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RF Magnetic Shielding Effects Found in the Superposition of a Wood Ceramics Cylinder over a BPSCCO Cylinder

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Electromagnetic shields are required in many applications to reduce the influence of environmental electromagnetic waves. An ideal electromagnetic shielding vessel, in the frequency region from direct current (DC) to radio frequency (RF), can be realized by the use of a high-critical temperature superconductor (HTS), due to its perfect diamagnetism. However, the value of shielding degree *SD* for the HTS shielding vessel was found to decrease as the value of frequency increased in the frequency region from 1 MHz to 800 MHz. The present research has improved the value of *SD* of an HTS cylinder by the superposition of a wood ceramics square cylinder over the HTS cylinder, termed the RF shielding system. Wood ceramics make an excellent shield, due to a very large value of relative permittivity ε_r in the RF region. It was found that the value of magnetic *SD* of the RF shielding system at 80 MHz is improved by about 14 dB over that of the HTS cylinder. The present paper examines the RF magnetic shielding effects as a function of frequency. In addition, the fabrication conditions of wood ceramics, and the characteristics of ε_r of wood ceramics as a function of frequency are also examined.
Key words: Wood Ceramics, Superconducting BPSCCO, RF Magnetic Shielding, Magnetic Shielding Vessel

1. INTRODUCTION

Electromagnetic shields are required in many applications to reduce the influence of environmental electromagnetic waves. There has been an increasing need in electronics for an arrangement of electromagnetic shields to guard against disturbances in the radio frequency (RF) region. Typical examples of such needs are found in industrial robots, medical instruments, and superconducting devices.

The present authors have developed a new type of electromagnetic shielding system by making use of wood ceramics. The ceramic is new industrial material, fabricated from a wood pulp by a special technique [1]. The relative permittivity ε_r of the wood ceramic in the very high frequency region can be expressed as $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$, where ε_r' and ε_r'' are the real relative permittivity and imaginary relative permittivity as the loss factor, respectively, and j is the imaginary unit. The value of ε_r is the determinant used for deciding the electromagnetic shielding effect. The shielding effect is proportional to the value of ε_r, and varies inversely to the characteristic impedance Z_0. The values of ε_r' and ε_r'' are, in general, functions of frequency, and decrease as the frequency increases. The values found for the wood ceramics used in the present study are very large (10^4 - 10^2) in the very high frequency region (300 MHz - 15 GHz). Therefore, wood ceramics are considered optimum materials for use as electromagnetic shields.

The present paper examines the fabrication conditions for the wood ceramics, the characteristics of ε_r' and ε_r'' as functions of frequency, and the electromagnetic shielding characteristics as functions of frequency. In addition, an examination is conducted of the shielding characteristics for the RF shielding system constructed from a combination of wood ceramic and high-critical temperature superconductor (HTS) vessels. Also discussed is the possibility of the use of wood ceramics for shielding over a broad frequency range.

2. EXPERIMENTAL PROCEDURE

2-1. Fabrication of wood ceramics tile

In the process of obtaining wood ceramics, similar problems occur as in the fabrication of conventional charcoal, namely fissures and warping. Therefore, the wood ceramic is sintered under high temperature conditions, 1000 °C as an example, and then rapidly cooled. In Japan, similar fabrication processes have been used for making high quality charcoal, known as bincho charcoal. This charcoal is made from very hard oak, and the hardness results in, fewer fissures, and less warping compared with other charcoals. Resin exhibits poor properties when undergoing a change of structure during the carbonization process. Consequently, the problem is to prevent fissures and warping in the wood ceramics when the resin is impregnated into the gaps in the wood pulp or woody material before carbonization. The carbonization process of wood ceramics, result in hardness of the material with small porous structure, and when crushed, acts like glass; therefore termed a glassy carbon [1].

