phases were transformed to Z-type phase including traces of W- and Y-type phases. However, these W- and Y-type phases almost disappeared leaving behind Z-type phase after sintering process at 1300 °C. This is shown in Fig. 1. On the other hand, decomposition of Co_2Z hexaferrite to M- and Y-type phases was

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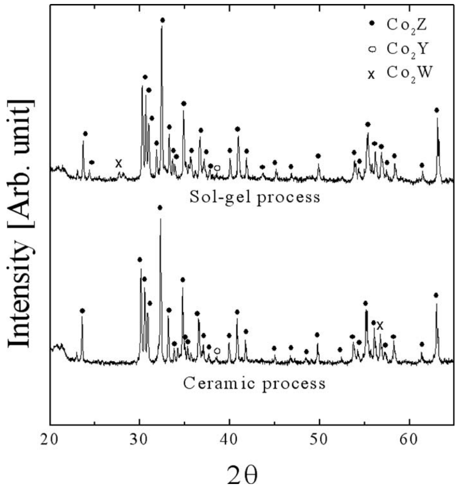

FIG. 1. XRD patterns of sintered Co_2Z hexaferrites processed by SGP and CCP.

observed during cooling the Co_2Z in air from 1300 to 1000 °C. Therefore, oxygen was sufficiently supplied into the tube furnace during the second-step calcination and sintering process in this work.

The Co_2Z phase was identified as the main phase after the second-step calcination at a temperature ranging from 1250 to 1350 °C. However, above 1350 °C, a minor *W*-type phase appeared due to thermal decomposition of Co_2Z around 1360 °C and increased with cooling time.[5] Therefore, the temperature of 1300 °C was chosen for the second-step calcination in this study.

Our previous work, which is not reported here, shows that the traces of *W*- and *Y*-type phases have a negligible effect on loss tan δ at 200 MHz because their permeability and ferromagnetic resonance frequency are lower and greater than Co_2Z, respectively.

Magnetic hysteresis loops of Co_2Z powder and sintered body are given in Figs. 2(a) and 2(b), respectively. Magnetization of CCP Co_2Z powder is very close to the theoretical value of 50 emu/g, while the magnetization of SGP Co_2Z powder is 41.4 emu/g at 10 kOe. It is speculated that greater Fe/Ba ratio of 8.0 for CCP than SGP of 7.2 contributes to higher magnetization of CCP Co_2Z. On the other hand, coercivity of Co_2Z powder by SGP and CCP were 17.58 and 22.57 Oe, respectively. The magnetization and coercivity of SGP and CCP sintered Co_2Z ring were 41.31 and 48.17 emu/g at 10 kOe, 7.1 Oe, and 5.7 Oe, respectively, as shown in Fig. 2(b). These lowered coercivity values are attributed to minimized trace of hard magnetic *W*- and *Y*-type phases by sintering.

The scanning electron microscopy (SEM) micrographs in the Figs. 3(a) and 3(b) are surface images of SGP and CCP sintered Co_2Z bodies, respectively. Grains of SGP Co_2Z show more uniform size distribution and smaller size than those of CCP Co_2Z. According to previous reports,[7,8] high frequency loss property of ferrite is dependent upon microstructure. Permeability of CCP Co_2Z ring was higher than SGP due to high magnetization of CCP, as shown in Fig. 4(a). In particular, the SGP Co_2Z shows 0.010 of loss tan δ at 200 MHz, while CCP Co_2Z has 0.068. This is attributed to

