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Research on extinction performance of expanded graphite at band of 3 millimeter wave

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Expanded graphite is a kind of materials with good capability of electromagnetic wave absorption. In order to explore the extinction and scattering characteristics of expanded graphite in 3mm wavelength passive interference, the integral equation and the formula of extinction, scattering, absorption and backscattering cross sections are established based on the electromagnetic field theory. The method of moment (MOM) is used to solve the integral equation. The relationships between infrared extinction cross section of expanded graphite and the conductivity, magnetic permeability, the fiber length and diameter are analyzed and calculated. Theoretical calculation results show that the factors of length, radius, conductivity and magnetic permeability are closely related with the performance of expanded graphite in extinction, scattering, absorption cross section and back scattering in 3mm band. And the properties can be improved when the conductivity and magnetic permeability of the expanded graphite are increased properly. This research provides a valuable insight into the improvement of interference performance of expanded graphite in 3 millimeter wave.

Key words: Expanded graphite, Scattering, Absorption, Infrared extinction.

INTRODUCTION

Expanded graphite is high-temperature puffing products of graphite intercalation compound, which has unique structure, good floatation and conductivity. In recent years, expanded graphite is widely used in the military field as shielding interference material in millimeter wave band. Compared with the traditional interference materials, such as chaff, foil and glass fiber coated with aluminum, expanded graphite has the advantages of masking jamming characteristics in wide band (can work in 3 mm and 8 mm simultaneously), dispersion and environment coordination. At present, the research on expanded graphite interfering millimeter wave at home and abroad is mainly aimed at the experimental study on attenuation performance. Based on the theory of computational electromagnetism, the research on extinction, scattering characteristics and influence factors of expanded graphite in millimeter wave band is necessary, which can provide a theoretical basis for the improvement of the extinction performance.

THE INTEGRAL EQUATION FOR EXPANDED GRAPHITE

Pocklington integral equation

Expanded graphite external appearance presents cylinder as follow Pic.1. Suppose expanded graphite particle radius as a, length as 2h, conductivity as σ, relative permeability as μr , relative dielectric constant as εr . When plane electromagnetic wave irradiates expanded graphite, its surface produces current flow μ(s) and the current flow radiation can produce scattered field. Suppose the incident angle of electromagnetic wave asθi, scattering angle as θ, as follow Figure 1-2.

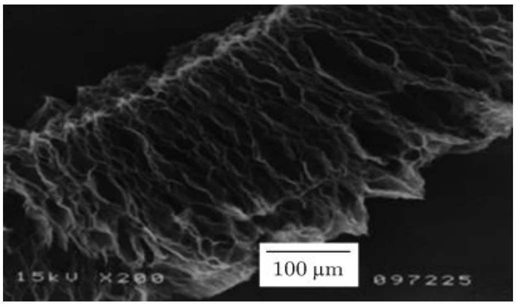

Fig. 1. Expanded graphite external appearance.

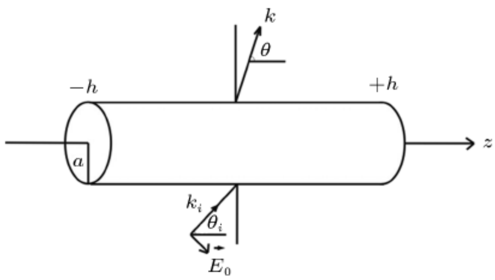

Fig. 2. Expanded graphite and incident electromagnetic wave angle.

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According to Maxwell equation and Pocklington integral equation, the expanded graphite surface induced current equation can be get as follows [1][2].

$$E_0\sqrt{1-q^2}e^{isq}=\int_{-x}^{x}u(s')G(s,s')ds'+\int_{-x}^{x}E(s')F(s,s')ds' \quad (1)$$

$$q=\cos\theta_i,\ p=\cos\theta, s=kz, y=ka, x=kh, k=2\pi/\lambda \quad (2)$$

$$G(s,s')=[1+\frac{\partial^2}{\partial s^2}]g(s,s'), F(s,s')=\frac{y^2}{2R}\frac{\partial}{\partial R}g(s,s') \quad (3)$$

$$g(s,s')=\frac{e^{iR}}{R}, R=\sqrt{(s-s')^2+y^2} \quad (4)$$

Obviously, to finite length expanded graphite, the particle terminal induced current disappeared. Then $u(\pm x)=0$, equation (1) is changed into equation (5) as following.

