Absorption properties of novolac-alumina-graphite mixture microwave absorbers in x-band frequencies

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Abstract
Absorption properties (Attenuation coefficient, the percentage of the reflection, and the percentage of absorption) in x-band have been investigated in this paper for novolac – alumina- graphite mixture. Using novolac as the host material, the samples are prepared with alumina concentrations (5%,10%,15%,20%) and graphite concentrations (5%,10%) with thickness equal to 2.2mm .Network analyzer produced by HP-8510 was used in this work to measure the attenuation coefficient. The samples (3, 5) have good attenuation of wave with bandwidth of frequencies. The maximum of attenuation is -25dB at frequency 10.28GHZ in sample (3) which has concentrations (80%novolac,10%alumina,and 5% graphite) and -24 dB at frequency 10.56GHZ in sample (5) which has concentrations (75%novolac, 15%alumian, and 10% graphite). From the results of the attenuation coefficient, the percentage of the reflection is calculated. The percentage of absorption can be calculated from the percentage of the reflection.

Keywords
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خصائص الامتصاص لخليط نوفولاك - الومينا-كرافايت ماصات المايكروويف في ترددات حزمة X

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الخلاصة:
تم في هذا البحث دراسة خصائص الامتصاص (معامل التوهين،النسبة المئوية للانعكاس ،النسبة المئوية للامتصاص) ضمن حزمة-X لخليط نوفولاك- الومينا -كرافايت. استخدم النوفولاك كمادة مضيف, وحضرت العينات بتراكيز الومينا (5%,10%,15%,20%) وتراكيز كرافايت (5%,10%)وبسمك مقداره 2.2mm .استخدم في هذا العمل المحلل الشبكي المنتج من قبل(HP-8510) لقياس معامل التوهين.العينات (5,3) أعطت أفضل توهين للموجات وبحزمة ترددية عريضة .ان اعظم توهين كان 25dB- عند التردد 10.28GHZ في العينة (٣) والتي تمتلك تراكيز(٨٠%نوفولاك ,١٠%الومينا ,١٠%كرافايت) و 24dB- عند التردد 10.56GHZ في العينة (٥) والتي تمتلك تراكيز (٧٥%نوفولاك ,١٥%الومينا ,١٠%كرافايت). من النتائج لمعامل التوهين تم حساب النسبة المئوية للانعكاس ومن النسبة المئوية للانعكاس تم حساب النسبة المئوية للامتصاص.

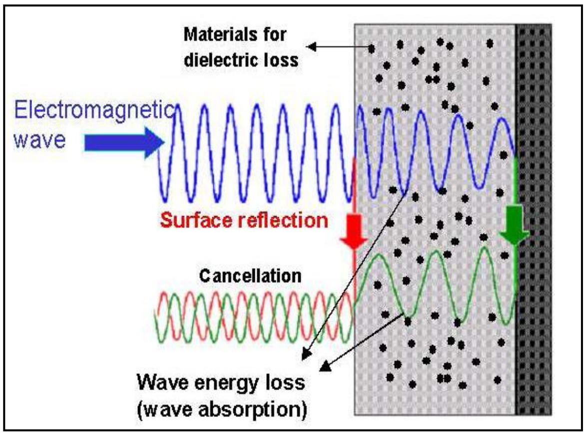
Introduction

The absorption of microwaves by a material depends on the properties of the material and its structure. One technique used to produce low reflectivity is to match the impedance of the electromagnetic radiation at the air-absorber interface, allowing the electromagnetic radiation to propagate into the absorber. Another technique used is to create destructive interference between the electromagnetic waves reflecting from different layers of the absorber. This class of absorbers is called resonant absorbers as examples being Dallenbach layers, Salisbury Screens and Jaumann layers.