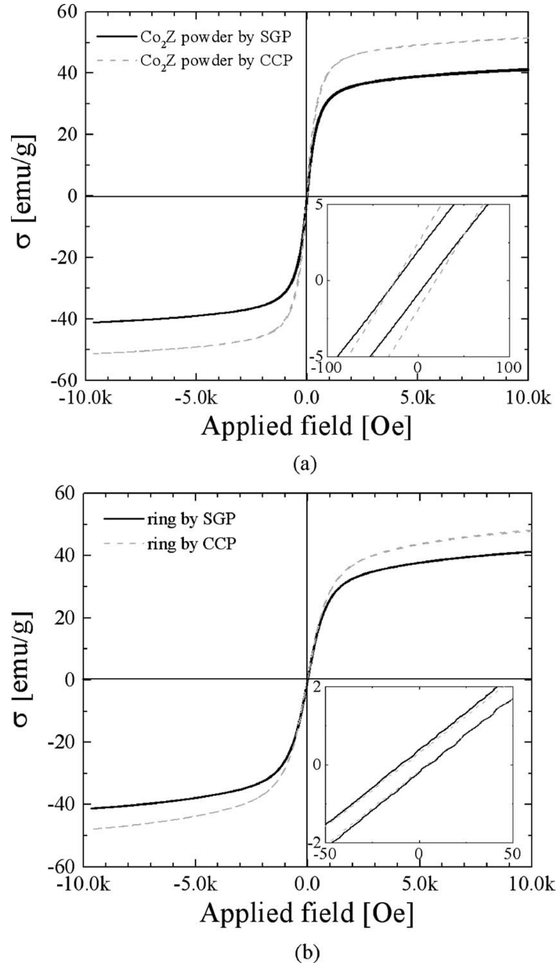

FIG. 2. Magnetic hysteresis loops of Co_2Z (a) powder and (b) sintered body.

smaller and more uniform grains of SGP than CCP, which leads to low P_e (eddy current loss) and P_r (residual loss) in the high frequency range.[7] Frequency dispersion of polycrystalline ferrite permeability can be written by the following equations:[9]

$$\mu' = 1 + \frac{\omega_d^2\chi_{d0}(\omega_d^2+\omega^2)}{(\omega_d^2-\omega^2)^2\omega^2\beta^2} + \frac{\chi_{s0}\omega_s^2[(\omega_s^2+\omega^2)+\omega^2\alpha^2]}{[\omega_s^2-\omega^2(1+\alpha^2)]^2+4\omega^2\omega_s^2\alpha^2}, \tag{1}$$

$$\mu'' = \frac{\chi_{d0}\omega\beta\omega_d^2}{(\omega_d^2-\omega^2)^2+\omega^2\beta^2} + \frac{\chi_{s0}\omega_s\omega\alpha[\omega_s^2+\omega^2(1+\alpha^2)]}{[\omega_s^2-\omega^2(1+\alpha)^2]^2+4\omega^2\omega_s^2\alpha^2}. \tag{2}$$

Here, ω is the electromagnetic field frequency, ω_d and ω_s are resonance frequency of domain wall and spin components, χ_{d0} and χ_{s0} are static magnetic susceptibilities, and α and β are the damping factors of spin and domain wall movement, respectively.

The measured permeability data given in Fig. 4(a) were fitted to the Eqs. (1) and (2) by six fitting parameters (ω_d, ω_s, χ_{d0}, χ_{s0}, α, and β). Accordingly, the ω_d and ω_s of SGP Co_2Z ring were found to be 10 and 1160 MHz, respectively. On the other hand, the ω_d and ω_s of CCP were 17 and 1025 MHz,

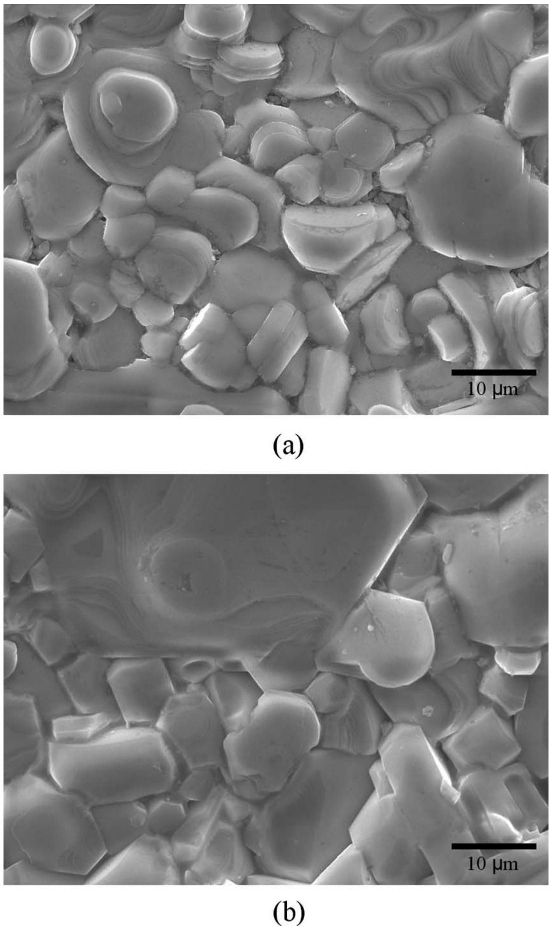

FIG. 3. SEM images of (a) surface of sintered Co_2Z by SGP and (b) CCP.

