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Hardened Glass Particle and Carbon Black Using Resin for Potential Electromagnetic Shielding in Biomedical Electronic Equipments

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Abstract. This study aims to investigate the electromagnetic properties of a composite of hardened glass particle and carbon using resin in determining the absorbability of the composite for electromagnetic interference (EMI). The electromagnetic absorption measurement was conducted using T-R method (transmission-reflection) by measuring the dielectric constant, loss factor, real and imaginary part of permeability, reflection coefficient and transmission coefficient. The measurement is taken for X band frequency and Ku band frequency within the frequency range from 8.2GHz to 12.4GHz and 12.4GHz to 18GHz, respectively. Dielectric constant of sample decrease when frequency increases. The high dielectric constant of material implies that the material has high absorbability of field energy, resulting in high attenuation of the applied field.

1. Introduction

Recently, the implementation of wireless technology has increased rapidly. Many wireless devices are ubiquitous in our daily life. The wireless technology brings massive convenience to all walk of life nowadays. There are also several EMI issues have been arisen. As a result, various electromagnetic absorbers were proposed to overcome this problem. The early research on electromagnetic-wave absorber was conducted during the second war by Germans [1]. They introduced a kind of paint that can act as the absorbing material. It was the earliest absorbing material that has been introduced. Nowadays, radar absorbing material for enhancement in national security is also triggered among the countries [1].

Electromagnetic interference in medical device occurs when another external source of electromagnetic energy interferes the electrical medical devices. As the popularity of wireless device increase, there will also be a rise in electromagnetic radiation within the segment of spectrum [2]. Various metallic materials have been used as EMI shielding materials such as steel, copper, aluminium, and nickel. Although these metallic materials are effective in shielding the electromagnetic wave, limitations are still available. Generally, metallic materials are heavy, susceptible to oxidation (rust) and corrosion which can lead to difficulty in electromagnetic shielding electronic device [3]. Glass is a material that can be implemented in many applications because it has many potential values. Generally, this material can be recycled limitlessly without losing its quality and also the purity of this material [4]. As a result, glass particle has been selected to be backbone material which can act as a matrix material in the fabrication of absorbing material incorporating with carbon black using epoxy/resin. A composite with glass particle and carbon black are proposed in this work.

2. Methodology

2.1 Sample Preparation
Samples were prepared by integrating carbon black powder with glass powder using epoxy/resin. Two dimensions of sample need to be prepared for measurement using waveguide WR90 and WR62. The prepared samples are in ratio of 20:80, 30:70, 60:40, 70:30, 80:20 and 90:10 of carbon black to glass particles.

The resin/epoxy and carbon black are commercially available. Glass particle is acquired by crushing the domestic glassware. The glass particle needs to be compressed and ground into powder form using a pestle and a mortar. Lastly, resin/epoxy is applied to harden and integrate glass powder and carbon black into a cuboid shape which needs to be fitted into sample holder for waveguide WR62 and WR90. The dimension of both sample holders are tabulated in Table 1.

Table 1. Operation frequency range and dimension of sample holders

Sample holder	Frequency Range (GHz)	Internal Dimensions (mm)
WR90	8.2 – 12.4	22.860 × 10.160
WR62	12.4 – 18.0	15.799 × 7.899

2.2 Measurements
Calibration on P-series network analyzer (PNA) is conducted before measurement. The systematic error can be avoided through the calibration using standard loads, i.e. air, water and shorting block. The required measurement parameters, i.e. frequency range, the dimension of the waveguides and sample under test need to be defined. The operation frequency range in this work is X band (8.2GHz to 12.4GHz) and Ku band (12.4GHz to 18GHz).

The calibration needs to be conducted before measurement. The electrical standards used during the calibration process are short, line and thru. Before the measurement is conducted, the sample must be placed in sample holder. Then, the sample holder with the sample placed between waveguides without a gap. The measured data are dielectric constant (ε'), loss factor (ε''), reflection coefficient (S11), transmission coefficient (S21) and absorption coefficient (A).

