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Electric Characteristics of the Woodceramics and Its Application

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The Woodceramics is a porous carbon materials which is obtained from wood or woody-materials by impregnated with phenol resin and then carbonized in vacuum. In this report, resistivity of the Woodceramics and its temperature dependence in the range of 100 to 700 K were measured and discussed. It was found that the resistivity of the Woodceramics varied over a wide range on the sintering temperature and its temperature dependence was always semiconductor-like in the range of 100 to 600 K. We conjecture that this is caused by an energy gap decrease which increase of the sintering temperature, and is caused by the change in size of the graphite micro-crystallites in glassy carbon, which is comprised in the Woodceramics. Also, temperature sensor with the Woodceramics composed and obtained sensitivity of 0.36 %/K.

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 material[1]. We investigated the conductivity and conductive mechanism of WCS, and its possible use as a porous conductor. We measured and analyzed the temperature dependence of the resistivity. As an example of its application, we fabricated and evaluated an experimental temperature sensor.

2. EXPERIMENTAL METHOD

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. We used the DC 4-probe method as shown in Figure 1 to measure the resistivity of this specimen. We attached a mending tape to a copper plate of 0.5 mm thickness and fastened the specimen on the electrically-insulated sample holder. We used phosphor-bronze spring electrodes and gold paste to connect the electrodes to the specimen. The gap between the electrodes was approximately 1 mm. We used liquid nitrogen to cool the specimen and inert gas replacement to heat it.

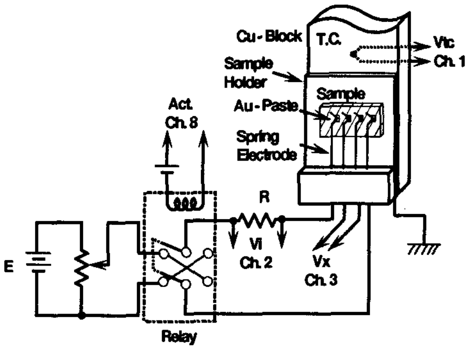

Figure 1. Measuring system of resistivity on the Woodceramics for DC 4-probe method.

3. RESULTS AND DISCUSSION

3.1. Resistivity characteristics

Figure 2 shows the sintering temperature dependence of the resistivity at room temperature. The resistivity falls as the sintering temperature rises. As the sintering temperature becomes higher, the resistivity hardly varies. The resistivity varies over a wide range of more than 4 figure orders. At or below 600 ℃, WCS is almost an insulator. We conjecture that WCS is not carbonized enough at or below this temperature. The resistivity of WCS can be varied over a wide range by changing the sintering temperature to give the required resistivity.

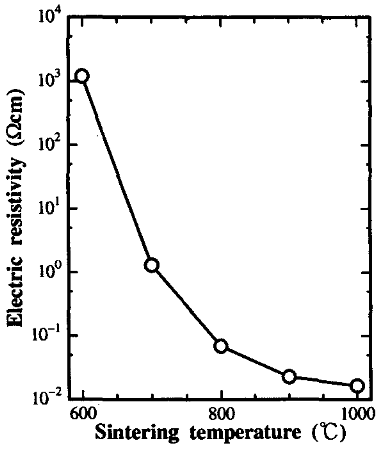

Figure 2. Resistivity for sintering temperature.

3.2. Temperature dependence of resistivity

Figure 3 shows an Arrhenius' plot of resistivity change with specimen temperature from 100 to 300 K. As the specimen temperature rises, the resistivity lowers almost linearly. As the sintering temperature rises, the resistivity change becomes gentle, and the inclination also becomes gentle. This characteristic reduction in WCS resistivity as the temperature rises is more like that of a semiconductor than that of a metal.

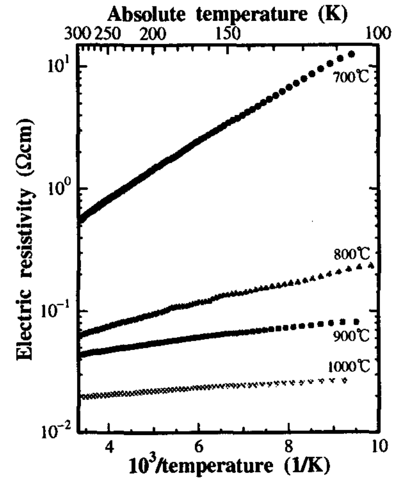

Figure 3. Temperature dependence of resistivity.