The wood ceramic specimens were fabricated as described in the following procedure, such as reported in Ref. [1]. The wood pulp or woody material is impregnated with phenol resin which changes the pulp into a glassy carbon by the carbonization treatment. At this time, an ultrasonic wave is applied to improve the efficiency of the impregnation. The medium density fiber (MDF) board constructed from the wood pulp or woody material impregnated with phenol resin, was then formed into square tiles measuring 150 mm in length and width, and 5 mm thick. The ratio of the weight of the MDF board and phenol resin represents a one-to-one correspondence. The wood ceramics tiles were then sintered in a vacuum furnace. The specific gravity and moisture content for the sintered tiles are 0.54 and 10 %, respectively. There is a close relation between the sintering temperature and the relative permittivity of the wood ceramics. In the present experiments, wood ceramics are sintered for periods of about 10 hours under temperatures of 400, 800 and 1600 °C.

2-2. Measuring system of the relative permittivity

Measurements of the relative permittivity were carried out using a coaxial tube, such as illustrated in Fig. 1. By setting the S_{11} parameter (or scattering parameter) [2] measuring mode in the network analyzer (HP 8510), measurements can be made of the traveling and reflecting waves, from which the reflectiton coefficient Γ is calculated. The relative permittivity ε_r (=ε_r' - $j\varepsilon_r''$) of the plane wave, given by Eq. (1), is then calculated by a computer from the measured values of Γ, over the frequency region of 300 MHz - 15 GHz. In general, Γ and $Z_{x=d}$ can be written as

$$\left.\begin{aligned} \Gamma &= \frac{Z_{x=d}-Z_0}{Z_{x=d}+Z_0} \\ Z_{x=d} &= \sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh\left(j\frac{2\pi}{\lambda}\sqrt{\varepsilon_r\mu_r}\,d\right) \\ &= \sqrt{\frac{1}{\varepsilon_r}}\tanh\left(j\frac{2\pi}{\lambda}\sqrt{\varepsilon_r}\,d\right) \end{aligned}\right\} \quad (1)$$

respectively. Here, $Z_{x=d}$ is the impedance at $x = d$ such as illustrated in Fig. 1, Z_0 the characteristic impedance ($=\sqrt{\mu_0\mu_r/\varepsilon_0\varepsilon_r}$), μ_0 the permeability, μ_r the relative permeability, ε_0 the permittivity, λ the wave length, and d the sample thickness. The wood ceramic specimen used for measuring ε_r was cut into the shape of a disk (6.96 mm outside diameter, 3.1 mm inner diameter, 4 mm thick) from the wood ceramic tile, and then attached

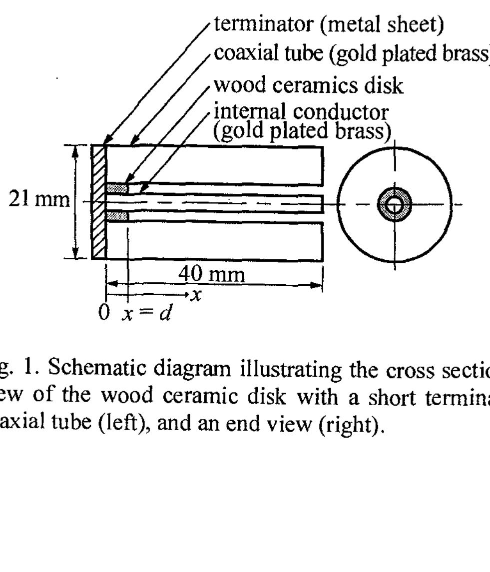

Fig. 1. Schematic diagram illustrating the cross sectional view of the wood ceramic disk with a short terminated coaxial tube (left), and an end view (right).

by a metal sheet in a coaxial tube as illustrated in Fig. 1. In the calculations, the value of μ_r is assumed equal to 1.0, such as given in Eq. (1), since wood ceramics do not retain any magnetism. Figure 1 also illustrates the cross sectional view of the wood ceramic disk as the specimen with a short terminated coaxial tube.

