DESIGN AND FABRICATION OF RAS WITH GRAPHENE ADDED KEVLAR FIBER REINFORCED COMPOSITE

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1 Introduction

In modern warfare, stealth technology is applied to aircrafts and weapons. Stealth technology can improve the survivability and performance of aircrafts and weapons to gain the upper hand. Stealth technology involves the minimization of acoustic, optical, infra-red, and electromagnetic signatures. Among them, the minimization of electromagnetic signature is the most important. It can be realized in several ways which include stealth shaping design, radar absorbing material (RAM), and radar absorbing structures (RAS). Stealth shaping design involves the scattering of the incidence electromagnetic wave from a radar to other directions minimizing the reflective electromagnetic wave to the radar. However, stealth shaping design deteriorates the aerodynamic properties of aircrafts and is not useful against bistatic radars. RAM absorbs the incidence electromagnetic wave or cancels it by interference and ohmic loss. However, RAM has maintenance problems. RAS a load bearing concept based on RAM. It is resistant to high temperature and humidity. So RAS has less problems of maintenance[1-3].

In this paper, an RAS with Graphene added Kevlar fiber reinforced composite was designed and fabricated. The target frequency of the RAS was 12.4 – 18 GHz (Ku-band). The complex permittivity of Graphene added Kevlar fiber reinforced composites was measured using a network analyzer (HP 8510C) and rectangular wave guide. MATLAB and MWS CST STUDIO were used to design the RAS and predict the reflection loss of the RAS. Finally, the reflection loss was measured using a network analyzer and rectangular wave guide.

2 Materials and Fabrication method

The Graphene used in this paper, donated by the Korea Research Institute of Chemical Technology (KRICT), was manufactured by Nbarotech, Co. with a carbon mass fraction of approximately 73%. The mass fractions of other elements are tabulated in Table 1. The values were obtained from an Energy Dispersive Spectrometer (EDS) using Scanning Electron Microscope (SEM). A SEM image of the Graphene is shown in Fig. 1. The thickness of the Graphene is less than 5 nm.

Kevlar KM2® was used, and YD-128 epoxy resin and TH-431 hardener were used as an epoxy system. The epoxy and hardener were supplied by KUKDO chemical, Co.

A three-roll-mill, EXAKT 80S, was used to disperse the Graphene into epoxy. The three-roll-mill method showed a high degree of dispersion[4]. There were seven steps and different roller gap length was applied to each step. The three-roll-mill facility is shown in Fig. 2 and the roller gap length of each step is shown in Table 2.

By using Graphene added epoxy and Kevlar fabric, Kevlar/Graphene/epoxy composite was manufactured by a hand lay-up process and cured by an autoclave. After that, the composites were cut by a diamond cutter to produce specimen for the measurement of the complex permittivity of the composites. The specimen dimension was 15.8 x 7.9 mm and 3 mm thick. The Graphene content of the specimens was 1 wt%, 2 wt%, 3 wt%, 7 wt%, and 9 wt%. Complex permittivity was calculated using S-parameter and phase change in measurement frequency.

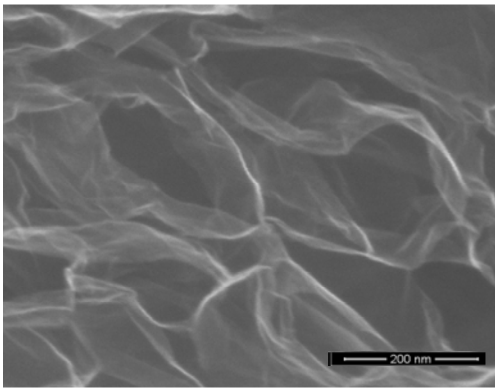

Fig. 1. SEM image of the Graphene

Fig. 2. Three-roll-mill and rotating speed

Table 1. Weight percent (wt%) of as-received Graphene

Atom	C	O	Na	Si	S
Graphene	72.69	18.51	6.66	0.29	1.85

Table 2. Roller gap length of each step (μm)

Roller	1	2	3	4	5	6	7
1 – 2	55	30	5	5	5	5	5
2 – 3	30	5	5	5	5	5	5

3 Properties of Kevlar/Graphene/epoxy composites

3.1 Complex permittivity

The complex permittivity measurement result is shown in Fig. 3 and Fig. 4. Complex permittivity is increases as the weight percent of Graphene is increases.

