Transactions of the Materials Research Society of Japan 32[4] 1063-1066 (2007)

Improvement in the Frequency Characteristics of a Bincho-Charcoal Plate as an RF Magnetic Shield: The Superposition of Ferrite and BPSCCO Plates on a Bincho-Charcoal Plate

T. Nishikubo*, H. Norikane*, H. Endo*, K. Itoh**, F. Tojo*,***, and M. Itoh*
*Interdisci. Grad. School of Sci. and Engi., Grad. School of Kinki Univ., 3-4-1, Kowakae, Higashi-Osaka, Osaka, 577-8502, Fax: 81-6-5782-2353, e-mail: t-nishikubo@hotmail.co.jp
** Kasugai EMC Center, Kitagawa Industrial Co. Ltd., 1-27, Hikizawa, Kamiya-cho, Kasugai, Aichi, 480-0304 Fax: 81-568-93-0686, e-mail: keitoh@s7.dion.ne.jp
*** Yamabun Electronics Co. Ltd., 632-2, Nakano, Higashi-Osaka, Osaka, 578-0913, Fax: 81-72-964-8480, e-mail: yamabun@mxa.mesh.ne.jp

Recently, electromagnetic environmental problems have become more serious. With rapid development in the field of information technology, there has been increased interest in electromagnetic shielding in the radio frequency (RF) region. The present paper has examined bincho-charcoal, a high quality charcoal found in Japan, for use as RF magnetic shielding. This is advantageous since the relative permittivity of bincho-charcoals has a very large value (10^7 - 10^2) in RF region of 1 MHz - 3 GHz. In the frequency region from 1 MHz to 100 MHz, however, the RF magnetic shielding degree (SD_H) for bincho-charcoal plate is not sufficient to shield electromagnetic waves. The present paper has improved the frequency characteristics of SD_H for a bincho-charcoal plate by the superposition of ferrite and Bi-Pb-Sr-Ca-Cu-O (BPSCCO) plates on the bincho-charcoal plate, under conditions of room temperature (300 K) and is termed the compound plate. Experimental results revealed several characteristics of the compound plate that included, among others, the dependence of SD_H on radio frequency, and the dependence of SD_H on the value of RF output power.
Key words: RF magnetic shielding, bincho-charcoal plate, ferrite plate, BPSCCO plate, compound plate

1. INTRODUCTION

The contamination of the environment by electromagnetic pollution has increased with the employment of more electronic instruments. Therefore, there has been increased interest in electromagnetic shielding, coinciding with the rapid development in the field of information technology [1-4]. The present research has applied bincho-charcoal, a high quality charcoal found in Japan, to radio frequency (RF) magnetic shields [5]. Bincho-charcoal has a very large value of relative permittivity (10^7 - 10^2) in the RF region of 1 MHz to 3 GHz, and is, therefore, an excellent material for RF electromagnetic shielding, such as reported in Refs. [6, 7].

In the present research, it is found that the values of the RF magnetic shielding degree SD_H for a bincho-charcoal plate increased with frequency in the region of 1 MHz (SD_H=1 dB) to 3 GHz (SD_H=53 dB) [8]. In the RF frequency region from 1 MHz to 100 MHz, however, the RF magnetic shielding degree (SD_H) for the bincho-charcoal plate is not sufficient enough to shield electromagnetic waves.

The present paper seeks to improve the frequency characteristics of a bincho-charcoal plate by the superposition of ferrite and Bi-Pb-Sr-Ca-Cu-O (BPSCCO) plates on the bincho-charcoal, termed the compound plate. Also, a BPSCCO plate was developed as new RF electromagnetic shielding material, under conditions of room temperature (300 K). The frequency characteristics of the SD_H for the compound plate were found to be above 40 dB in the frequency region of 1 MHz to 3 GHz.

Experimental results reveal several characteristics of the compound plate that include the RF magnetic and electric shielding degrees, SD_H and SD_E, as functions of radio frequency f, and the non-dependencies of SD_H and SD_E on the value of RF output power.

2. EXPERIMENTAL PROCEDURE

2. 1 Fabrication of the bincho-charcoal plate

As reported in Ref. [6], the bincho-charcoal plate (50 mm square, 5 mm thick) was constructed from 25 tiles (10 mm square, 5 mm thick), which were cut with the use of a diamond saw at low cutting speeds to inhibit any heat effects. The tiles were glued together using a paste, and then dried naturally under room temperature for about 8 hours. The paste was prepared by mixing bincho-charcoal powder (about 2 μm or smaller) with polyvinyl alcohol.

