Multicomponent composite layers as elements for effective multilayered microwave shields and absorbers

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INTRODUCTION

With rapid growth of wireless communication technology and the vast application of electronic equipment the large additional electromagnetic radiation arises and influence on human health and the operation of precision electric devices. Constructing a multi-layered structure as an absorbing coating is an important tool for improving the characteristics of microwave absorbing (MA) and shielding materials. The influencing factors on microwave absorption performances of multi-layered structures are filler types and their spatial distribution in composite layers, filler loadings, stacking sequences and thicknesses, etc. Combining the electrical conductivity and magnetic susceptibility in the composite layers is a promising way due to the synergy of dielectric and magnetic losses.

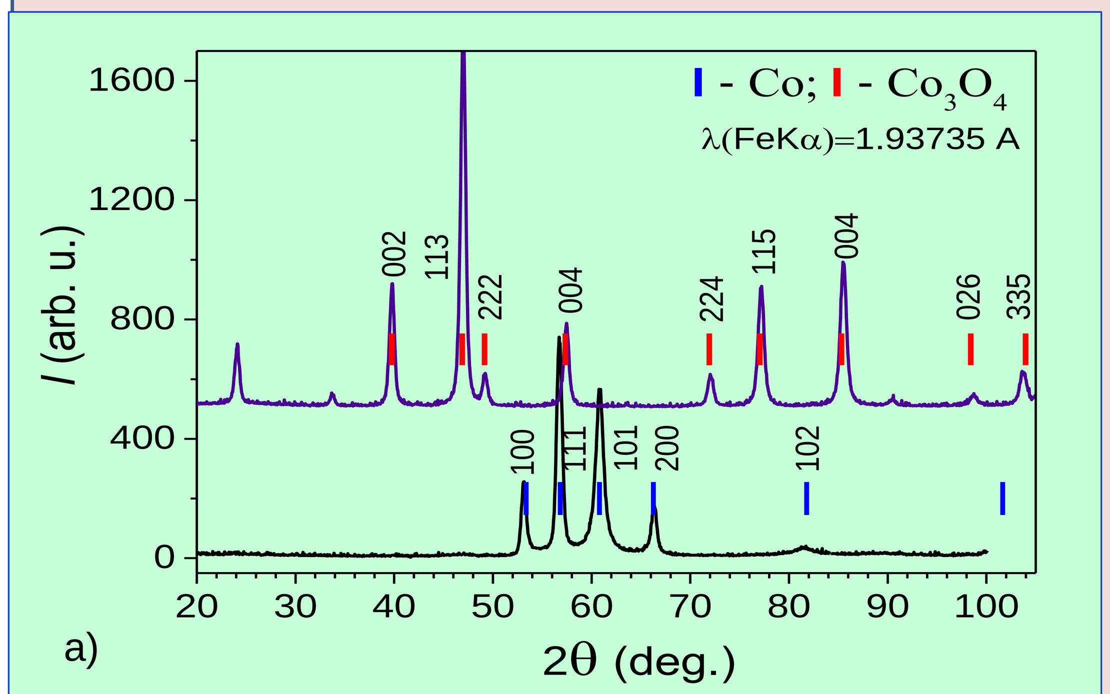
The **aim** of this study is to investigate the microwave absorbing and shielding properties of epoxy composites with multiphase filler (nanocarbon+Co (or Co_3O_4) in the frequency range (1-67) GHz.

METHODS OF PREPARATION AND INVESTIGATION

Preparation of CMs via: Ultrasonic dispersing of mixture nanocarbon/magnetic fillers-epoxy resin with subsequent curing. The content of Co or Co_3O_4 particles was fixed at 30wt%, while the content of nanocarbon, graphite nanoplatelets (GNPs) or carbon nanotubes (CNTs) was varied from 1 to 5 wt.%.

The shielding properties and complex permittivity and permeability spectra were derived from S-parameters measured by Keysight PNA N5227A vector network analyzer using the transmission–reflection method in the frequency range of 1–67 GHz. The measured complex permittivity and permeability data were used for simulation of the reflection loss *RL* in single and multilayered samples.