3. Experimental Results

3.1 Dielectric measurements
In Figure 1, the sample with 30% carbon black varies insignificantly with frequency compared to samples with carbon black 60% to 90%. ε' for sample with 30% present at the highest level. The percentage of carbon black exceeds the percolation threshold is the main factor. When carbon exceeds the percolation threshold agglomeration of carbon occurs. The agglomeration causes the increment of

conductivity. Hence, ε' decreases. Sample with 20% is exempted because the carbon content is too low and its dielectric behaviour is dominated by glass particles and resin. Overall, ε' of all samples decreases when frequency increases [5] at X band. It is due to inconsistency between relaxation frequency of composites and the operating frequencies of the applied field. The similar observation can be noticed through Figure 5 for Ku Band. The variation of ε' at Ku band as shown in Figure 2 seem more dispersive. It is attributed to inhomogeneity of the prepared samples. The drastic is conducted within frequency range from 14.5 GHz to 16 GHz are most probably due to inactivation of a particular type of polarisation.
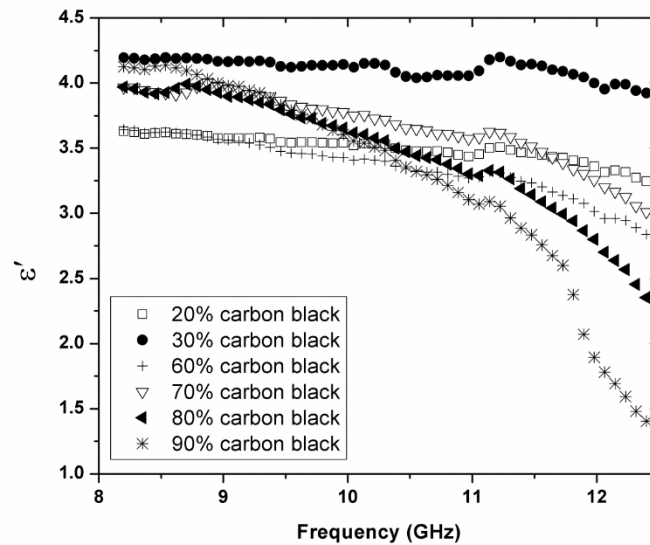
Figure 1. Dielectric constant (ε') versus frequency at X band

Dielectric loss factor, ε" for all samples at X band and low percentage of carbon content change insignificantly. When carbon content ≥ 80%, ε" increases remarkably at high frequencies, especially 90% carbon black. It shows highest loss might be due to conduction loss when conductivity of sample of 90% carbon black increases due to presence of carbon black in substantial amount. This insignificant variation of ε' as exhibited by samples with low carbon black as shown in Figure 1 explain the behavior of ε" in Figure 3. The polarisation direction is able to remain align with the applied field. Hence, ε" is low due to low energy dissipation. However, the inactivation of polarization at Ku Band that exhibited by the drastic decrement of ε' as shown in Figure 2 implies the asynchronous of polarization between applied field and sample. It increases the friction loss where the energy dissipated in heat loss. As a result, it shows peak for ε" in Figure 4.
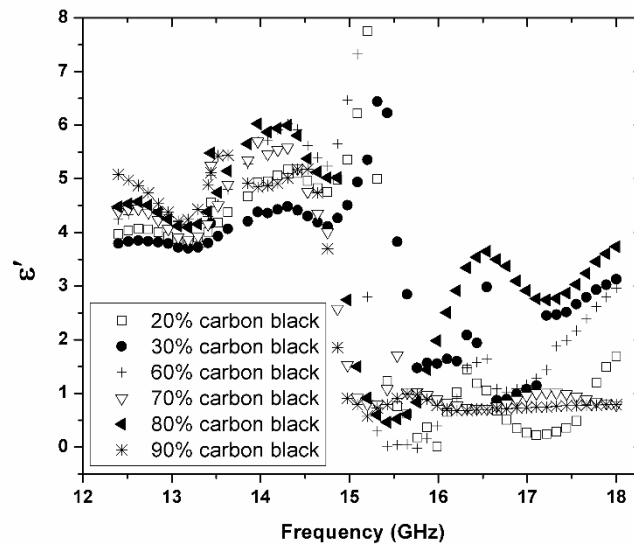
Figure 2. Dielectric constant (ε') versus frequency at Ku band
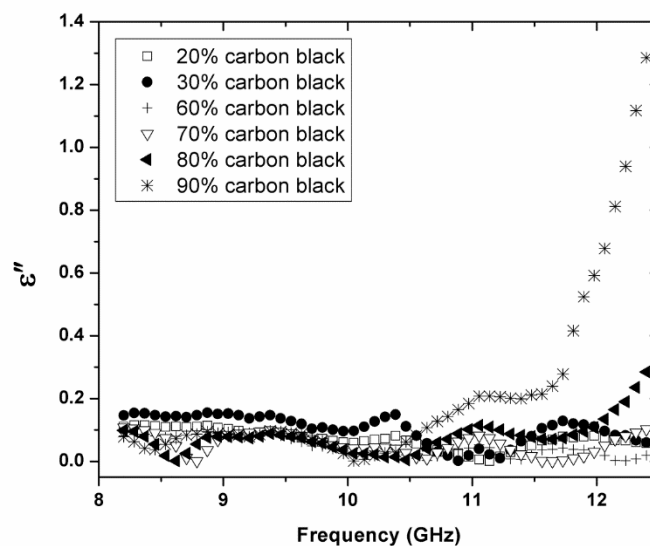