The reflectivity from these absorbers can be calculated if the thickness, permittivity and permeability of all layers are known. The procedure to calculate the reflection and transmission coefficients for each layer, based on the permittivity and permeability, and then recursively propagate the electromagnetic field through the absorber. One technique used for microwave reflection from radar absorbers on perfect electrical conductors, PEC, is the recursion formulation.[1] In this case the recursion analysis starts at PEC surface and works back through the absorber to the air/absorber interface. Although it is possible to calculate the reflectivity from an absorber, it is only feasible to analytically solve for the optimum absorber properties over a few layers. Some strategies have been proposed for creating good absorbers by grading the impedance of the layers, however, these are not the optimum absorbers that can be achieved, in terms of minimum reflection over the widest possible bandwidth.[2] Microwave absorbing materials (MAM) have been widely used to prevent or minimize electromagnetic reflections from large structures such as aircraft, ships and tanks and to cover the walls of anechoic chambers.[3] Microwave absorbers are materials specifically designed to attenuate or absorb microwave energy. The increased use of military electronics, more specifically, microwaves electronics, including electromagnetic wave systems, radar systems, and Radio Frequency communications systems all bring to bear increased RF interference. Microwave absorbing materials are designed to attenuate or absorb microwave energy with the absorbed energy converted to heat. Attenuation of microwave energy occurs due to the dielectric loss and/or magnetic loss of a microwave absorber. Dielectric loss is found in the imaginary component of the complex permittivity and acts on the electric (E) field. Magnetic loss is found in the imaginary component of the permeability and acts on the magnetic (H) field. Microwave absorbers using dielectric loss to absorb the electric field portion of an electromagnetic wave. Dielectric-loss microwave absorbers are generally thicker physically than the magnetic-loss microwave absorbers due to their smaller real and imaginary parts of the permittivity.[4] the Efficient in absorption in a wide band range , Generally, magnetic or metal particles are used for the microwave absorption materials . Polymeric materials have been largely used as a matrix .[5] According to transmission line theory, when the electromagnetic wave transmits through a medium, the reflectivity is affected by many factors such as permittivity, permeability, sample thickness, and electromagnetic wave frequency. [5]

The operating bandwidth of single layer absorbers can be extended by applying two or more layers. The idea is to provide a slowly changing effective impedance profile with distance into the material [6]

Dielectric loss materials can reduce the incident/reflected wave energy figure (1). Thereby the RAM/RAS could absorb the incidence waves effectively.[7]



Picture (1) Principle of RAM/RAS with dielectric loss Materials. [7]

Lossy materials attenuate electromagnetic waves that pass through them. This can be modeled with the refraction index, relative permittivity, or relative permeability which are all complex numbers. The imaginary component causes the loss in the material. Physically, the absorbed power is converted to heat. In practical engineering applications where only the cumulative loss is of interest, the different loss mechanisms are combined into one set of normalized complex permittivity and permeability values ε_r and μ_r, given as [6]

$$\varepsilon_r = \varepsilon_r^{'} + j\varepsilon_r^{''} \qquad (1)$$

$$\mu_r = \mu_r^{'} + j\mu_r^{''} \qquad (2)$$

In the above equations, the real parts showing the energy storage are denoted by single primes, and the complex parts showing the loss with double primes. If we specify the electric and magnetic loss tangents as [6]

$$\tan\delta = \frac{\varepsilon_r^{''}}{\varepsilon_r^{'}} \qquad (3)$$

$$\tan\delta = \frac{\mu_r^{''}}{\mu_r^{'}} \qquad (4)$$

Equations (1) and (2) can be written in polar form as

$$\varepsilon_r = |\varepsilon_r| e^{j\delta} \qquad (5)$$

$$\mu_r = |\mu_r| e^{j\delta_m} \qquad (6)$$

The refraction index between free-space and a lossy material is

$$n = k/k_0 = \sqrt{\mu_r \varepsilon_r} \qquad (7)$$

Where k and $k_o = 2\pi f\sqrt{\mu_o \varepsilon_o}$ are the wave numbers in a lossy material and in free Space, respectively. If $Z_0 = 120\pi$ is the free-space impedance, the intrinsic impedance of a material with $\varepsilon_r \neq 1$ and/or $\mu_r \neq 1$ can be defined as

