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Permittivity Characteristics of the Woodceramics

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The Woodceramics is a porous carbon materials which is obtained from woody-materials by impregnated with phenol resin and then carbonized in vacuum. In this report, permittivity at 1 KHz or dielectric function in the range of 0.3 to 15 GHz was measured and discussed. It was found that the permittivity of the Woodceramics increased as increase of sintering temperature and its maximum value was about 70 at 1000 ℃. Also, dielectric function of the Woodceramics increased as increase of sintering temperature and decreased as increase of frequency. It is thought that the high permittivity of the Woodceramics was cased by the depolarizing π-electron of C-C bonding and then behaving the free-electron like. Since imaginary part of dielectric function was greater than real part on the Woodceramics, the Woodceramics is useful to absorption material of electromagnetic wave.

1. INTRODUCTION

Porous carbon woodceramic materials (Woodceramics, WCS) is new environment-friendly materials obtained from woody materials such as wood or sawdust by carbonizing. The woody materials is impregnated with a thermosetting resin and then sintered[1]. WCS is characterized by their porous structure, light-weight, hardness, heat resistance, low cost, conductivity, and so on. Much research is now underway to find new applications for WCS, such as for structural, heat-resistant, filtering, acoustic, and electromagnetic shielding materials. It has been reported that the electromagnetic shield characteristics of WCS are acceptable in the high-frequency band[2,3]. However, to clarify these characteristics, it is necessary to better understand the permittivity behavior, which is a fundamental property. We therefore measured and analyzed the permittivity of WCS at 1 KHz and complex dielectric function in the high-frequency band of 0.3 to 1.5 GHz.

2. EXPERIMENTAL METHOD

2.1. Specimens

The WCS specimen was made from medium-density fiberboard (MDF, air-dried density: 0.73, moisture content: 8 %) made from Pinus radiata. The MDF was impregnated with phenol resin (PX-1600, manufactured by Honen Corporation) using ultrasonic vibration in a weight ratio of approximately 1:1 under a reduced pressure environment. The specimen was then heated in a vacuum furnace, then gradually cooled.

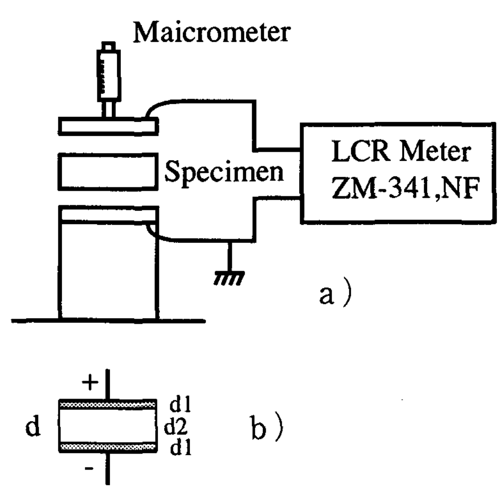

Figure 1. Measurering system of the permittivity on the Woodceramics; a) Schematic diagram of system, b) Capacitance of 3-layer dielectrics.

2.2. Measuring Relative Permittivity

We measured the relative permittivity of WCS at 1 KHz. As shown in figure 1 a), we used an LCR meter (ZM-341, NF) and inserted a specimen between the electrodes by holding it between sheets of insulating paper. We assumed the specimen to be a three-layer dielectric as shown in figure 1 b), and calculated the relative permittivity from the capacitance of the three layers using the following expression:

$$C = \frac{S}{\frac{d_1}{\varepsilon_1} + \frac{d_2}{\varepsilon_2} + \frac{d_1}{\varepsilon_1}} \qquad (1).$$

Where, S is area of electrodes, d_1 and d_2 is thickness of insulating paper and specimen, ε_1 and ε_2 is permittivity of insulating paper and specimen, respectively. In this measurement, S=8.7 cm^2, d_1=57 um, and $\varepsilon_1/\varepsilon_0$=2.2.