Figure 4 shows how the resistivity depends on specimen temperature from 300 to 700 K. The resistivity lowers as the specimen temperature rises, then suddenly becomes higher at around 650 K is the ignition point of charcoal and the number of carriers decreases due to oxidation. From these measuring results, the upper temperature bound for using WCS in air is estimated to be approximately 600 K (330 ℃). This is an acceptable value for applications such as far-infrared heaters. The temperature dependence of the resistivity of WCS shows semiconductor-like characteristics. From our experiments, we assumed that the linear range shown in figure 3 is an inherent range. Figure 5 shows the energy gap values obtained from this assumption. We used the following expressions to calculate the energy gaps[2].

$$\sigma = \frac{1}{\rho} = en\mu \qquad (1)$$

$$n = N \exp\left(\frac{-E_g}{2k_bT}\right) \qquad (2)$$

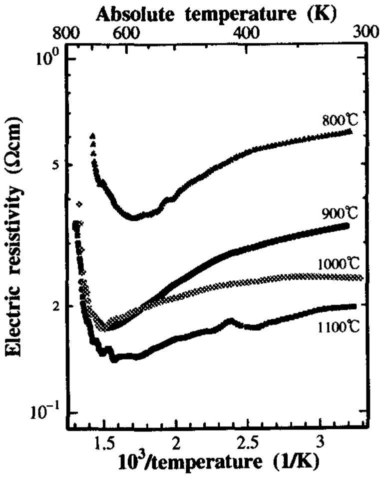

Figure 4. Temperature dependence of resistivity.

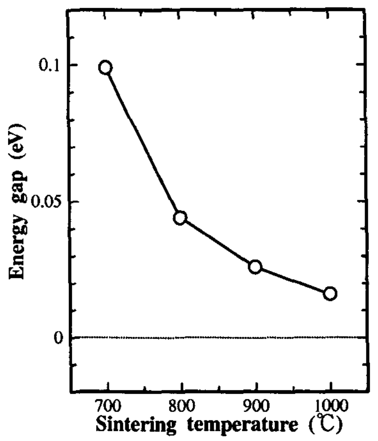

Figure 5. Energy gap of the Woodceramics for sintering temperature.

In the above expressions, e is the base electric charge of the carrier, n is the carrier density, μ is the degree of carrier mobility, N is the effective density of state, E_g is the energy gap value, k_b is the Boltzmann constant, and T is absolute temperature. The energy gap of approximately 0.1 eV at 700 ℃ lowers as the sintering temperature rises, and is approximately 20 meV at 1000 ℃.

Glassy carbon comprising WCS is regarded as a group of graphite micro-crystallites. It is known that if the heat treatment temperature of graphite is low, the size of micro-crystallites is small and the graphite becomes a semiconductor, having a gap of approximately 0.3 eV. It is also known that if the heat treatment temperature becomes higher, the size of micro-crystallites becomes large and finally the graphite becomes semi-metal as the band is overlapped by approximately 0.04 eV[3]. In this research, we obtained the result that the energy gap of approximately 0.1 eV at 700 ℃ lowers as the sintering temperature roses, and falls to approximately 20 meV at 1000 ℃. This result qualitatively matches the above properties of graphite. We believe that the WCS specimens in this research showed semiconductor-like temperature characteristics because their micro-crystallite sizes were small. We suppose that in glassy carbon comprising WCS, it is hard for the graphite micro-crystallites to grow as the sintering temperature increases because glassy carbon is non-graphitizable and hard to graphitize. This is perhaps why the resistivity of WCS shows a semiconductor-like temperature dependence even at higher sintering temperature.

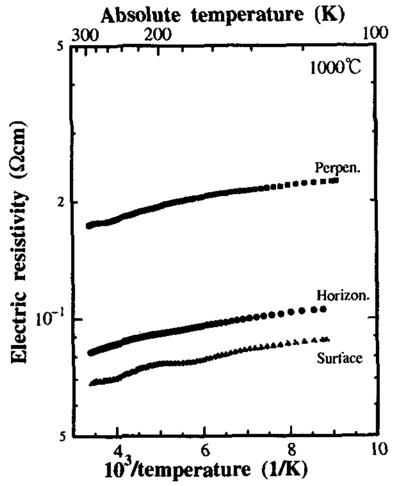

Figure 6. The resistivity anisotropy of the Woodceramics; Surface: surface of the Woodceramics, Horizon.: horizontal direction of the cross section, Perpen.: perpendicular direction of the cross section.