2-3. Measuring system of the electromagnetic shielding degree

The electromagnetic shielding degree SD for near field and far field components [3] can be calculated as in the following equation,

$$SD = 20 \log(Q_{no}/Q_{sit}) \text{ (dB)}, \quad (2)$$

where Q_{sit} and Q_{no} are the output data of the receiving antenna with and without the wood ceramic tile, respectively. Figures 2 and 3 are schematic diagrams illustrating the experimental arrangement used to measure the values of SD for the near and far fields, respectively. In Figs. 2 and 3, the RF output of the tracking generator in the network analyzer is amplified by 40 dB, by use of the broad band power amplifier, and guided to the transmitting antenna. The output of the receiving antenna is amplified by 60 dB by the preamplifier, and guided to the input terminal. The results from the spectrum analyzer are then transferred through the GPIB to a desk-top computer.

The SD for the near field component involve the electrical field (E-field), and magnetic field (H-field). Use is made of two antennas, namely the high impedance

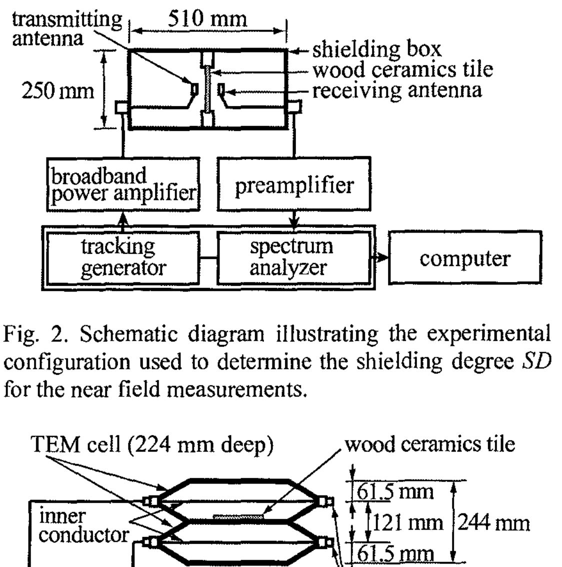

Fig. 2. Schematic diagram illustrating the experimental configuration used to determine the shielding degree SD for the near field measurements.

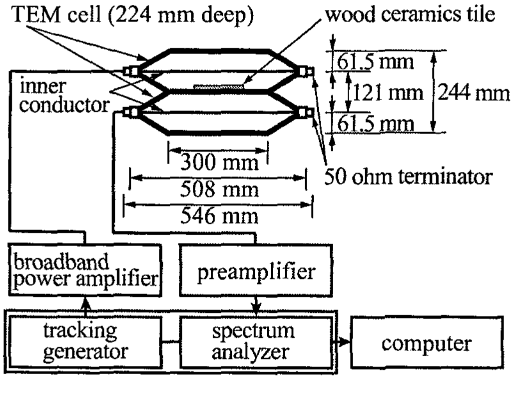

Fig. 3. Schematic diagram illustrating the experimental configuration used to determine the shielding degree SD for the far field measurements.

capacitance voltage antenna for the E-field and the low impedance inductive loop antenna for the H-field. The wood ceramic tile (150 mm square in length and width, 5 mm thick) was tightly fixed to the metal frame and conductive mesh, such as illustrated in Fig. 2. The shielding box (510 mm wide, 250 mm in height, 230 mm deep) illustrated in Fig. 2 is made of pure aluminum plate (5 mm thick).

The *SD* of the far field is determined by use of two transverse electromagnetic (TEM) cells such as illustrated in Fig. 3. The wood ceramic tile (150 mm in length, 50 mm wide, 5 mm thick) is positioned over a rectangular hole (100 mm in length, 20 mm wide) between the upper and lower TEM cells. Therefore, the tile is exposed in a vertical orientation to the E-field, and in a horizontal orientation to the H-field. The other side terminals of the two TEM cells, such as illustrated in Fig. 3, are each terminated with a 50 Ω resistance.