2.3. Measuring Dielectric Function

We used the coaxial tube method used for the high-frequency band to measure the dielectric function in the range of 0.3 to 1.5 GHz. As shown in figure 2, we inserted a short length of specimen into the end of the coaxial tube. We used a vector network analyzer to measure the reflection coefficient $\dot{\Gamma}$, and obtained the relative permittivity $\dot{\varepsilon}_r$ (= ε'-jε") as the distributed constant system from the following expression:

$$\dot{\Gamma} = \frac{\dot{Z} - 1}{\dot{Z} + 1} = \frac{\sqrt{\dot{\mu}_r / \dot{Z}_r} - 1}{\sqrt{\dot{\mu}_r / \dot{Z}_r} + 1} \qquad (2)$$

$$\dot{Z} = \sqrt{\frac{\dot{\mu}_r}{\dot{\varepsilon}_r}} \tanh\left(j \frac{\omega}{c} \sqrt{\dot{\varepsilon}_r \dot{\mu}_r}\, d \right) \qquad (3).$$

Where, $\dot{Z}$ is impedance of specimen, c is speed of light, ω is angular frequency, and d is thickness of specimen.

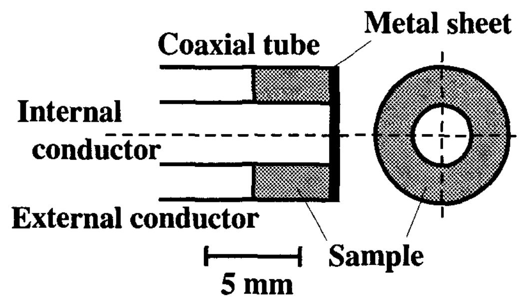

Figure 2. Coaxial tube inserted specimen with short of the end.

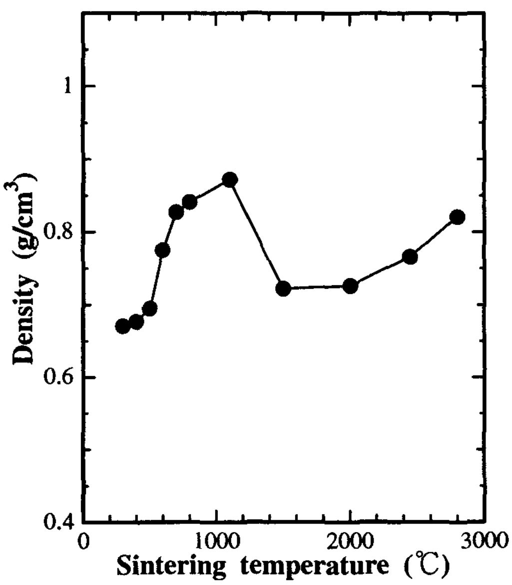

Figure 3. Density of the Woodceramics for sintering temperature.

3. RESULTS AND DISCUSSION

3.1. Sintering temperature dependence of density

Figure 3 shows the dependence of WCS density on sintering temperature. As the sintering temperature rises, the density increases below approximately 1000 ℃, temporarily decreases, then increases over 2000 ℃. We believe that the first gradual increase below 600 ℃ is caused by the elimination reaction of components, and that the second increase is caused by the formation of an aromatic polycyclic structure and the progress of cabonization. We also consider that the decrease over 1000 ℃ is caused by the development of the graphite structure.