In the present research, use was made of commercial ferrite (TDK, IB-015, 50 mm square, 6 mm thickness), and BPSCCO (Toshima, Lot. 7805, 50 mm square, 4 mm thickness) plates for constructing the compound plate.

2.2 Construction of the compound plates

In present experiment, three different compound plates were constructed as shown in Fig. 1. In this figure, plates (a), (b), and (c) are termed samples 1 (CBF), 2 (BCF), and 3 (CFB), respectively. As shown in this figure, the arrows represent the incident direction of the electromagnetic wave.

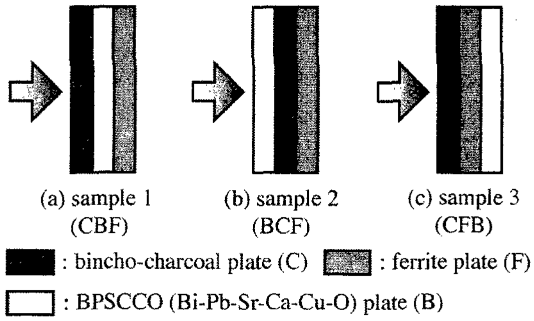

Fig. 1. Construction of the three different compound plates. Here (a), (b), and (c) represent the sample 1 the bincho-charcoal, BPSCCO, and ferrite plates (CBF), sample 2 the BPSCCO, bincho-charcoal, and ferrite plates (BCF), and sample 3 the bincho-charcoal, ferrite, and BPSCCO plates (CFB), respectively.

2.3 Evaluation of the compound plates

Figure 2 is a schematic diagram illustrating the experimental apparatus used to measure the RF magnetic and electric shielding degrees, SD_H and SD_E, of the compound plates. The RF output of the tracking generator with a spectrum analyzer (HP, 8594E) is amplified 50 dB by use of a broadband amplifier (Kalmus, 210LC-CE), and guided to a transmitting antenna in a metal cell. The signal of the receiving antenna is amplified by 38 dB by use of a preamplifier (Sonoma, 317), and then guided to the input terminal of the spectrum analyzer. In this arrangement, the coaxial

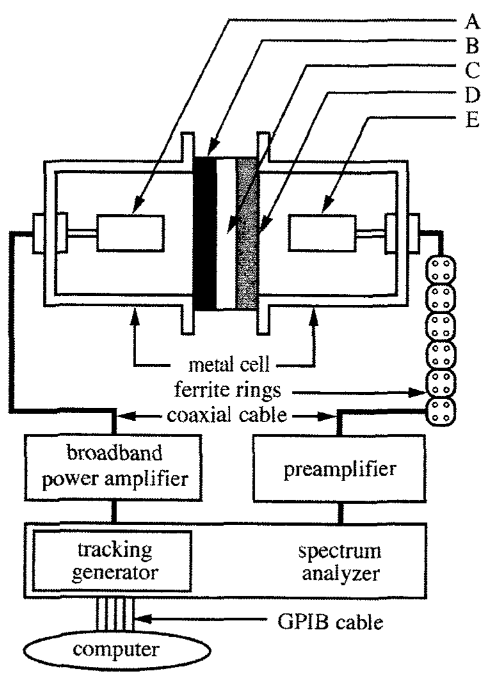

Fig. 2. Schematic diagram of the experimental apparatus used to measure the RF magnetic and electric shielding effects for the three compound plates. In this arrangement, A represents the transmitting antenna, B the bincho-charcoal plate, C the BPSCCO plate, D the ferrite plate, and E the receiving antenna.

cable employed as the receiving line was threaded through ferrite rings in order to reduce any mutual relationship between the transmitting and receiving lines, such as reported in Ref. [8]. Loop and probe antennas are used for the measurement of SD_H and SD_E, respectively.

The electromagnetic shielding degree SD can be specified in terms of the reduction in the incident magnetic and/or electric field strength to that from the compound plate [9]. In general, the value of SD_H is defined as SD_H=10log(P_{H0}/P_{H1}). Here, P_{H0} and P_{H1} are the strengths of the incident magnetic field power of the transmitted wave and the magnetic field power as it emerges from the shielding plate, respectively. Also, the electric shielding degree SD_E, similar to the above equation, is defined as SD_E=10log(P_{E0}/P_{E1}), where P_{E0} and P_{E1} are the strengths of the incident electric field power and the electric field power of the transmitted wave as it emerges from the shielding plate.