3. RESULTS AND DISCUSSION

3.1 Relative permittivity

Figures 4 show the respective relative permittivities, ε_r' (solid symbols, the left-hand ordinate) and ε_r'' (open symbols, the right-hand ordinate), as functions of frequency f for several specimens sintered at various temperatures. In this figure, the diamonds, squares, and circles represent the results for specimens sintered at temperatures of 400 °C, 800 °C, and 1600 °C, respectively. It was found that both ε_r' and ε_r'' for wood ceramics exhibit large values greater than those of conventional dielectric materials used in electromagnetic shielding. It should also be noted that the permittivities increase as the sintering temperatures increase. The reason for this is that the deoxygenation and dehydrogenation induced during thermal decomposition formations of the carbon-carbon bonding as well as different degrees of graphitization for the various sintering temperature. In addition, it was also found that ε_r' and ε_r'' increase as the values of f decrease.

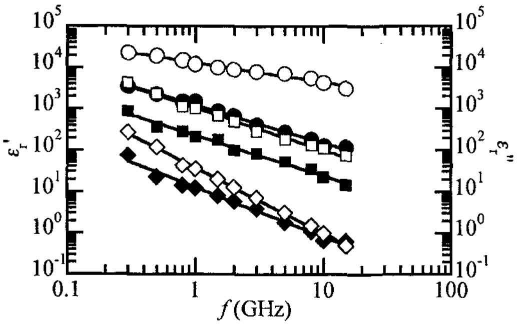

Fig. 4. Typical characteristics of the relative permittivity of wood ceramics as a function of frequency f for the real ε_r' (solid symbols, the left-hand ordinate), and the imaginary ε_r'' (open symbols, the right-hand ordinate) relative permittivities. The diamonds, squares, and circles denote the sintering temperatures of 400 °C, 800 °C, and 1600 °C, respectively.

3.2 RF Shielding effect of wood ceramics tile

In Fig. 5, the results for the near field component exhibit the typical electromagnetic shielding characteristics *SD* of the wood ceramics as a function of frequency, over the

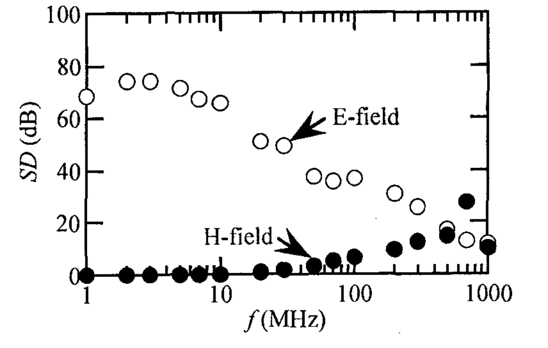

Fig. 5. Typical shielding degree *SD* characteristics of the wood ceramic tile (sintering temperature of 800 °C) in the near field experiment as a function of frequency f. The results are shown for the electrical field (open circles, E-field) and the magnetic field (solid circles, H-field).

frequency range 1 MHz - 1 GHz at room temperature. In this figure, the open and solid circles are the measured results for the E-field and H-field, respectively. It is found that the shielding effect *SD* for the H-field is held at 0 dB in frequency range 1 MHz - 10 MHz, and then increases over the frequency range of 10 MHz - 1 GHz. In addition, the maximum value of *SD* of approximately 30 dB is found at 700 MHz. On the other hand, the maximum value of *SD* for the E-field of about 75 dB occurs at 3 MHz. From these results, it was concluded that wood ceramics can be employed to reduce the E-field that results from the electromagnetic emission from electronic equipment, over frequencies between the HF (3 MHz - 30 MHz) and VHF (30 MHz - 300 MHz) regions.