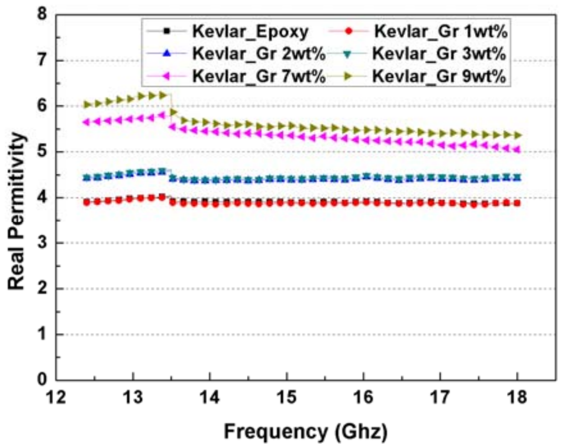

Fig. 3. Real permittivity of Kelvar/Graphene/epoxy composites

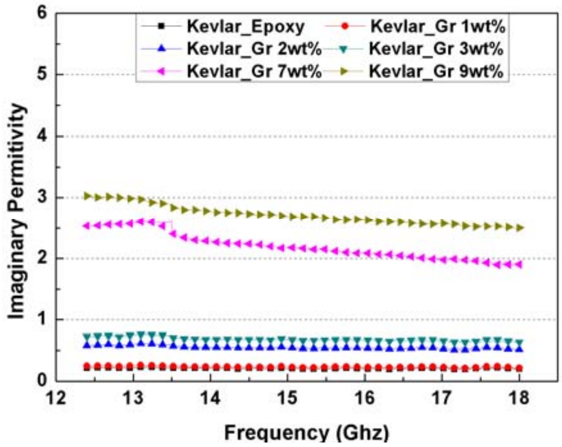

Fig. 4. Imaginary permittivity of Kelvar/Graphene/epoxy composites

3.2 Thickness per ply

Thickness is a significant parameter in the production of RAS. The thickness per ply of each specimen was listed in Table 3. The thickness per ply was almost uniform for the specimens with lower than 3 wt% Graphene. However, the thickness per ply dramatically changed with the 3 wt% Graphene specimen.

Table 3. Thickness per ply

Specimen (Matrix)	Thickness (mm)	Ply	Thickness per ply (mm)
Kevlar (Pure epoxy)	0.837	5	0.1674
Kevlar (Graphene 1 wt%)	1.656	10	0.1656
Kevlar (Graphene 2 wt%)	1.654	10	0.1654
Kevlar (Graphene 3 wt%)	1.999	10	0.1999
Kevlar (Graphene 7 wt%)	1.996	10	0.1996

4 Design and Simulation of RAS

In this paper, the RAS is of single layer. A single layer absorber can be considered a transmission line equivalent circuit as Fig. 5. This transmission line equivalent circuit consists of the characteristic impedance of each layer. This can be expressed as equation (1).

$$Z_{in} = Z_c \frac{Z_L + Z_c tanh(\gamma_c d)}{Z_C + Z_L tanh(\gamma_c d)} \qquad (1)$$

$$Z_c = Z_0\sqrt{\frac{\mu_r}{\varepsilon_r}}, \quad \gamma_c = j\frac{2\pi}{\lambda}\sqrt{\varepsilon_r\mu_r} \qquad (2)$$

Applying the condition of characteristic impedance of metal, a dielectric lossy material, and the non-reflecting condition expressed in equation (2) to equation (1), the equation of non-reflecting condition is derived as equation (3). If the frequency and complex permittivity are given, the matching thickness 'd' can be determined by equation (3)[2].

$$1 = \frac{1}{\sqrt{\varepsilon_r}}\tanh(j\frac{2\pi d}{\lambda}\sqrt{\varepsilon_r}) \qquad (3)$$

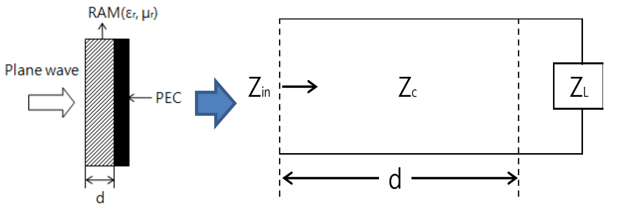

Fig. 5. Schematic design of single layer absorber (left) and transmission line equivalent circuit (right)

Solution sets of the non-reflecting condition were obtained through MATLAB. In-house code was used and the center frequency of the Ku-band, 15 GHz, was selected. The complex permittivity values were obtained at specific thicknesses. Thickness was varied from 1.0 mm to 5.0 mm with 0.1 mm intervals. Adaptive meshing technique was applied to obtain the solution sets. These solution sets can be displayed through the the Cole-Cole plot. Then the measured complex permittivity values of the Kevlar/Graphene/epoxy composites are added to Cole-Cole plot. Finally, it is able to find the point of intersection between the Cole-Cole plot and complex permittivity values can be found. The complex permittivity and thickness of the point of intersection were used as the design values. The 9 wt% Graphene specimen almost coincided with the Cole-Cole plot. Using the complex permittivity of the 9 wt% Graphene specimen, the corresponding thickness was found through MATLAB. It was 2.21 mm at 15 GHz.

Afterwards, to predict the reflection loss of the designed RAS in Ku-band, MWS CST STUDIO 2010 was used. The fiber and matrix system of Kevlar/Graphene/epoxy composite was simplified such that an isotropic dielectric material and perfect electric conductor used for the absorbing layer and reflector, respectively, for the modeling and simulation. The -10 dB bandwidth of the model was 12.36 – 18 GHz (5.64 GHz) from the simulation results. The Ku-band is all covered.