Figure 3. Loss factor (ε'') versus frequency at X band

3.2 Reflection, Transmission and Absorption Measurement

In Figure 5, reflection coefficient, S11 for all samples decrease when frequency increases. It implies that mismatch impedance between sample decline when frequency increases. S11 increases when an impedance of sample largely deviates from the characteristic impedance of waveguide, i.e. 50 Ω. The consistent decrement of ε' in Figure 3 lead to trendline in Figure 5 where ε' contributes to capacitive reactance. Subsequently, this capacitive reactance is used to determine the impedance. On the other hand, the sinusoid trendline as exhibit in Figure 4 leads to the variation from a negative gradient to a positive gradient at higher frequency as shown in Figure 6.

In Figure 7 and Figure 8, it can be noticed that the gradient of their trendline is in contrary with Figure 5 and Figure 6. When the reflection energy decline, the transmission energy and absorbed energy (absorption coefficient) increases. It is consistent with literature [6] where absorption

coefficient increases over frequency. The absorption coefficient in percentage as shown in Figure 9 and Figure 10. These percentage is acquired through $A(\%) = 1 - S11^2 - S21^2$. Sample with 90% carbon black exhibit the highest absorption among other samples at Ku band where it can up to 30% of absorption. It shows the highest absorption too when compared with X band.
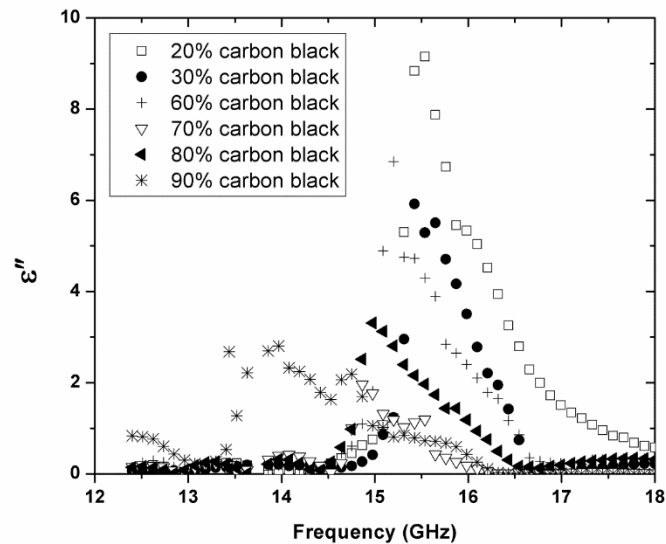