In Fig. 6, the results of the far field component (plane wave) exhibit the typical electromagnetic shielding characteristics *SD* of the wood ceramics as a function of frequency f over the frequency range 1 MHz - 1 GHz at room temperature. The shielding effect *SD* is maintained at 0 dB in the frequency range of 1 MHz - 10 MHz, and that increases as the value of f increases. From these results, it was determined that wood ceramics can be used to reduce the effect of electromagnetic waves in the frequency range above 300 MHz as commonly found in broadcasting, radio communications, and at microwave sites, to name a few.

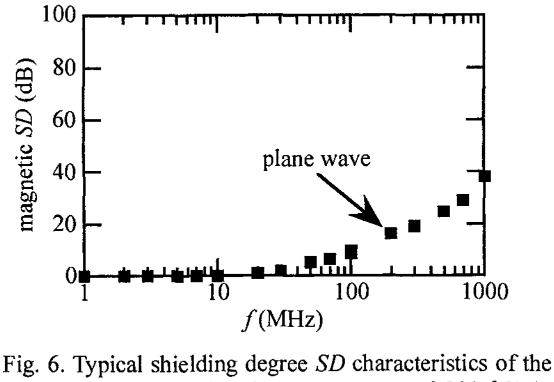

Fig. 6. Typical shielding degree *SD* characteristics of the wood ceramic tile (sintering temperature of 800 °C) in the far field experiment as a function of frequency f. The results (solid squares) demonstrate the shielding degree from electromagnetic (plane) wave.

3.3. The RF shielding system constructed from wood ceramic and HTS vessels

The measuring system used in the present study to measure the RF electromagnetic shielding effect *SD* for the RF shielding system has been previously reported in Ref. [6]. In order to construct the RF shielding system, wood ceramic tube were formed into a rectangular shaped open - ended box (246 mm long, 48 mm on each side, and 9 mm thick). Hereafter, this vessel is simply termed the wood ceramic cylinder. The BPSCCO cylinder (2.3 mm thick, 159 mm long, 10.4 mm inner radius) was then inserted into the wood ceramic cylinder. Measurements of the critical current density J_c and critical temperature T_c of the BPSCCO cylinder were about 150 A/cm^2 and 103 K, respectively. The system was then immersed in liquid nitrogen, and measurements were conducted under conditions of the boiling point of liquid nitrogen (77.4 K). Electromagnetic waves were always applied perpendicular to either the axial direction of the RF shielding system, the wood ceramic square cylinder, or the BPSCCO cylinder [4], [5]. Values of the electromagnetic shielding degree *SD* were calculated by Eq. (2). The values of Q_{sit} and Q_{no} in Eq. (2) were replaced by E_{sit} and E_{no}, which are the output voltages from the receiving antenna, with and without the given shielding vessel, respectively.

Figure 7 shows the typical magnetic shielding characteristics of the shielding system as a function of frequency over the frequency range 1 MHz - 800 MHz at a temperature of 77.4 K. The curves denoted by (a), (b), and (c) in Fig. 7 represent the results when use is made of the wood ceramic cylinder alone (open diamonds), the BPSCCO cylinder alone (solid circles), and the RF shielding system (open circles), respectively. The magnetic shielding degree *SD* of the wood ceramic vessel was found to increase as the frequency increased over the range from 1 MHz to 40 MHz, and to decrease in the frequency region from 40 MHz to 800 MHz, as shown in Fig. 7 by curve (a). Furthermore, it can be seen that magnetic *SD* of the BPSCCO cylinder decreases with an increase in frequency, as shown in Fig. 7 by curve (b). The magnetic *SD* of the RF shielding system was found to be improved over that of the BPSCCO cylinder by superimposing the wood ceramic cylinder over the BPSCCO cylinder, in the frequency region from 20 MHz to 200 MHz, such as shown in Fig. 7 by curve (c). The electric *SD* of the RF system exhibited no remarkable effect, and averaged about 15 dB in the frequency region from 20 MHz to 800 MHz (not shown).