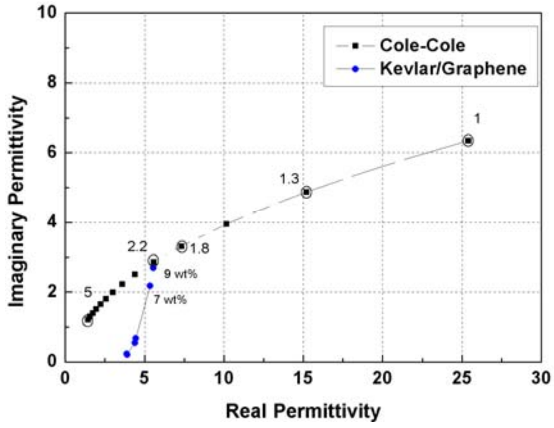

Fig. 6. Cole-Cole plot and Kevlar/Graphene/epoxy composites permittivity at 15 GHz

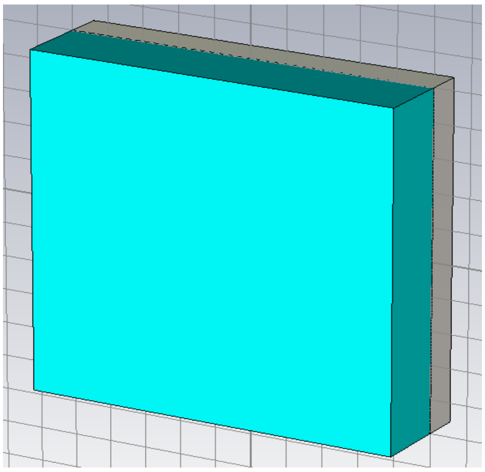

Fig. 7. Simulation model

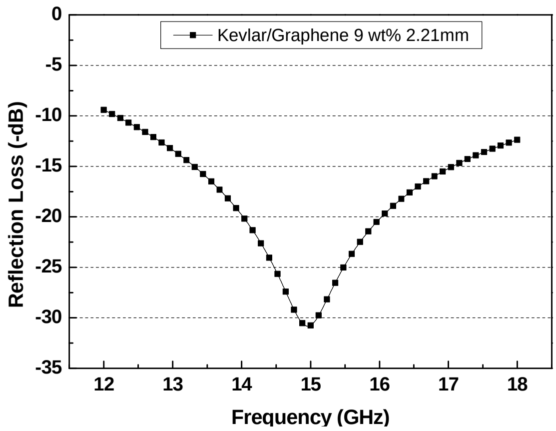

Fig. 8. Simulation result

5 Fabrication and Verification of RAS

Finally, the single layer RAS was fabricated using the designed values specified in Chapter 4. The 9 wt% Graphene epoxy was used and the thickness per ply was assumed as 0.2 mm. 11 layers of fabric Kevlar fiber were stacked by the hand lay-up method to manufacture a 2.21 mm thick Kevlar/Graphene/epoxy composite. However, the limitations of the Kevlar/Graphene/epoxy composite thickness per ply and the hand lay-up process led to manufacturing errors. So the thickness of the final specimen turned out to be 2.12 mm. Copper film was used as the back plate or reflector.

The reflection loss measurement result is shown in Fig. 9. The result is compared with the simulation result using a thickness of 2.12 mm. As this thickness is thinner than the prescribed design value, the resonance frequency shifted to a higher frequency. The shifted resonance frequency reduced -10 dB bandwidth.

Comparing the simulation and measured results, the measured data shows lower absorption due to the errors from manufacturing. However, the tendencies of the simulation and measured results are almost the same.

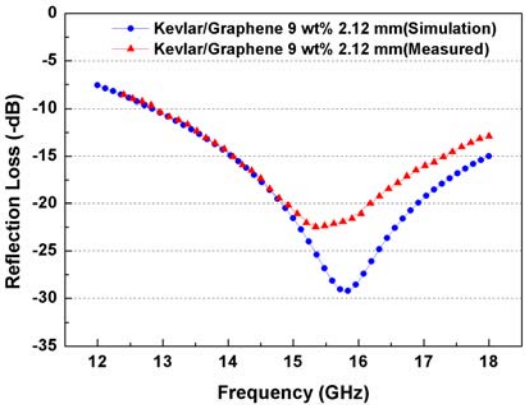

Fig. 9. Simulation and measured value of Kevlar/Graphene/Epoxy composite

Table 4. -10 dB bandwidth of single layer absorber

Absorber	Thickness (mm)	-10dB bandwidth (GHz)	
Kevlar/ Graphene 9wt%/ Epoxy	2.21 (simulation)	12.18 – 18	5.82
	2.12 (simulation)	12.84 – 18	5.16
	2.12 (measured)	12.89 - 18	5.11

Acknowledgement

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