$$z = z_0\sqrt{\frac{\mu_r}{\varepsilon_r}} \qquad (8)$$

For normal incidence, the reflection coefficient of the material interface is calculated as

$$R = \frac{z - z_0}{z + z_0} = \frac{z/z_0 - 1}{z/z_0 + 1} \qquad (9)$$

In many practical applications, the dielectric absorbing material (with thickness d) has a metal backing, and its normalized input impedance (for normal incidence) can be shown to be [6]

$$z_{mb} = \sqrt{\frac{\mu_r}{\varepsilon_r}} \tan\ h(-jk_0 d\sqrt{\mu_r \varepsilon_r}) \qquad (10)$$

In most cases we are only interested in the amplitude of the attenuation coefficient in decibels, i.e.,

$$|R|(dB) = 20\log|R| \qquad (11)$$

However, the phase angle of R is important in some narrowband RAM applications where resonant energy cancellation is used.

The design of a RAM is a compromise between the front-face reflection coefficient and the loss per unit thickness. If low reflection is desired, then the material thickness will become large in wavelengths. In practice, multilayer structures are used to obtain the desired loss and low reflection inside the RAM sheet. These along with the use of [6]

Experimental part

The absorber which prepared in this work is consisting of novolac, alumina graphite mixture. The novolac is a polymer material which can be prepared from putting Phenol Formaldehyde powder in the thermal furnace with proper temperature approximately (150C^o) for one hour. This powder has been changed to hard material and the color of powder is changed from Wight to yellow. Hard material (novolac) has been milled by using electrical mill to obtained new kind from powder. This powder material is used as a host material in this work. Tow kinds of powder are investigated as fillers in this work. The first is conductive powder, graphite (purity 99.9%) with concentrations (5%, 10%), and the second is ceramic powder, alumina with concentrations (5%, 10%, 15%, 20%). Mixing of materials has been down by choosing above concentrations by weight of the total mixture content from graphite and alumina. The rest of weight balance is the host material novolac powder by using sensitive balance. This percent has been mixed by using a ceramic mortar. Then this mixture was milled with ceramic spheres.

Proper quantity has been weighted from final mixture transferred in die a home. A solid press of outer diameter equal to the inner die diameter is used to compact the above weighted mixture. The best compacted discs are choosing. Large press is used to press the die which includes the proper quantity from mixture. The operation of press is down with pressure equal to 200 bar and with time about (30 minutes) with temperature equal to 150C^{o}. After the operation of press is down, the press has been removed and exited the sample from the die. The thermal treatment with the operation of press is used for hardening the novolac material. The samples have been cutted by using electrical saw with the proper shape, obtained, which equal to the dimension of the measurement with dimensions (10mm-20.3mm) with specimen thickness equal to 2.2mm. Finally, samples have been tested. The network analyzer from HP-8510 type has been used to measure the attenuation coefficient, Reflection and absorption.

Table (1) show the concentrations of samples with thickness equal to 2.2mm

samples	Novolac concentration	AL2O3 concentration	Graphite concentration
1	90%	5%	5%
2	85%	10%	5%
3	80%	10%	10%
4	80%	15%	5%
5	75%	15%	10%
6	75%	20%	5%
7	70%	20%	10%

Results and discussion

The mixture novolac material, which was used as a host medium, and alumina material are isolated materials and have complex dielectric constant and with very little electric loss. Therefore they have attenuation to the wave is little. So they allow the electromagnetic wave to pass through them with very little absorption. But by adding the graphite powder to this mixture, according to the mentioned concentration, there conductivity will increase and this will cause an increase in there dielectric constant. Where the dielectric constant increases as a function of increasing conductive material content. The variation of dielectric constant values decreases as frequency increases. [8].