3.3. Anisotropy of resistivity

Figure 6 shows the temperature dependence of the resistivity on the surface and in the horizontal and perpendicular (woody fiber lamination) directions of the cross section. The resistivities on the surface and in the horizontal direction of the cross section are almost the same, but the resistivity in the perpendicular direction of the cross section is slightly larger. At all the temperature, resistivities vary linearly with almost the same inclination. This demonstrates that there is no clear difference in the energy gap values between the surface, horizontal direction, and the perpendicular direction, and that there is no anisotropy in the size of the graphite micro-crystallites. Because the MDF from which WCS is made is formed by applying pressure to woody fibers, the woody fibers cross one another and are laminated. Therefore, the structure differs between the surface and the fiber lamination direction, and this difference is reflected in the different resistivities.

4. FABRICATING AN EXPERIMENTAL TEMPERATURE SENSOR

The electrical resistance of WCS is sensitive to temperature and has a negative temperature coefficient. Therefore, temperature can be measured from value of its electrical resistance. Resistance bulbs such as the thermistor and platinum are mainly used in temperature sensors based on change in resistance, but the temperature measuring range of the thermistor is not so wide. Furthermore, resistance bulbs are complicated and expensive. The change of resistance of WCS is linear over a wide temperature range, so WCS is likely to find use in cheap temperature sensors covering a wide temperature range.

Figure 7 shows an experimental WCS temperature sensor which we fabricated by cutting WCS sintered at 700 ℃ to 10x5x1 mm and fastening the section on a glass epoxy substrate. The sensor element was sealed with silicon rubber to prevent humidity effects. The electrodes were connected using an epoxy electron conductive adhesive. Figure 8 shows the temperature characteristics of this temperature sensor. The electrical resistance falls almost linearly as the temperature rises. The temperature coefficient is -0.36 %/℃ (-0.22 Ω /℃). This value is close to the value of 0.36 %/℃ of the accurate platinum resistance bulb covering a wide temperature range. The voltage sensitivity of the WCS temperature sensor should be 0.44 mV/℃ for a constant current of 2mA for resistance measurement. This experimental sensor is easy to handle because of its 2-probe structure, but it is sensitivity to contact with the electrodes and is affected by the electrode connection method. To improve the accuracy, a 4-probe structure must be adopted.

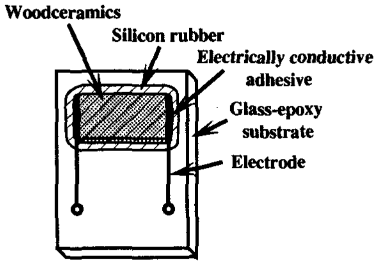

Figure 7. Temperature sensor using the Woodceramics.

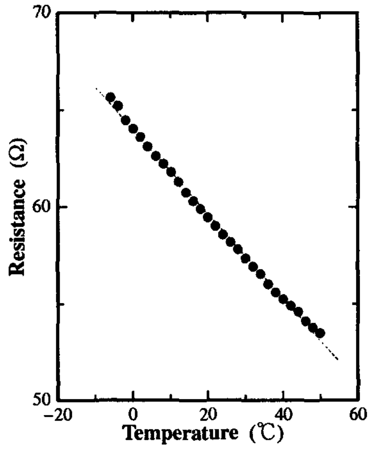

Figure 8. Temperature characteristic of the temperature sensor using the Woodceramics.

5. CONCLUSION

We investigated the electrical characteristics of porous carbon WCS materials. The results showed that the resistivity varies over a wide range depending on the sintering temperature, and the temperature dependence was semiconductor-like over a wide range from 100 to 600 K. We believe this semiconductor-like property of WCS is because the glassy carbon comprising WCS consists of graphitic micro-crystallites and a microscopic energy gap is produced because of the size of these micro-crystallites. We also demonstrated that WCS can be used in air up to 600 K. We fabricated an experimental temperature sensor and obtained a temperature coefficient of -0.36%/℃.

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.

REFERENCES

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