3.2. Relative permittivity characteristics

Figure 4 shows the relative permittivity at 1 KHz of WCS sintered at various temperatures. As the sintering temperature increases, the relative permittivity increases to a maximum of approximately 70 at around 1000 ℃, then gradually decreases. This transition corresponds to that of the density. The maximum permittivity of 70 is almost equal to the relative permittivity of water (approximately 80) which is

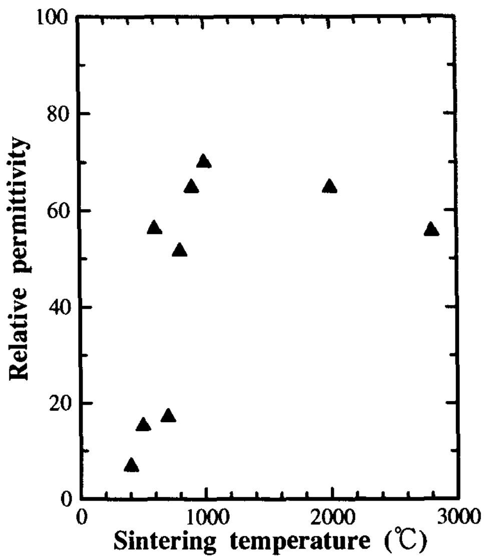

Figure 4. Relative permittivity of the Woodceramics.

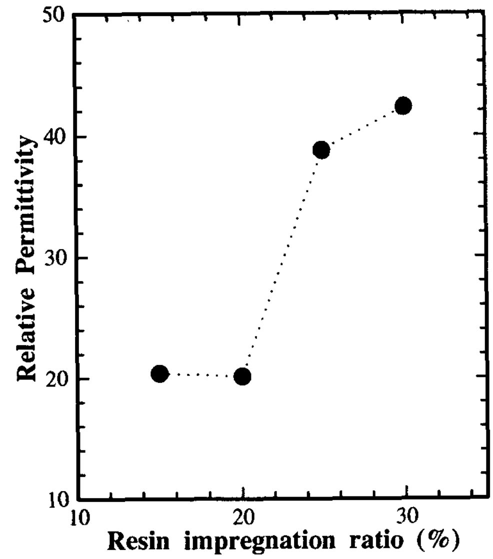

Figure 5. Relative permittivity of the Woodceramics. The Woodceramics was sintered at 800 ℃.

polar molecule. This suggests that polarization occurs in WCS. Figure 5 shows how the relative permittivity of WCS depends on the phenol resin impregnation ratio. As the resin impregnation ratio increases, the relative permittivity tends to increase. Figure 6 shows the sintering temperature dependence of the relative permittivities on the surface and cross section, which was obtained using WCS specimens cut in different directions. The relative permittivity on the surface is grater than that on the cross section.

These measurements demonstrate that the relative permittivity increases as either the sintering temperature or resin impregnation ratio is increased. As the sintering temperature rises, the WCS becomes increasingly carbonized, which reduces its resistivity and increases its density. As the resin impregnation ratio increases, the density increases and the phenol resin increasingly changes to glassy carbon. Carbon materials are known as good electric conductors. The electric charge on the surface of a conductor is caused by the movement of internal free electrons to counteract the electric field in the conductor. In the WCS, we conjecture that the unlocalized π-electrons of C-C bonds behave like free electron, thus creating the polarization charge. Because the density of the WCS increases as the sintering temperature or resin

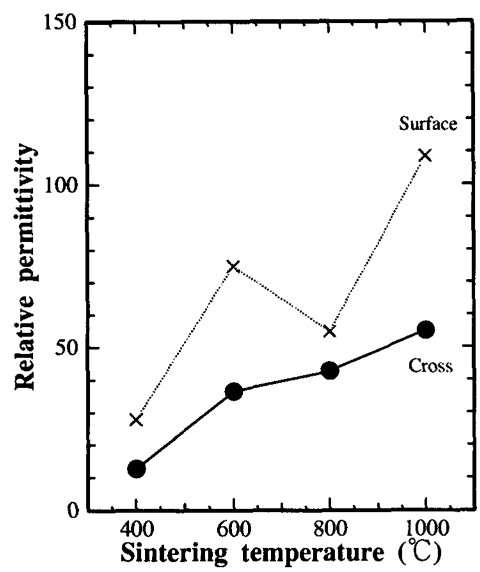

Figure 6. Relative permittivity of the Woodceramics.

impregnation ration increases, we believe that the carrier density in WCS, which increases the polarization charge, increases with WCS density, and that the permittivity increases likewise.