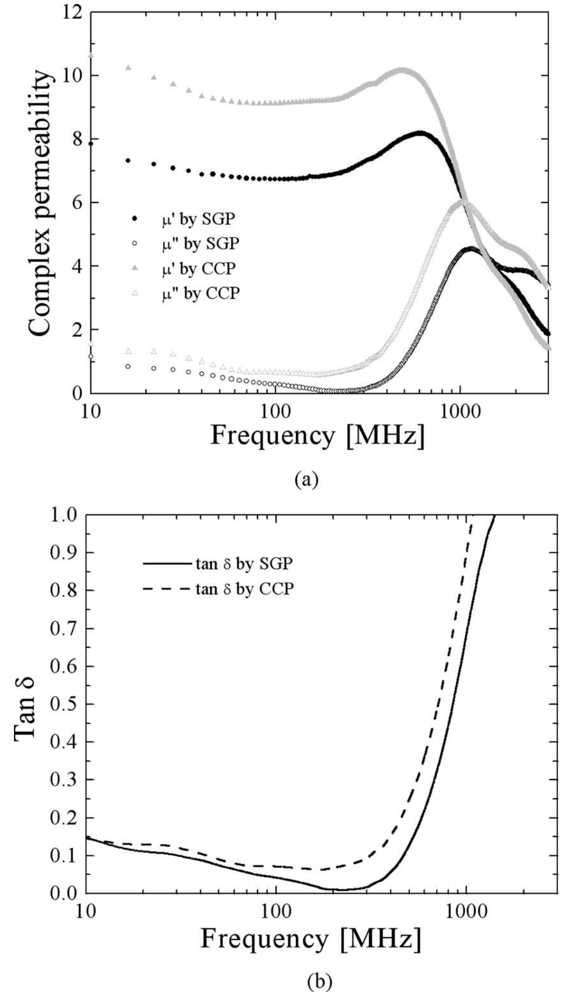

FIG. 4. Frequency dependences of (a) complex permeability and (b) tan δ_μ of SGP and CCP Co_2Z rings.

respectively. Therefore, the low loss tan δ of SGP Co_2Z at 200 MHz is attributed to a wider frequency gap between ω_d and ω_s than that of CCP Co_2Z. In addition, α and β of SGP Co_2Z were estimated around 0.88 and 2.0×10^8, respectively, while α and β are 0.91 and 8.5×10^8 for CCP Co_2Z. In order to minimize loss tan δ at 200 MHz, small (<10 μm) and uniform grain and $\mu_r<7$ are desired. Furthermore, measured ε_r of Co_2Z at 200 MHz were 6.88 and 7.64 for SGP and CCP, respectively.

IV. CONCLUSIONS

Almost single phase Co_2Z was successively synthesized by SGP and CCP. Traces of *W*- and *Y*-type phases of calcined Co_2Z powder are effectively reduced by sintering process. Magnetization and coercivity of sol-gel processed and sintered Co_2Z hexaferrite were 41.3 emu/g and 7.1 Oe at 10 kOe, respectively. The μ_r of 6.91 was greater than ε_r of 6.88 at 200 MHz for sol-gel processed and sintered Co_2Z. Antenna miniaturization and broadband performance can be realized by these higher μ_r than ε_r property and high μ_r value.

The loss tan δ of 0.010 at 200 MHz was achieved for sol-gel processed and sintered Co_2Z hexaferrite and 0.068 for conventional ceramic processed and sintered Co_2Z. This is attributed to smaller grains and uniform grain size distribution of sol-gel processed and sintered Co_2Z as compared to the conventional ceramic processed and sintered Co_2Z. Therefore, dynamic property of sol-gel processed and sintered Co_2Z hexaferrite meets desired loss tan δ for high electromagnetic radiation, thus, making this hexaferrite is an excellent candidate for broad bandwidth T-DMB antenna application.

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