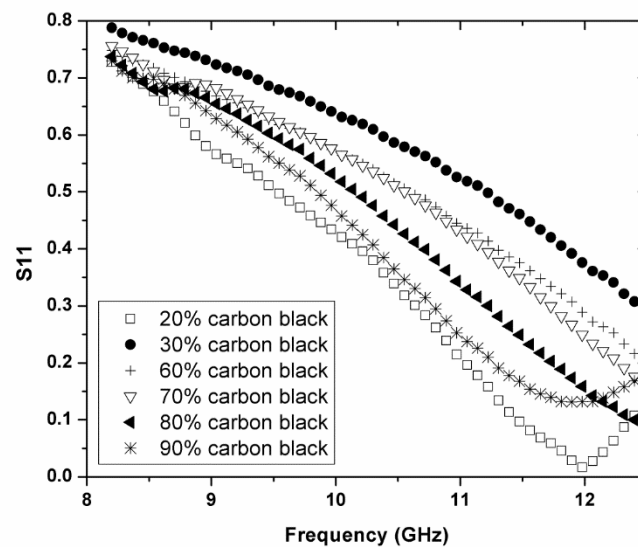**Figure 4.** Loss factor (ε") versus frequency at Ku band

Figure 5. Reflection coefficient response to frequency at X band
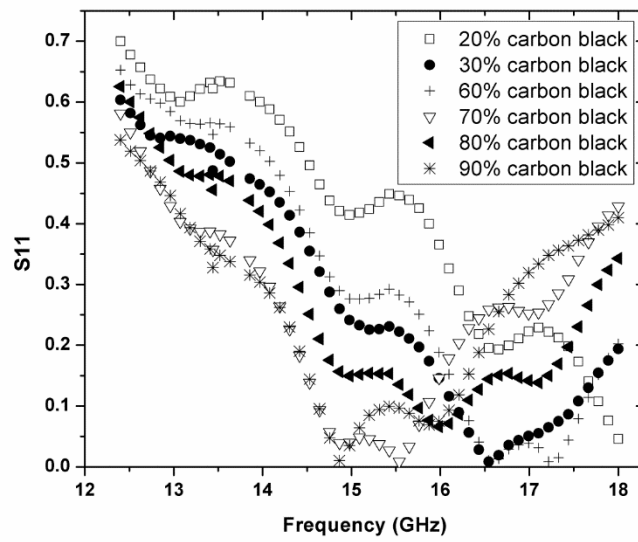
Figure 6. Reflection coefficient response to frequency at Ku band
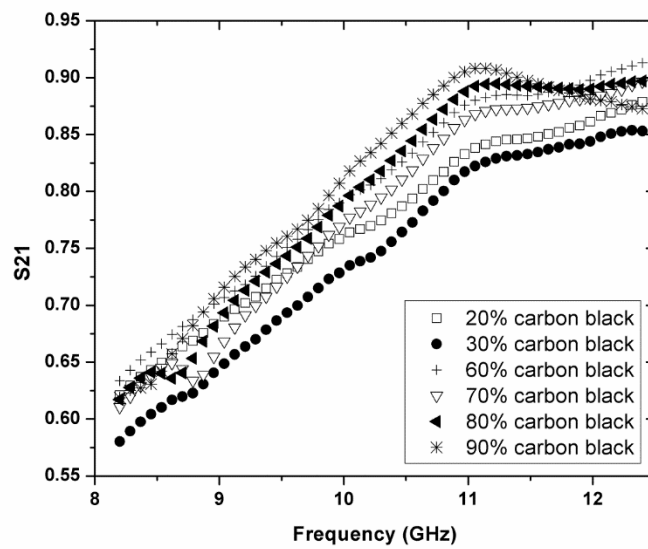