The MDF from which WCS is made is formed by applying pressure to woody fibers, and the woody fibers cross one another and are laminated. Therefore, the difference in relative permittivity between the surface and cross section is likely due to the difference in structure and resistivity.

3.3. Dielectric function characteristics

Figure 7 shows the sintering temperature dependence of imaginary part ε'' of the dielectric function in the high-frequency band. ε'' increases as the sintering temperature rises, and decreases as the frequency increases. Figure 8 shows the real part ε' and imaginary part ε'' of the dielectric function in WCS sintered at 1600 ℃. Both ε' and ε'' decreases as the frequency increases. ε'' is grater than ε'.

We conjecture that the difference in relative permittivity values at 1 KHz and in the high-frequency band is caused by the differences in the measurement method and measurement frequency. However, the relative permittivity increases both at 1 KHz and in the high-frequency band as the sintering temperature rises. Both the real part and imaginary part values of the dielectric function decreases linearly as the frequency increases, which may be due to the skin effect caused by the frequency increase or because the polarization charge cannot follow the applied electric field. The real part of the complex permittivity indicates the polarization size and the imaginary part indicates the energy loss. Therefore, we conclude that the WCS whose imaginary part is greater than the real part is a superior absorption material of electromagnetic wave.

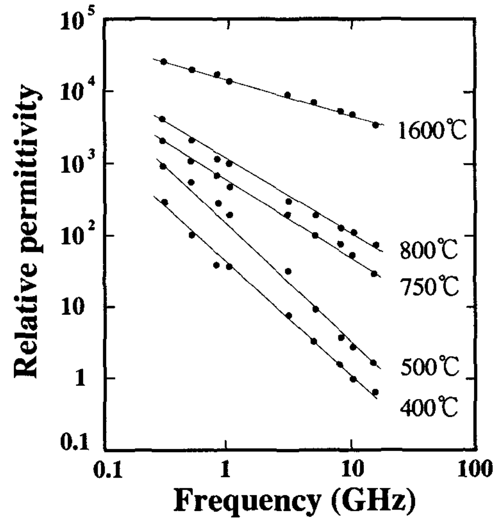

Figure 7. Imaginary part of dielectric function on the Woodceramics.

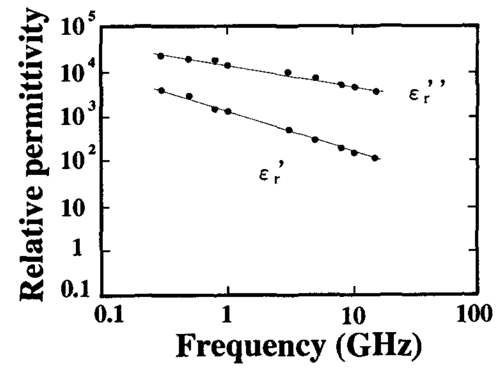

Figure 8. Dielectric function of the Woodceramics. The Woodceramics was sintered at 1600 ℃.

4. CONCLUSIONS

We investigated the permittivity and dielectric characteristics of porous carbon WCS materials. The results demonstrated that the relative permittivity at 1 KHz increases as the sintering temperature rises and reaches the maximum (approximately 70) at around 1000 ℃. The dielectric function increases as the sintering temperature rises, and decreases as the frequency increases. The permittivity of WCS is relatively high. We conjecture that this is because the π-electrons in C-C bonding behave like free electrons and cause polarization. We confirmed that the imaginary part of the dielectric function of WCS is greater than the real part, therefore WCS is a superior absorption material of electromagnetic waves.

WCS are likely to find application in many fields. They are environment-friendly materials that make effective use of natural materials and scrap woods such as from thinning, thus making good use of wood resources.

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3. T.Okaba, Japan patent, No. H4-162799 (1992).