Effect of Thickness and Patterns of Graphene Film on High-frequency Power Absorption

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Abstract. In this paper we discuss the effect of thickness and patterns of graphene film on high-frequency noise absorption performance, experimentally determine the graphene film of electromagnetic reflection, absorption loss and transmission. A simple thickness design microstrip line based structure has been used for the microwave characterization in high-frequency. The graphene material mixing with epoxy (graphene :70wt%, epoxy:30wt%, conductivity approximately 116 Siemens/m) was spin-coated or screen-printed on FR4 substrate to obtain the desired different film thickness. Complex S-parameter measures reveal different on thickness(0.05mm/0.5mm) in comparison to microstrip line. In this paper we found the graphene dual-film fabricated into the stair pattern with a thickness ratio of 1:10 has better performance than single layer. Both the S parameters and absorption power performance (Ploss/Pin) were measured in the high frequency range of 0.05 GHz–10 GHz. In this study the experiment results show that dual-film power loss reaches 95% at 2GHz were measured using an Agilent Technologies vector network analyzer PNA-X N5242A OPT200(VNA).

1. Introduction
Electrical devices having mobile characteristic must have electromagnetic compatibility (EMC) at all moments; unfortunately electromagnetic interference could affect any electrical device. In order to maintain the functional performance of electronic devices, there is need to avoid electromagnetic waves and noise interference. EM noise could be suppressed by using filters [1] [2], shielding gaskets [3], and films [4]–[7]. The filter circuits can suppress the device noise signal; films can absorb the noise signal; and the shields and gaskets could absorb and reflect the power from high frequency [8]. According to the shielding theory [9], the absorption and reflection coefficients determine the absorbing capabilities of a film; varying the film size and thickness would affect its power absorption [10]. In this study we examined power absorption by stair film structure which was printed on the microstrip line of a FR4 substrate. We used the S parameter to calculate Ploss/Pin in order to evaluate the absorption performance, and analysis of the Ploss/Pin is conducted. A vector network analyzer PNA-X N5242A OPT200(VNA) was employed for the S parameter analysis.

2. Fabrication of a graphene-based film on a microstrip line
The EM noise absorption was evaluated using a 50 Ω microstrip line to examine the attenuation characteristics. The microstrip line with dimensions of 3 mm × 40 mm was fabricated on an FR4 substrate
(40 mm × 40 mm) with an $\varepsilon_r$ of 4.4, loss tangent of 0.02, and thickness of 1.6 mm, referenced in the text as figure 1. The absorption film with a dimension of 40 mm × 30 mm × 0.05 mm was presented in figure 2. The graphene used was Enerage I-MS18 with a sheet resistance of <50 $\Omega$/square/mil. The paste consisting of graphene (70 wt%) · epoxy (30 wt%) was mixed completely by using a triple roller for 5 min, the mixer air bubbles in the vacuum box were removed for 20 min. After the film-printing technique, the FR4 was baked at 150 °C on a hot plate for 30 min. In this study, high frequency noise absorption characteristics of the film was examined based on the film thickness.

3. Results and discussion

3.1 S-parameter

In this study, we discuss the return loss($S_{11}$) and transmission coefficient($S_{21}$) of the microstrip line in compare different conductivity, pattern and thickness, design a better absorption film with return loss and transmission coefficient of at least -10 dB, the ANSYS HFSS (High Frequency Structure Simulator) was employed to simulate and analyze the film performance.

3.1.1 Single film. In figures 3 and 4, we observed that magnitude of $S_{11}$ and $S_{21}$ is a function of conductivity of the film. $P_{\text{loss}}/P_{\text{in}}$ based on the formula $P_{\text{loss}}/P_{\text{in}} = 1 - (|S_{11}|^2 + |S_{21}|^2)$ could be used to evaluate the film absorbability. When the signal passes to the microstrip line on different parameter film, the signal will be absorbed by the film.

Referenced as figure 5, the simulated results show that different conductivities bring about different $P_{\text{loss}}/P_{\text{in}}$ and $R_{\text{sheet}}; R_{\text{sheet}} = 1/(\text{conductivities} \times \text{thickness})$. In other words, the conductivity also controlled the signal easily enters into the film and increase the $P_{\text{loss}}/P_{\text{in}}$.