$$E_0\sqrt{1-q^2}e^{isq}=\int_{-x}^{x}u(s')G(s,s')ds'+E(s) \quad (5)$$

If the electromagnetic wave is vertical incidence, then $q=0$. The surface electric field is equal to the arithmetic product of surface impedance and surface induced current.

$$E(s)=\eta_s u(s) \quad (6)$$

If the electromagnetic wave is not vertical incidence, then

$$E_0\sqrt{1-q^2}e^{isq}=\int_{0}^{x}u(s')[G(s,s')+\eta_s F(s,s')]ds' \quad (7)$$

Moments method solution

The method of moment (MOM) is used to solve the integral equation. Dividing expanded graphite into N parts along with Z axis, the unknown induced current is expanded by pulse primary function as following [3].

$$P_i(s)=\begin{cases}1, & s\in i,\\ 0, & others\end{cases} \quad (8)$$

$$u(s)=\sum_{i=1}^{N}\alpha_i P_i(s) \quad (9)$$

(9) is substitute in (8) ,Select point matching weight function to multiply formula(7),

$$\sqrt{1-q^2}e^{is_jq}=\sum_{i=1}^{N}\alpha_i\int_{cell_i}[G(s_j,s')+\eta_s F(s_j,s')]ds', i,j=1,2,3,\cdots,N \quad (10)$$

The induced current distribution inside the expanded graphite can be obtained by solving the matrix equation above.

In far field condition, According to formula (9), the expanded graphite scattered field is [4]

$$f(q,p)=\sqrt{1-p^2}\int_{-x}^{x}ds[u(s)-(\frac{ka}{2})^2E(s)]\exp(-ips) \quad (11)$$

(6) is substitute in (11)

$$f(q,p)=\sqrt{1-p^2}[1-(\frac{ka}{2})^2\eta_s]\times\int_{-x}^{x}dsu(s)\exp(-ips) \quad (12)$$

To unit amplitude incidence wave, the scattered field can be obtained from above and the expanded graphite scattering cross section is:

$$\sigma_s(q)/\lambda^2=2\pi\int_0^{\pi}|f(q,p)|^2\,dp \quad (13)$$

the expanded graphite absorption cross section is

$$\sigma_a(q)/\lambda^2=-\frac{1}{\pi}\mathrm{Im}(\eta_s)\int_{-x}^{x}ds\,|u(s)|^2 \quad (14)$$

Extinction cross section is composed by absorption cross section and scattering cross section, that is

$$\sigma_e=\sigma_a+\sigma_s \quad (15)$$

Calculation parameter solution

The dielectric constant of expanded graphite is[5]

$$\varepsilon=\varepsilon_0\varepsilon_r+\varepsilon_0(\varepsilon'-j\varepsilon'') \quad (16)$$

Adopting four-point probe method, the average electric conductivity in normal room-temperature is about $1.13\times10^4 s\bullet m^{-1}$.

The magnetic conductivity is

$$u=u_0u_r+u_0(u'-ju'') \quad (17)$$

Common expanded graphite is not magnetism, in calculation relative permeability $u_r=1$.

NUMERICAL CALCULATION AND DISCUSSION

According to theory above, the code of expanded graphite scattering cross section, absorbing cross section, extinction cross section and RCS model are programmed based on Matlab [6][7]. The relationships between each cross section and grain size, electric conductivity and magnetic conductivity of expanded graphite are analyzed and calculated [8].

Effect of expanded graphite length

To verify the method valid of this paper, it is compared with the calculus of variation about conduction fiber scattering cross section [3]. The calculation parameters are followed:

Frequency $f=94.5GHz$, angular frequency $\omega=2\pi f$, wavelength $\lambda=3.17mm$, fiber radius $a=0.12mm$, dielectric constant $\varepsilon=8.85\times10^{-12}(15.54-4.76i)$, electric conductivity $\sigma=1\times10^4 S\bullet m^{-1}$, magnetic conductivity $\mu=\mu_0\mu_r=4\pi\times10^{-7}$, incidence angle $\theta=\pi/4$, length variation range $h=0.3-1.8mm$. The relationship between each cross section and particle length is followed as Figure 3.