3. RESULTS AND DISCUSSION

3.1 RF magnetic shielding effects of the bincho-charcoal, ferrite, and BPSCCO plates

Figure 3 shows the RF magnetic shielding degree SD_H for the bincho-charcoal, ferrite, and BPSCCO plates as functions of frequency f, over the radio frequency region from 1 MHz to 3 GHz, under constant RF magnetic output power P_H of 30 dBm of the transmitting antenna at room temperature. In this figure, the solid circles, open triangles, and open squares represent the shielding characteristics for bincho-charcoal, ferrite, and BPSCCO plates, respectively. It can be seen that the values of SD_H for the bincho-charcoal plate increase as the frequency f increases. In the present research, five bincho-charcoal plates were fabricated, but all bincho-charcoal plates had the same characteristics of RF magnetic shielding as shown in Fig. 3 (solid circles). It can also be seen that the values of SD_H for the ferrite plate decrease as the frequency f increases. The characteristics of SD_H for a BPSCCO plate at room temperature were previously unknown, but are now revealed to increase from 18 dB to 35 dB in the frequency region from 1 MHz to 3 GHz. Namely, the BPSCCO plate is effective as a magnetic shield over a wide frequency region.

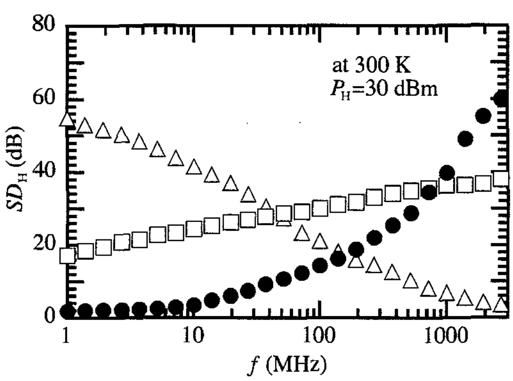

Fig. 3. The characteristics of SD_H for bincho-charcoal, ferrite, and BPSCCO plates as functions of frequency f. The solid circles, open triangles, and open squares represent the results for bincho-charcoal, ferrite, and BPSCCO plates, under conditions of room temperature, respectively.

3.2 RF electric shielding effects of the bincho-charcoal, ferrite, and BPSCCO plates

The plotted points in Fig. 4 denote the RF electric shielding degree SD_E for the bincho-charcoal (solid circles), ferrite (open triangles), and BPSCCO (open squares) plates as functions of frequency f, under constant RF electric output power P_E of 30 dBm of the transmitting antenna. It can be seen that the values of SD_E for the bincho-charcoal plate exhibit tendencies similar to those for the BPSCCO plate. It is also found that the values of SD_E for the ferrite plate remain constant in the frequency region from 1 MHz to 3 GHz, and it is concluded that the ferrite plate alone dose not satisfy the conditions for RF electric shielding. In addition, it is found that the bincho-charcoal and BPSCCO plates are conducting materials while the ferrite plate is an insulating material.

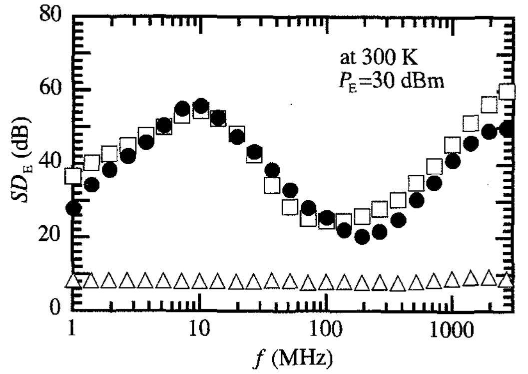

Fig. 4. The characteristics of RF electric shielding degree SD_E as functions of frequency f, under constant RF electric field power P_E of 30 dBm of the transmitting antenna. The solid circles, open triangles, and open squares represent the shielding characteristics for bincho-charcoal, ferrite, and BPSCCO plates, under conditions of room temperature, respectively.

3.3 RF magnetic and electric shielding effects of the three different compound plates

The present research attempts to improve the frequency characteristics of a bincho-charcoal plate. In order to achieve this, three different compound plates were formed as shown in Fig. 1. Figure 5 displays the typical characteristics of the RF magnetic shielding degree SD_H for the three different compound plates as functions of frequency f, under a constant RF magnetic output power P_H of 30 dBm of the transmitting antenna. In this figure, the curves formed by the solid diamonds, open diamonds, and open squares represent the shielding characteristics for samples 1 (CBF), 2 (BCF), and 3 (CFB), under conditions of room temperature, respectively. As can be seen in this figure, the shielding characteristics for sample 1 (CBF) are improved over those of the bincho-charcoal plate over the entire region of measuring frequency. Furthermore, it is found that the magnetic shielding characteristics of sample 2 (BCF) exhibit characteristics similar to those of sample 1 (CBF). However, the characteristics of SD_H for sample 3 (CFB) display different characteristics, as shown in Fig. 5.