The graphite material changed the properties of the isolated materials, where the increasing in the graphite material leads to increasing in the conductivity and permittivity of the materials. Due to the graphite, which is a conductive material and non-magnetic therefore the permeability of this material is equal to one. Due to its ability to dispersion of microwave energy and convert it to an inductive electrical currents in the host material. This leads to attenuation of waves. Also the graphite is a lossy material; because of these powders have non-perfect conductivity compares with materials which have a reasonable conductivity like aluminum and nickel. This non-perfect conductivity benefits in attenuating the energy of the wave and convert it to an inductive currents in the host material with finite flow converted into a heat and this is called the finite conductivity which is considered the main mechanism in absorption of waves by these powders. The results of absorption are shown in figures (1, 2, 3, 4, 5, 6, and 7).

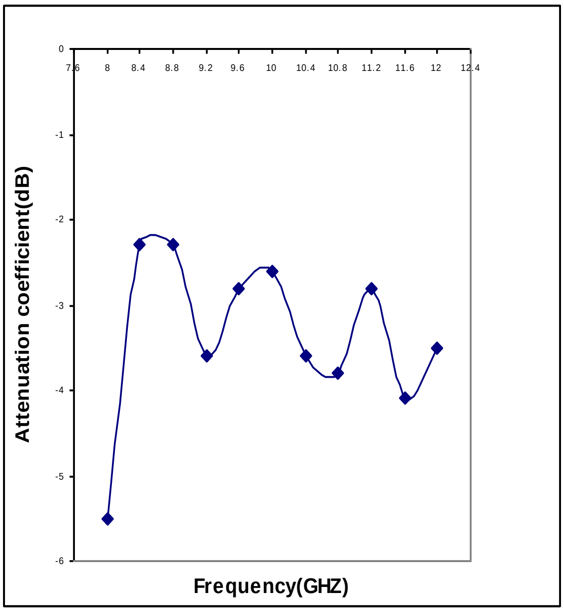


Figure (1) the attenuation coefficient as a function of frequency for sample (1)

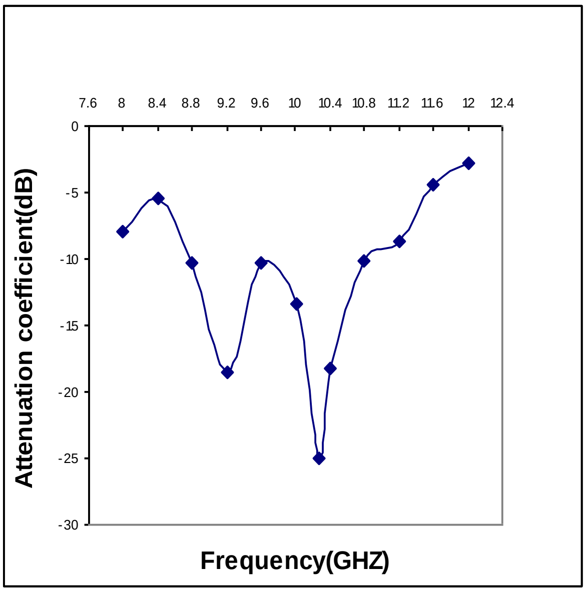


Figure (3) the attenuation coefficient as a function of frequency for sample (3)

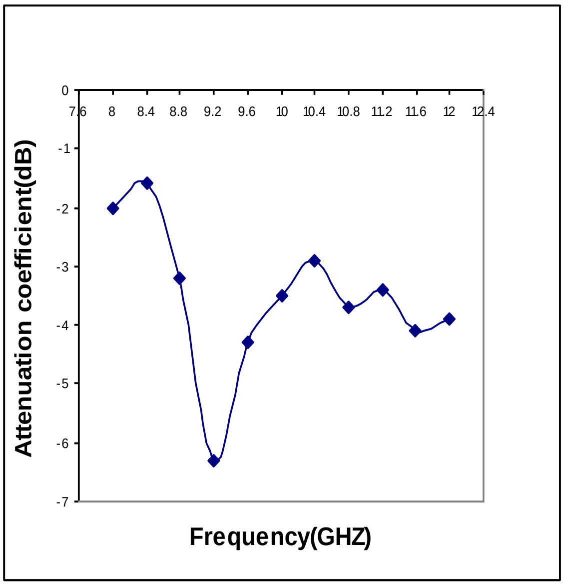


Figure (2) the attenuation coefficient as a function of frequency for sample (2)

