A Study on Absorption Properties of the EM Wave Absorber Using TiO₂ in W-band

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Abstract : In this paper, the electromagnetic (EM) wave absorbers using TiO₂ as a dielectric material with chlorinated polyethylene (CPE) were investigated in W-band radio frequencies. We compared the relative permittivity with reflectionless curve and the absorption properties of samples containing 40 wt.%, 50 wt.%, 60 wt.%, 70 wt.%, and 80 wt.% TiO₂. It is possible to realize a complex relative permittivity satisfying the reflectionless condition by choosing composition ratio of TiO₂. The optimized composition ratio of TiO₂ for the maximum absorption property is about 70 wt.%. As a result, we have confirmed the realization of an EM wave absorber with a high absorption property in W-band radio frequencies.

Key words : Absorption property, Complex relative permittivity, Material property, Reflectionless condition, TiO₂.

1. Introduction

Millimeter waves offer a solution to the increasing demand for frequency allocation due to low-frequency band saturation and the requirement for higher data rates. Moreover, a high directivity can be obtained by the small antennas which are associated with small-sized circuits. For these reasons, the extensive research on the applications of millimeter waves has been done. In particular, research on applications in W-band is progressing rapidly (Russell., 1997; Brooker, 2005). The electromagnetic (EM) wave absorbers are effective for prevention of electromagnetic interference possibly caused by high degree of usage of electromagnetic waves. Therefore, researchers have confirmed the realization of a sheet-type absorber with a high absorption property at these frequency ranges (Soh and Hashimoto, 2001).

As is well known, EM wave absorbers can be broadly divided into two types from the viewpoint of material. One is a wave absorber using a dielectric material and the other is a magnetic wave absorber using a ferrite material (Kotsuka and Yamazaki, 2000).

In general, Carbon and titanium dioxide as a dielectric material, and Permalloy as a magnetic material are useful materials for EM wave absorption in W-band, and absorption properties of EM wave absorbers using Carbon or Permalloy have been investigated (Choi, 2007; Kim, 2007). But, absorption properties of samples in composition ratio of

TiO₂ have not been reported yet.

In this research, we investigated EM wave absorbers using TiO₂ as a dielectric material with chlorinated polyethylene (CPE) as a binder. First of all, we fabricated sheet-type EM wave absorbers containing 40 wt.%, 50 wt.%, 60 wt.%, 70 wt.%, and 80 wt.% TiO₂. These material properties were calculated using S-parameters and analyzed along with reflectionless condition. The optimized composition ratio of TiO₂ as a dielectric material has been estimated for high absorption property under reflectionless condition. We have confirmed the realization of an EM wave absorber containing TiO₂ in W-band.

2. Preparation and measurement of samples

2.1 Preparation of samples

In this research, we fabricated some samples in different composition ratio of TiO₂ and CPE. TiO₂ was mixed with the binder of CPE, and a sheet-type absorber was fabricated by using an open roller as shown in Fig. 1. The open roller's surface temperature was maintained at 70 °C during sample preparation because the surface temperature affects the EM wave properties of sheet-type absorbers (Moon, 2003). To investigate the effect of the composition ratio of the material, we fabricated samples containing 40 wt.%, 50 wt.%, 60 wt.%, 70 wt.%, and 80wt.% TiO₂.

The dimensions of the sample to measure the complex

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relative permittivity were $2.54 \times 1.27 \times 1.5$ mm and $2.54 \times 1.27 \times 3$ mm.

Fig. 1 Manufacturing process of an EM wave absorber

2.2 Measurement for reflection coefficient

The measurement equipment in this research is used for the reflection measurement. It includes an ANRITSU ME 78080A broadband vector network analyzer, rectangular waveguide, sample holder, and short circuit. Figures 2 and 3 are diagrams of the measurement setup used for measuring the reflection coefficient and the sample holder for rectangular waveguide, respectively. The reflection coefficient of the sample can be obtained from S_{11} after critical calibration.