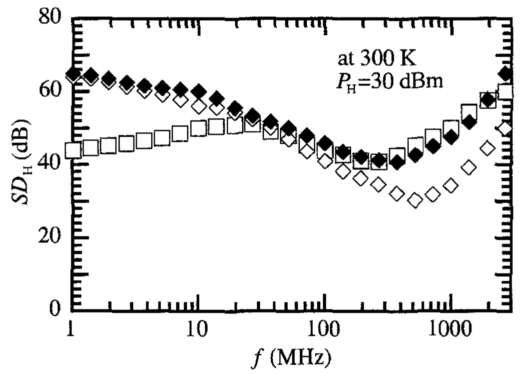

Fig. 5. Typical characteristics of RF magnetic shielding degree for the three different compound plates as functions of frequency f, under a constant RF magnetic output power P_H of 30 dBm of the transmitting antenna. The solid diamonds, open diamonds, and open squares represent the shielding characteristics for samples 1 (CBF), 2 (BCF), and 3 (CFB), under conditions of room temperature, respectively.

The characteristics of SD_H for values of RF magnetic output power P_H of the transmitting antenna for sample 1 (CBF) are displayed in Fig. 6. The open circles, solid circles, open diamonds, and solid diamonds represent the values of SD_H for RF frequencies of 1 MHz, 10 MHz, 100 MHz, and 1 GHz, respectively. It can be seen that the characteristics of SD_H for sample 1 (CBF) display no evidence of dependence on the values of P_H over the region between 5 dBm to 30 dBm. Similar results were found for samples 2 (BCF) and 3 (CFB) (not shown). Namely, the values of SD_H remain constant and are not dependent on the values of P_H over this power region.

The plotted points in Fig. 7 denote the RF electric shielding effect SD_E for the three different compound plates as functions of frequency f, over the radio frequency region from 1 MHz to 3 GHz, under constant RF electric output power P_E of 30 dBm for the transmitting antenna. In this figure, the solid diamonds, open diamonds, and open squares represent the values of

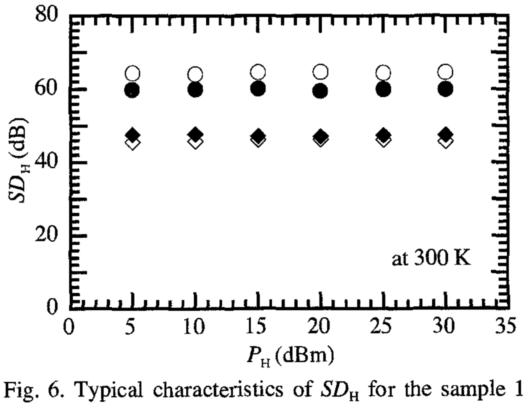

Fig. 6. Typical characteristics of SD_H for the sample 1 (CBF) as functions of RF magnetic output power P_H. The open circles, solid circles, open diamonds, and solid diamonds represent the results for 1 MHz, 10 MHz, 100 MHz, and 1 GHz, under conditions of room temperature, respectively.

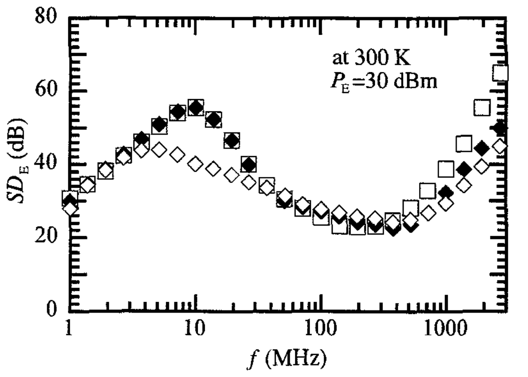

Fig. 7. Distributions of RF electric shielding degree SD_E for the three different compound plates as functions of frequency f, under a constant RF electric output power P_E (30 dBm) of the transmitting antenna. The solid diamonds, open diamonds, and open squares represent the shielding characteristics for samples 1 (CBF), 2 (BCF), and 3 (CFB), under conditions of room temperature, respectively.

SD_E for samples 1 (CBF), 2 (BCF), and 3 (CFB), respectively. As can be seen in this figure, the values of SD_E for the three different compound plates display different shielding characteristics. Namely, the characteristics of SD_E for sample 2 (BCF) are found to exhibit lower values over the frequency region from 4 MHz to 20 MHz, than those of samples 1 (CBF) and 3 (CFB). It is also found that sample 3 (CFB) exhibits excellent characteristics of SD_E for frequencies above 500 MHz. In addition, the characteristics of SD_E for the three compound plates displayed no evidence of dependence on the RF electric output power P_E over the range between 5 dBm to 30 dBm, similar to the case of RF magnetic output power as displayed in Fig. 6 (not shown).