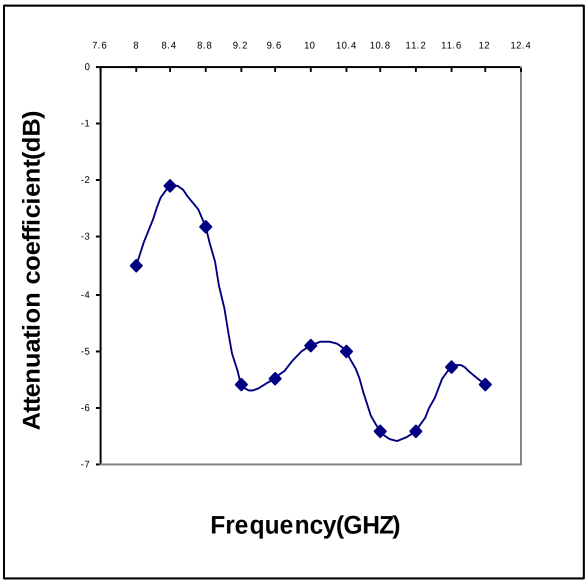


Figure (4) the attenuation coefficient as a function of frequency for sample (4)

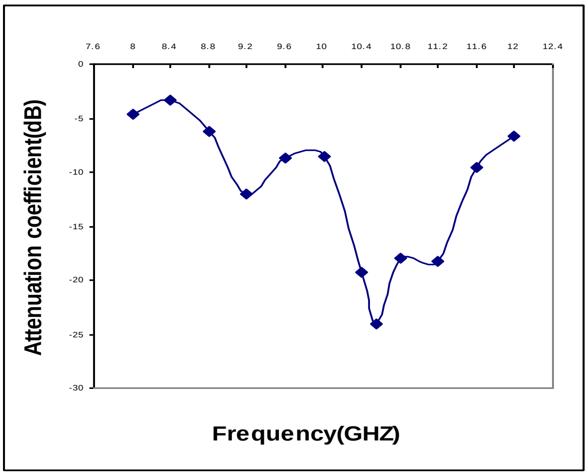


Figure (5) the attenuation coefficient as a function of frequency for sample (5)

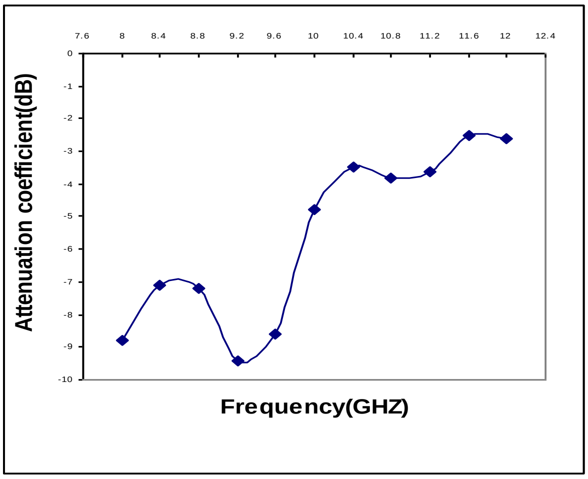


Figure (6) the attenuation coefficient as a function of frequency for sample (6)