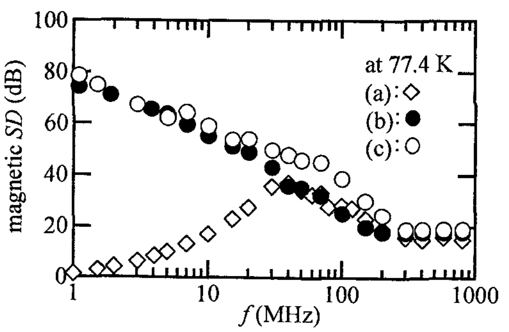

Fig. 7. The magnetic shielding degree *SD* characteristics of the RF shielding system at 77.4 K. The curves represent the results for (a) the wood ceramic cylinder alone (open diamonds), (b) the BPSCCO cylinder alone (solid circles), and (c) the RF shielding system (open circles).

The value of the magnetic *SD* was found to be sensitive to the dimensions of the wood ceramic cylinder, especially to the length, for optimum magnetic shielding. Therefore, the authors are now investigating ceramic cylinders to determine the optimum size that yields the greatest *SD* results.

5. CONCLUSIONS

The present paper examined the relative permittivities, ε_r' and ε_r'', of wood ceramics having porous structure formed at different sintering temperatures (400 °C, 800 °C, and 1600 °C) in the frequency range of 300 MHz to 15 GHz. It was found that both the ε_r' and ε_r'' for wood ceramics have large values greater than those of conventional dielectric materials used in electromagnetic shielding. Furthermore, it was determined that the permittivities increased as the sintering temperatures increased. In addition, both ε_r values increased as the frequency f decreased. Similar results such as those shown in Fig. 4 at room temperature were obtained for the wood ceramics under temperature conductions of 77.4 K.

Measurements were conducted of the electromagnetic shielding degrees *SD* for the near field and far field components. It was found that the *SD* for the magnetic field in the near field component was maintained at 0 dB over the frequency range of 1 MHz - 10 MHz, and increased in the frequency range of 10 MHz - 1 GHz. The maximum *SD* value of about 30 dB was obtained at 700 MHz. On the other hand, the maximum *SD* value for the electrical field was about 75 dB at 3 MHz. In addition, it was found that the *SD* in the far field component was held at 0 dB over the frequency range of 1 MHz - 10 MHz, and then increased as the frequency f increased.

The present research has examined the magnetic shielding degree *SD* of the RF shielding system consisting of a wood ceramic cylinder superimposed over a BPSCCO cylinder in the RF frequency region of 1 MHz to 800 MHz. The RF characteristics of the wood ceramic vessel was found to enhance the shielding degree of the BPSCCO cylinder in the frequency region from 1 MHz to 40 MHz. Furthermore, it was found that the magnetic *SD* was sensitive to the dimensions of the wood ceramics cylinder, especially the cylinder length. The electrical *SD* of the RF shielding system exhibited no remarkable characteristics, and averaged about 15 dB in the frequency region from 20 MHz to 500 MHz.

REFERENCES

[1] T. Okabe, and K. Saito, *T. MRS Japan*, 18A, 681-684 (1994).
[2] J. D. Kraus, "Electromagnetics", MacGraw-Hill, New York, (1992).
[3] E. N. Skomal, and A. A. Smith Jr., "Measuring the Radio Frequency Environment", Van Nostrand Reinhold, New York, (1985).
[4] M. Itoh, T. Ohyama, T. Minemoto, and K. Hoshino, *J. Physics D: Applied Phys.*, 24, 1630-1634 (1992).
[5] M. Itoh, T. Ohyama, K. Mori, and T. Minemoto, *T. IEE Japan*, 115-C, 696-701 (1995).
[6] Y. Hotta, K. Mori, and M. Itoh, *Proc. of 17th Int. Cryogenic Engineer. Conf.*, 507-510 (1998).

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