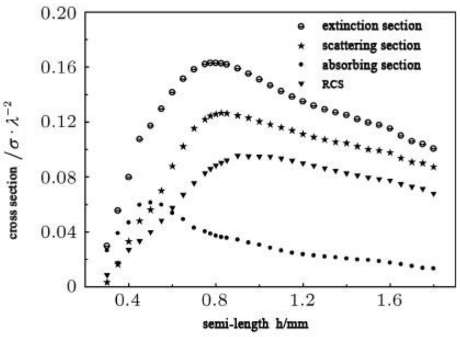

Fig. 3. Relationship between each cross section and expanded graphite particle length.

From Figure 3 above, to 3mm incident wave, when the length of expanded graphite is short, the value of each cross section is small. The absorption effect is most. The longer the length of expanded graphite is, the larger the each cross section value is. When the length of expanded graphite is longer than 1mm, the scattering effect is most. When the length is 1 mm, 1.55 mm and 1.65 mm individually, the value of the absorbing cross section, scattering cross section and extinction cross section is the maximizing. With the length of expanded graphite increases, the absorbing cross section, scattering cross section and extinction cross section decrease gradually.

Effect of expanded graphite radius

The expanded graphite is long column, its grain size includes the length and the radius. The calculation parameters are followed as 3.1 above. Suppose the length h = 0.75 mm, the radius variation range a = 0.01 ÷ 0.24 mm. The relationship between each cross section and particle radius is followed as Figure 4.

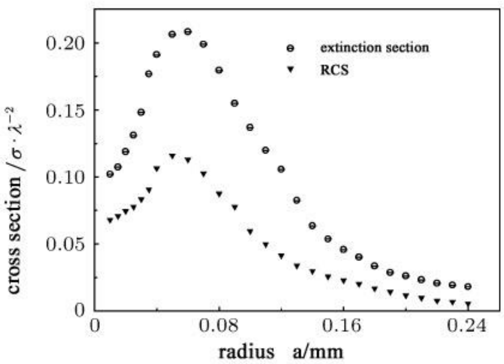

Fig. 4. Relationship between 3mm wave extinction cross section, RCS and expanded graphite radius.

From Figure 4 above, extinction cross section changes with the expanded graphite radius.

When the expanded graphite radius is small value, the extinction cross section and RCS gradually enhances with expanded graphite radius. The extinction peak value appears on the corresponding radius $a = 0.05mm$. After the peak value, the extinction cross section and RCS gradually decrease with expanded graphite radius increment. That is because the expanded graphite extinction effect on millimeter wave includes not only scattering effect, but also absorbing effect. So, the expanded graphite radius is too thin or too thick, that decreases the extinction cross section and RCS.

Effect of expanded graphite electric conductivity

The interference materials extinction effect on electromagnetic wave is combined with scattering effect and absorbing effect. It is decided by the interference materials form, dimension and electromagnetic character commonly. The calculation parameters are followed as 3.1above. Suppose the length $h = 0.75mm$, the electric conductivity variation range $\sigma = 2.5 \times 10^2 - 1 \times 10^6 S \bullet m^{-1}$. The relationship between each cross section and expanded graphite electric conductivity is followed as Figure 5.

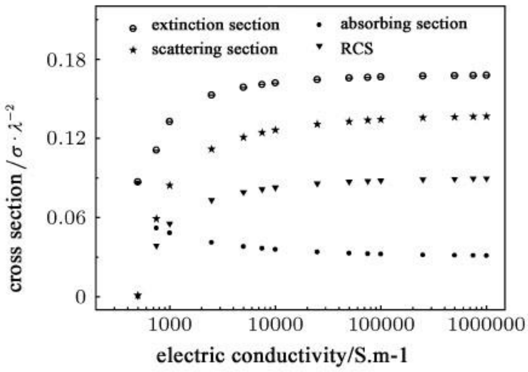

Fig. 5. Relationship between 3mm wave extinction cross section, RCS and expanded graphite electric conductivity.

From Figure 5 above, the absorbing cross section decreases with the expanded graphite electric conductivity increasing. When the electric conductivity is small value, the absorbing effect is the main extinction effect. To extinction cross section, scattering cross section and RCS, the values increase with the electric conductivity increasing. μr

Effect of expanded graphite magnetic conductivity

The expanded graphite calculation parameters are followed as 3.1 above. Suppose the length h = 0.75 mm, the magnetic conductivity variation range μ = (1-5)×4π×10^{-7}(*H/m*). The relationship between each cross section and expanded graphite magnetic conductivity is followed as Figure 6.