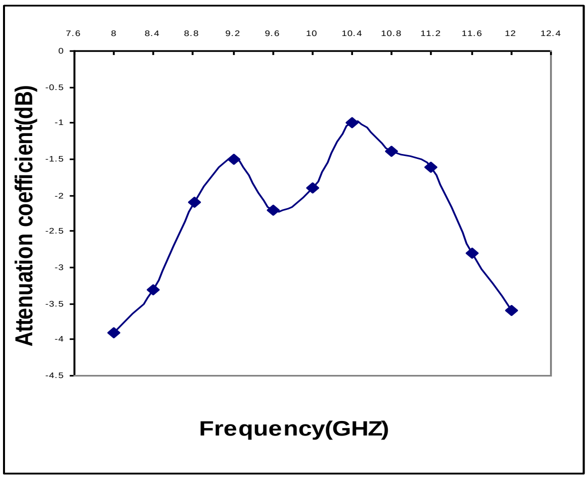


Figure (7) the attenuation coefficient as a function of frequency for sample (7)

From the result above we find that the samples (3, 5) have good attenuation of wave with bandwidth of frequencies because The maximum of attenuation is -25dB at frequency 10.28GHZ in sample (3) and -24 dB at frequency 10.56GHZ in sample (5). From the results of the attenuation coefficient in figures (1, 2, 3, 4, 5, 6, 7), the percentage of the reflection is calculated by using equation (11) as shown in figure (8)

Attenuation coefficient=20 Log|R|

Where R is the reflectivity**.**

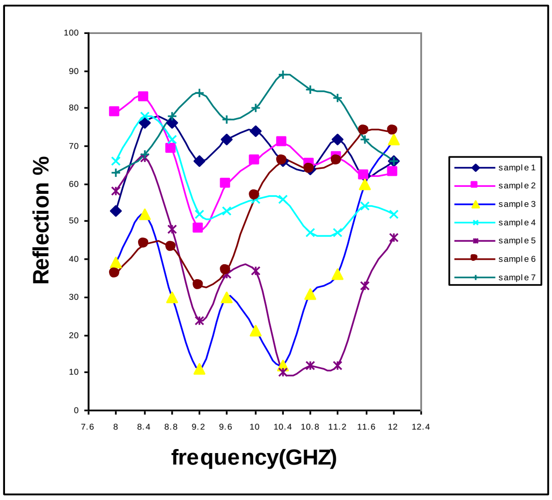


Figure (8) the percentage of Reflection as a function of the frequency

The percentage of absorption can be calculated from the percentage of the reflection by using the fallowing equation .

$$R+A+T=1 \qquad (12)$$

Where T equal to zero because of using short circuit in the measurement.

After calculating the percentage of the absorption can be drawn it as a function of the frequency as shown in figure (9), that seems to be the inverse of figure (8).

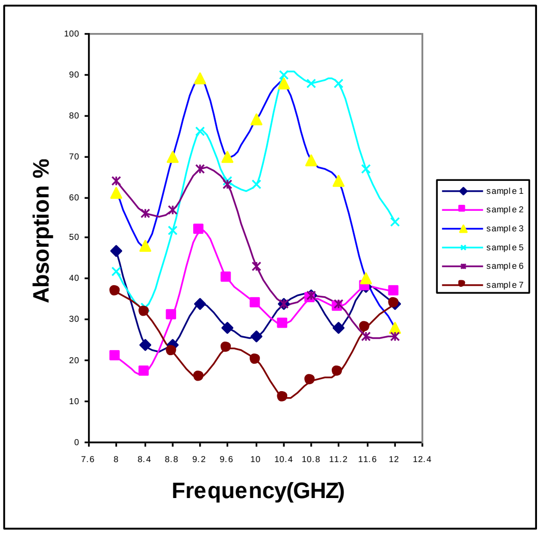


Figure (9) the percentage of absorption as a function of the frequency

Conclusion

1- The mixture can attenuate the microwave energy in x–band frequency.
2- Can use the novolac material as the host material.
3- The effect of graphite to change the conductive properties of the isolated materials

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