Figure 1. Structure of a microstrip line on FR4

Figure 2. Single graphene film on a microstrip line

Figure 3. $S_{11}$ of a single film with different conductivities

Figure 4. $S_{21}$ of a single film with different conductivities
The film of P\textit{loss}/P\textit{in} with the conductivity 100 S/m power loss reaches 80% at 2GHz, we conducted simulations with as same as conductivity and based the different film thicknesses in the single film pattern. It was observed that different thickness parameters (S) associated with different sheet thicknesses resulted in different P\textit{loss}/P\textit{in}, as shown in figures 6–8. The film with thickness of 0.05 mm had higher P\textit{loss}/P\textit{in}, as shown in figure 8, although the thickness about 0.005mm the S\textsubscript{11} <-10dB but S\textsubscript{21}>-10dB bring about P\textit{loss}/P\textit{in} low performance in all frequency. In other words, the thickness about 0.05mm and 5mm the S\textsubscript{11} >-10dB S\textsubscript{21}<-10 dB present the electromagnetic wave almost be reflection about P\textit{loss}/P\textit{in} low performance.

**Figure 5.** P\textit{loss}/P\textit{in} of a single film with different conductivities

**Figure 6.** S\textsubscript{11} of a single film with different thicknesses

**Figure 7.** S\textsubscript{21} of a single film with different thicknesses

**Figure 8.** P\textit{loss}/P\textit{in} of single film with different thickness
3.1.2 Dual film. Dual films with thicknesses of the first film and second film in the range of 0.1–5 mm/0.5 mm (aa/bb) and 0.05 mm/0.1 mm–0.05 mm (aa/bb), respectively was shown in figure 9. $S_{11}$, $S_{21}$ and $P_{loss}/P_{in}$ of the dual film with different thickness is shown in figures 10-12. It was observed that the thin/thick film has a better absorption performance than the thick/thin film so we found the thick/thin $S_{11}$>-10dB in return loss reflection situation and the thin/thick film $S_{11}$<-10dB at 1.7GHz, $S_{21}$<-10dB at 0.9GHz; moreover the thin/thick film showed lower magnitudes of $S_{11}$ and $S_{21}$. The dual film of $P_{loss}/P_{in}$ reaches 95% at 2GHz, exhibits have great absorbability in high frequency.

![Figure 9. Dual film on a microstrip line](image)

![Figure 10. $S_{11}$ of dual with different thicknesses](image)

![Figure 11. $S_{21}$ of dual film with different thicknesses](image)

![Figure 12. $P_{loss}/P_{in}$ of dual film with different thicknesses](image)

3.1.3 Triple film. According to the observed performance of the dual film, the $P_{loss}/P_{in}$ of thin/thick film is higher than that of the thick/thin film especially at low frequency, and thus a triple film was designed, as shown in figure 13, $S$ parameters of the thin/thin/thick and thin/thick/thin films were shown in figures 14 and 15. The magnitude of $S$ parameters of thin/thin/thick film was found to be higher than the other structures, as shown in figures 14 and 15. In figure 14, we found the thin/thin/thick film have low reflection at 1.7GHz, and the $P_{loss}/P_{in}$ of thin/thin/thick was higher than that of thin/thick/thin in the frequency range between 0.05 GHz–2 GHz, as shown in figure 16.
3.1.4 Quad film. The quad film with thin/thin/thin/thick and thin/thin/thick/thick structure was presented in figure 17, S parameters of the quad film were shown in figures 18 and 19. It was found that the Ploss/Pin of the thin/thin/thin/thick structure was higher than that of the thin/thick/thick/thick and thin/thick/thick/thin structure. For the thin/thin/thin/thick structure with different thicknesses of 0.5 mm and 5 mm at the fourth film, there was little difference for the value of Ploss/Pin in the frequency above 4 GHz, as shown in figure 20.