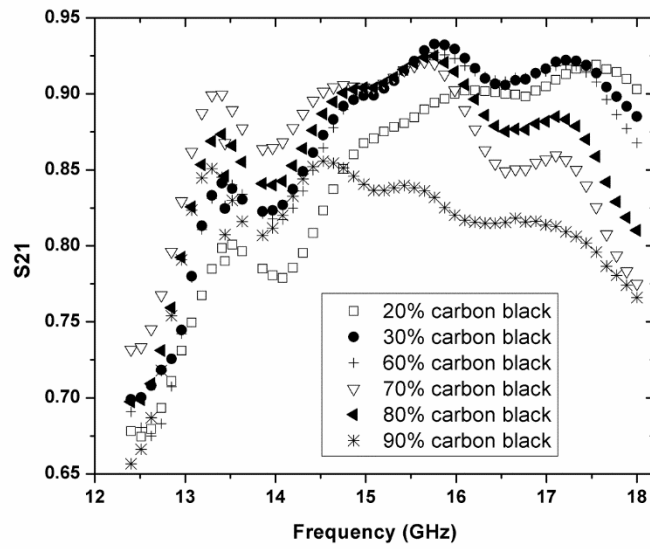**Figure 7.** Transmission coefficient response to frequency at X band

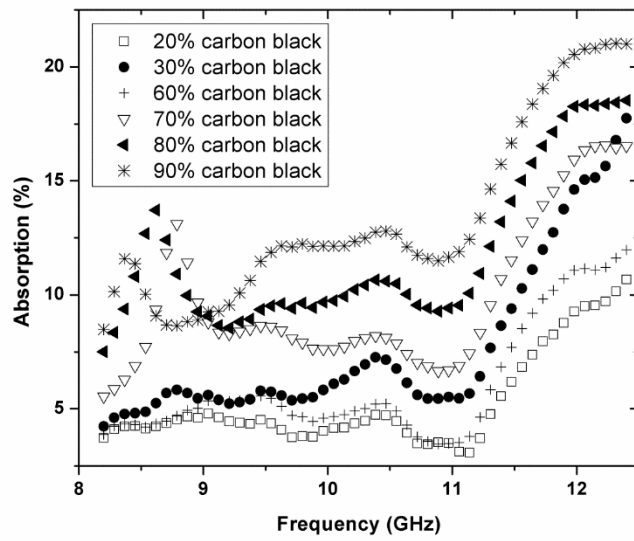**Figure 8.** Transmission coefficient response to frequency at Ku band

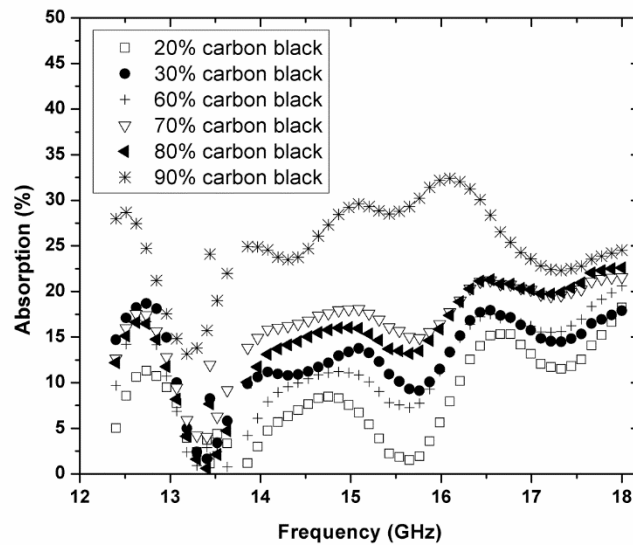**Figure 9.** Absorption coefficient at X band

Figure 10. Absorption coefficient at Ku band

4. Conclusions

This study is conducted to investigate the dielectric properties and propagation mechanism in the hardened glass particle and carbon black using resin. The dielectric, reflection and transmission measurement are conducted using rectangular waveguide in conjuction with P-series network analyser. It can be observed that sample with high percentage of exhibit low dielectric constant, ε' at X band due to higher conductivity, whereas ε' shows drastic decrement at Ku band because there is polarization mechanism become inactive. It leads to a peak of ε" at Ku Band. This dielectric behaviors cause decrement and increment of reflection coefficient and transmission coefficient, respectively at both bands. This results justify the highest absorption up to 30 % at Ku Band.

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