From Figure 6 above, when the magnetic conductivity is small value, the absorbing cross section increases with the expanded graphite magnetic conductivity increment. When the magnetic conductivity reaches 1.6, the absorbing cross section appears peak value. After the peak value, the absorbing cross section decrease with expanded graphite magnetic conductivity increment.

To extinction cross section, scattering cross section and RCS, the values increase with the magnetic conductivity increasing. When the relative magnetic conductivity is greater than 2, the influence on expanded graphite extinction, scattering performance and RCS are not obvious.

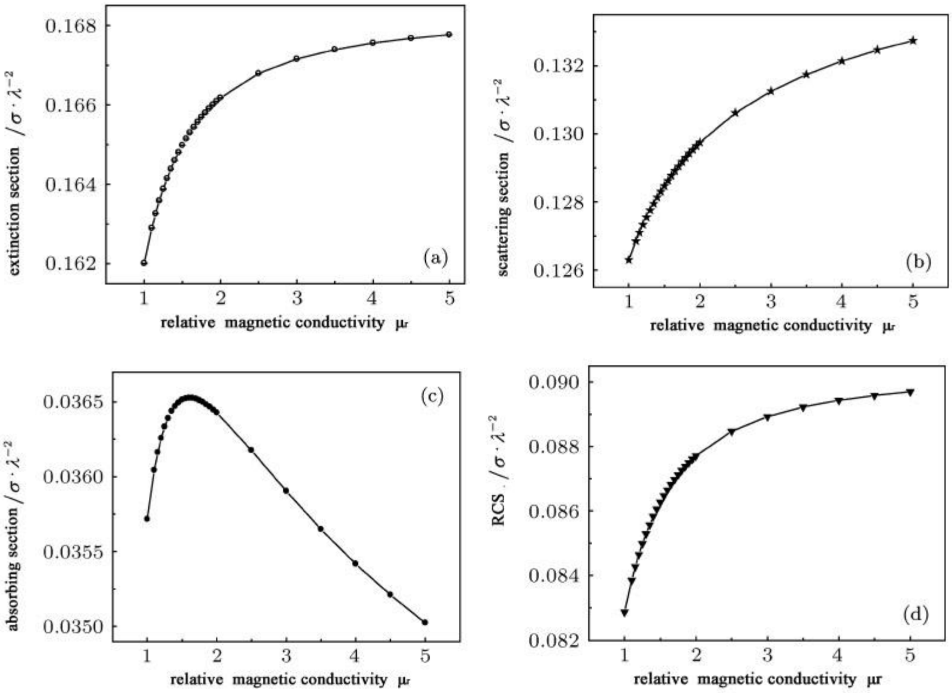

Fig. 6. Relationship between 3mm wave extinction cross section, RCS and relative magnetic conductivity.

CONCLUSION

(1) The expanded graphite extinction performance on 3 mm wave agrees with semi-wavelength theory and the optimum extinction radius is 0.05 mm. When particle length is near the semi-wavelength, the extinction and scattering performance are most intensive. If the expanded graphite radius is too thin or too thick, it can abate the extinction and scattering performance.

(2) The expanded graphite extinction and scattering performance increase with the electric and magnetic conductivity increment. When the electric conductivity is greater than 1×10^4 $S.m^{-1}$ and the magnetic conductivity is greater than 2, the influence on expanded graphite extinction and scattering performance is not obvious.

(3) The calculation result shows that the extinction and scattering performance on 3 mm wave can be intensified by controlling expanded graphite particle size, increasing expanded graphite electric and magnetic conductivity.

REFERENCES

1. H. Guan, G.P. Pan, L. Jiang, *J. Infrared Millimeter Waves*, **23**, 72 (2004).
2. I.M. Afanasov, V.T. Gustaaf, *Carbon*, **49**, 352 (2011).
3. Y.H. Zhang, Q. Lin, Y. Fan, *J. Infrared Millimeter Waves*, **30**, 38 (2011).
4. M.S. Zhou, C.J. Li, M. Xu, *J. Inorg. Mater.*, **22**, 509 (2007).
5. H. Ren, F.Y. Kang, Q.J. Jiao, *New Carbon Mater.*, **21**, 24 (2006).
6. P.C. Waterman, *J. Opt. Soc. America*, **22**, 2430 (2005).
7. A. Sharhabeel, Electromagnetic scattering and absorption by a finite conducting thin fiber, New Mexico State University, 2006.
8. A. Sharhabeel, *Trans..Antennas & Propagation*, **55**, 1856 (2007).