3. Results and discussion

3.1 A comparison of the relative permittivity of the samples

The relative permittivity of the samples is calculated using S-parameters of a network analyzer by using $\ell-2\ell$ method (Naito, 1987). Figure 4 shows plots of measured complex relative permittivity ($\epsilon_r = \epsilon'_r - j\epsilon''_r$) at different frequencies, together with the first-order, second-order and third-order curves among the reflectionless curves obtained by solving eq.(1)

$$\frac{1}{\sqrt{\epsilon_r}} \tanh(j \frac{2\pi d}{\lambda} \sqrt{\epsilon_r}) = 1 \quad (1)$$

where ϵ_r , d , and λ are the relative permittivity, the

sample thickness, and the wavelength, respectively (Hashimoto, 1997).

Fig. 2 Measurement setup for the reflection coefficient

Fig. 3 Sample holder for rectangular waveguide

If a material is used for the measured complex relative permittivity exists on the reflectionless curve, an ideal EM wave absorber can be obtained. From comparison in Fig. 4, it is found that the complex relative permittivity of the samples approaches to the reflectionless curve from 40 wt.% to 70 wt.% and gets away from 80 wt.% of TiO₂ by impedance matching. From above result, we know that the complex relative permittivity of the sample containing 70 wt.% of TiO₂ crosses the reflectionless curves. Therefore, the sample containing 70 wt.% of TiO₂ is suitable for developing an excellent EM wave absorber.

Fig. 4 Measured result of relative permittivity

3.2 A comparison of the SEM micrographs of the samples

The SEM micrographs of samples are presented in Fig. 5, and show that all TiO_2 particles were mixed with the binder and that the number air holes decreased with increasing composition ratio of TiO_2 .

(a) TiO_2 40 wt.%

(b) TiO_2 50 wt.%

(c) TiO_2 60 wt.%

(d) TiO_2 70 wt.%

(e) TiO_2 80 wt.%

Fig. 5 Sem micrographs of samples containing various composition ratio of TiO_2

3.3 A comparison of the absorption properties of the samples

Fig. 6 Reflection coefficient as a function of frequency for samples with a composition of TiO_2 :CPE=40:60 wt.% in several thickness

Figures 6–10 plot the reflection coefficients against frequency. The thicknesses of the samples shown in Figures are 1.5 mm and 2.0 mm. The absorption property has a

tendency to increase from 40 wt.% to 70 wt.% and decrease from 70 wt.% to 80 wt.% TiO₂. In Fig. 9, the maximum values of absorption properties of 1.5 mm and 2.0 mm thick samples are 30 dB at 87 GHz and 29 dB at 92 GHz, respectively. As a result, the absorption property of the sample containing TiO₂ : CPE = 70 : 30 wt.% has a maximum value in frequency range of 65–110 GHz.

Fig. 7 Reflection coefficient as a function of frequency for samples with a composition of TiO₂:CPE=50:50 wt.% in several thickness

Fig. 8 Reflection coefficient as a function of frequency for samples with a composition of TiO₂:CPE=60:40 wt.% in several thickness

Fig. 9 Reflection coefficient as a function of frequency for samples with a composition of TiO₂:CPE=70:30 wt.% in several thickness

Fig. 10 Reflection coefficient as a function of frequency for samples with a composition of TiO₂:CPE=80:20 wt.% in several thickness

4. Conclusion

In this paper, we investigated EM wave absorbers using TiO₂ as a dielectric material. Material properties of the samples were calculated from S-parameters and analyzed under reflectionless condition. It is found that the relative permittivity of the sample containing 70 wt.% of TiO₂ goes across the reflectionless curves. Therefore, the sample containing 70 wt.% of TiO₂ is suitable for developing an excellent EM wave absorber. The absorption properties of the samples were measured by using a vector network analyzer. The absorption property has a tendency to increase from 40 wt.% to 70 wt.% and decrease from 70 wt.% to 80 wt.% of TiO₂. 1.5 mm and 2.0 mm thick samples containing 70 wt.% of TiO₂ have a maximum absorption value 30 dB at 87 GHz and 29 dB at 92 GHz, respectively. As a result, the absorption property of the sample containing TiO₂ : CPE = 70 : 30 wt.% has a maximum value in W-band radio frequencies.

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