3.1.5 Compare film of thickness. The Ploss/Pin of the single film(0.05mm), dual film(0.05mm/0.5mm), triple film(0.05mm/0.05mm/0.5mm) and quad film(0.05mm/0.05mm/0.05mm/0.5mm) with different thickness compared with non-film was shown in figure 21. In figure 21, we found the stair pattern film Ploss/Pin reaches 90% better than signal film reaches 80% at 2GHz, especially S21 more absorbability thickness. The electromagnetic transfers current distribution has saturation curve bring about limit ohmic loss, so there was little difference of Ploss/Pin for the dual, triple and quad film with thickness ratio of 1:10.
Quad film
first film
second film
third film
fourth film

40mm
7.5mm
7.5mm
7.5mm
7.5mm

-40
-30
-20
-10
0
0 2 4 6 8 10
Frequency (GHz)
S11 (dB)
aa='0.05mm' bb='0.5mm' cc='0.5mm' dd='0.05mm'
aa='0.05mm' bb='0.05mm' cc='0.05mm' dd='0.5mm'
aa='0.05mm' bb='0.5mm' cc='0.5mm' dd='0.5mm'
aa='0.05mm' bb='0.05mm' cc='0.05mm' dd='5mm'
aa='0.05mm' bb='0.5mm' cc='0.5mm' dd='5mm'

0 0.2 0.4 0.6 0.8 1
0 2 4 6 8 10
Frequency (GHz)
Ploss/Pin
aa='0.05mm' bb='0.5mm' cc='0.5mm' dd='0.05mm'
aa='0.05mm' bb='0.05mm' cc='0.05mm' dd='0.5mm'
aa='0.05mm' bb='0.5mm' cc='0.5mm' dd='0.5mm'
aa='0.05mm' bb='0.05mm' cc='0.05mm' dd='5mm'
aa='0.05mm' bb='0.5mm' cc='0.5mm' dd='5mm'

0 0.2 0.4 0.6 0.8 1
0 2 4 6 8 10
Frequency (GHz)
Ploss/Pin
non-film
single film '0.05mm'
dual film aa='0.05mm' bb='0.5mm'
triple film aa='0.05mm' bb='0.05mm' cc='0.5mm'
quad film aa='0.05mm' bb='0.05mm' cc='0.05mm' dd='0.5mm'

Figure 17. Quad film on a microstrip line

Figure 18. S11 of quad film with different thicknesses

Figure 19. S21 of quad film with different thicknesses

Figure 20. Ploss/Pin of quad film with different thicknesses

Figure 21. Ploss/Pin of non/single/dual/triple/quad film
3.2 Current distribution

The Plot of J (current distribution) field in different frequency 1.5 GHz, 3 GHz, 6 GHz and 9 GHz was shown in figures 22–25. We observed that the second film had low current in the low-frequency regime, and we found the electromagnetic along microstrip line into the absorb film. In absorb film, the microwave energy transform hot by resistance.

![Figure 22. J field in 1.5 GHz](image)

![Figure 23. J field in 3 GHz](image)

![Figure 24. J field in 6 GHz](image)

![Figure 25. J field in 9 GHz](image)

3.3 Experiment

The dual film specimens with thickness of 0.046 mm/0.412 mm (1:10), conductivity(116 S/m) on FR4 using graphene material was fabricated. The characteristics of S parameters (S\(_{11}\) and S\(_{21}\)) for simulated and experimental results were compared and shown in figures 26 and 27. The experimental with simulated results of P\(_{\text{loss}}\)/P\(_{\text{in}}\) for single and dual film were shown in figure 28. The simulated P\(_{\text{loss}}\)/P\(_{\text{in}}\) is in agreement with experimental results. So in this study the stair film theory is available, and performance more than signal film, in this experiment we known different of thickness could improve the P\(_{\text{loss}}\)/P\(_{\text{in}}\) performance by stair pattern.

![Figure 26. S\(_{11}\) of the experiment and simulation results](image)

![Figure 27. S\(_{21}\) of the experiment and simulation results](image)
4. Conclusion

In this study, the effect of thickness and structure of graphene film on high frequency noise suppression was investigated. The characteristic impedance match absorption film impedance that decrease $S_{11}$ and $S_{21}$ and increase the $P_{\text{loss}}/P_{\text{in}}$. For dual film with thickness ratio of 1:10, the ability of high frequency power absorption effectivity is better than single film about $S$ parameter, the $P_{\text{loss}}/P_{\text{in}}$ value can reach 80% at 1.3 GHz and 95% at 2 GHz so this high-frequency noise absorption can be integrated into RF circuits. Have been seen in future that convenient to application at wearable component print circuit board and high-frequency circuit be suppressor noise.

5. References

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