From the results shown in Figs. 5 and 7, it is concluded that it is necessary to consider the order of the combination of the plates, such as bincho-charcoal, BPSCCO, and ferrite plates, when the compound plate is constructed. The present authors are now investigating the physical meanings of these results. However, these results demonstrate an important criterion for the fabrication of practical electromagnetic shielding.

4. CONCLUSIONS AND SUMMARY

As one of the basic areas of research for the improvement of the electromagnetic environment by using a bincho-charcoal plate, the present paper has attempted to construct the compound plates by the superposition of ferrite and BPSCCO plates on a bincho-charcoal plate. The results for the compound plates can be summarized as follows;

(1) The characteristics of the magnetic shielding degree SD_H for a BPSCCO plate at room temperature exhibited an increase from 18 dB to 35 dB in the frequency region from 1 MHz to 3 GHz. Namely, the BPSCCO plate is effective over a wide frequency region for use as an RF magnetic shield.

(2) The values of SD_E for the bincho-charcoal plate exhibited tendencies similar to those of the BPSCCO plate. In addition, the values of SD_E for the ferrite plate remain constant in the frequency region from 1 MHz to 3 GHz, and were not considered to be sufficient to act as an RF electric shield.

(3) The magnetic shielding characteristics SD_H for sample 1 (CBF), as shown in Fig. 1, were improved over those of the bincho-charcoal plate over the entire region of the measuring frequency. Furthermore, the characteristics of sample 2 (BCF) exhibited characteristics similar to those of sample 1 (CBF). However, the characteristics for sample 3 (CFB) displayed different characteristics.

(4) The characteristics of SD_H for sample 1 (CBF) displayed no evidence of dependence on the values of RF magnetic power P_H in the region between 5 dB to 30 dB. Similar results were obtained for samples 2 (BCF) and 3 (CFB). Namely, the values of SD_H remained constant and were not dependent on the values of P_H over this power region.

(5) The values of SD_E for the three different compound plates, samples 1 (CBF), 2 (BCF), and 3 (CFB), exhibited different shielding characteristics. Sample 3 exhibited excellent characteristics of SD_E for frequencies above 500 MHz.

These results indicate important criteria fundamental in the design of practical RF shielding systems having high reliability. The results also demonstrate the necessity to consider the order of the combination of the plates, such as bincho-charcoal, BPSCCO, and ferrite plates, for the formation of the compound plate.

The present authors are now investigating the physical meaning why the values of SD_H and SD_E for the compound plates are influenced by the order of the combination of the bincho-charcoal, ferrite, and BPSCCO plates.

REFERENCES

[1] Henry W. Ott, "Noise Reduction Techniques in Electronics Systems", John Willy & Sons, Inc., Canada (1988) pp. 1-27.

[2] M. Itoh, "Advances in Cryogenic Engineering (Materials)", Vol. **40**, Part A, Ed. By R. P. Reed et al, Plenum Press, New York (1994) pp. 261-270.

[3] F. Pavese, M. Bianco, A. Tampieri, M. Itoh, M. Vanolo, D.Giraudi, G. Celotti, and K. Mori, "Advances in Cryogenic Engineering (Materials)", Vol. **44B**, Ed. By U. B. Balachandran et al, Plenum Press, New York (1998) pp. 397-403.

[4] M. Itoh, K. Itoh, K. Mori, and Y. Hotta, "Applied Superconductivity 1999", Vol. **2**, Ed. By X. Obradors et al, IOP, London (2000) pp. 777-780.

[5] K. Itoh, Y. Sasai, Y. Hotta, and M. Itoh, *Physica C*, Vol. **372**, (2002) pp. 1333-1338.

[6] K. Itoh and M. Itoh, *IEEJ Trans EIS*, Vol. **124-C**, No. 2, (2004) pp. 399-403.

[7] H. Norikane, T. Nishikubo, S. Gokyu, K. Itoh, and M. Itoh, *IEEE Transactions on Applied Superconductivity*, Vol. **16** (2006) pp. 1765-1768.

[8] Y. Hotta, K. Mori, and M. Itoh, *Proc. 17th Int, Cryogenic Engi. Contf.*, IOP, London (1998) pp. 507-510.

[9] S. A. Schelkunoff, "Electromagnetic Waves", Van Nostrand, Princeton (1943) pp. 303-311.

(Received February 16. 2007;Accepted July 12, 2007)