Microwave electromagnetic parameters of three-phase epoxy composites



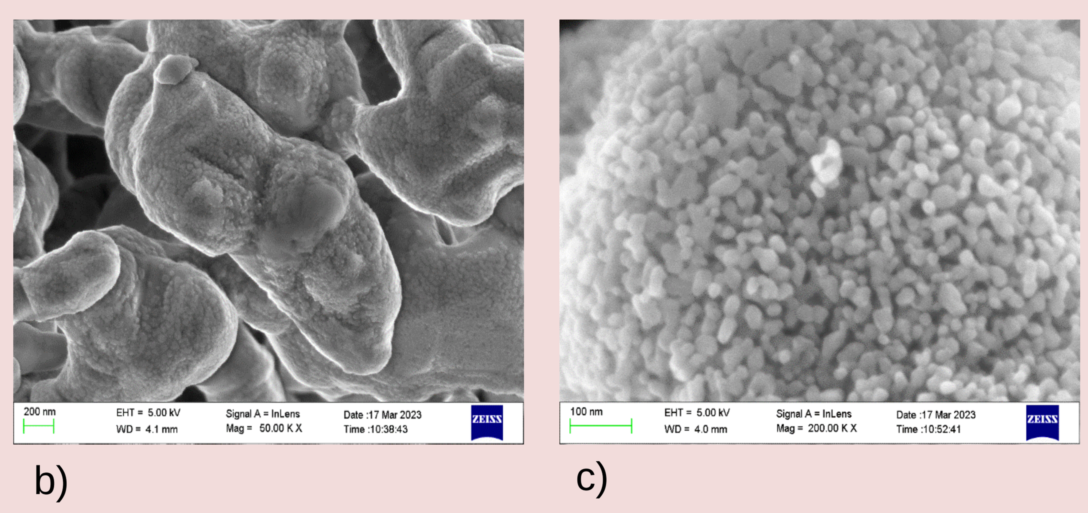


Fig.1. XRD pattern (a) and SEM-images of Co (b) and Co_3O_4 (c) particles

For multi-layer shield the reflection loss $RL(f)$ can be calculated using the following relations:

$$RL = 20\log\left|\frac{(X_n - Z_{n+1})}{(X_n + Z_{n+1})}\right| , \quad (1)$$

where $Z_j(X_j)$ — input (output) impedance for *j*-th layer, determined as following:

$$Z_j = \frac{Z_0}{\sqrt{\varepsilon_{rj}\mu_{rj}}}, \quad X_j = \frac{Z_j\left(X_{j-1} + Z_j \cdot \tanh\left(\gamma_j \cdot d_j\right)\right)}{\left(Z_j + X_{j-1} \cdot \tanh\left(\gamma_j \cdot d_j\right)\right)}, \quad (2)$$

where $\gamma = i \cdot 2\pi / \lambda_0 \sqrt{\varepsilon_j^* \mu_j^*} = \alpha + i\beta$ — propagation constant

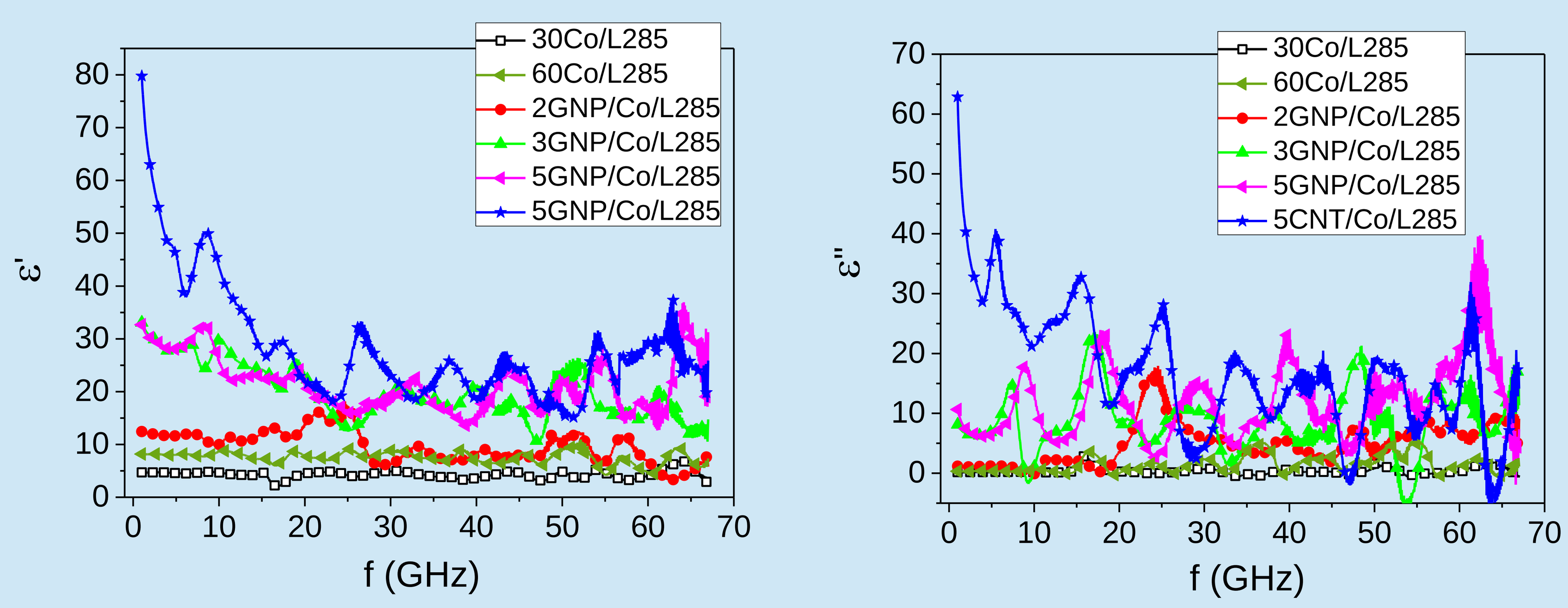


Fig. 2. Permittivity of nanocarbon/Co/epoxy composites versus frequency; μ'=0.9-1.2 and μ''~0-0.3 (f=1-67 GHz)

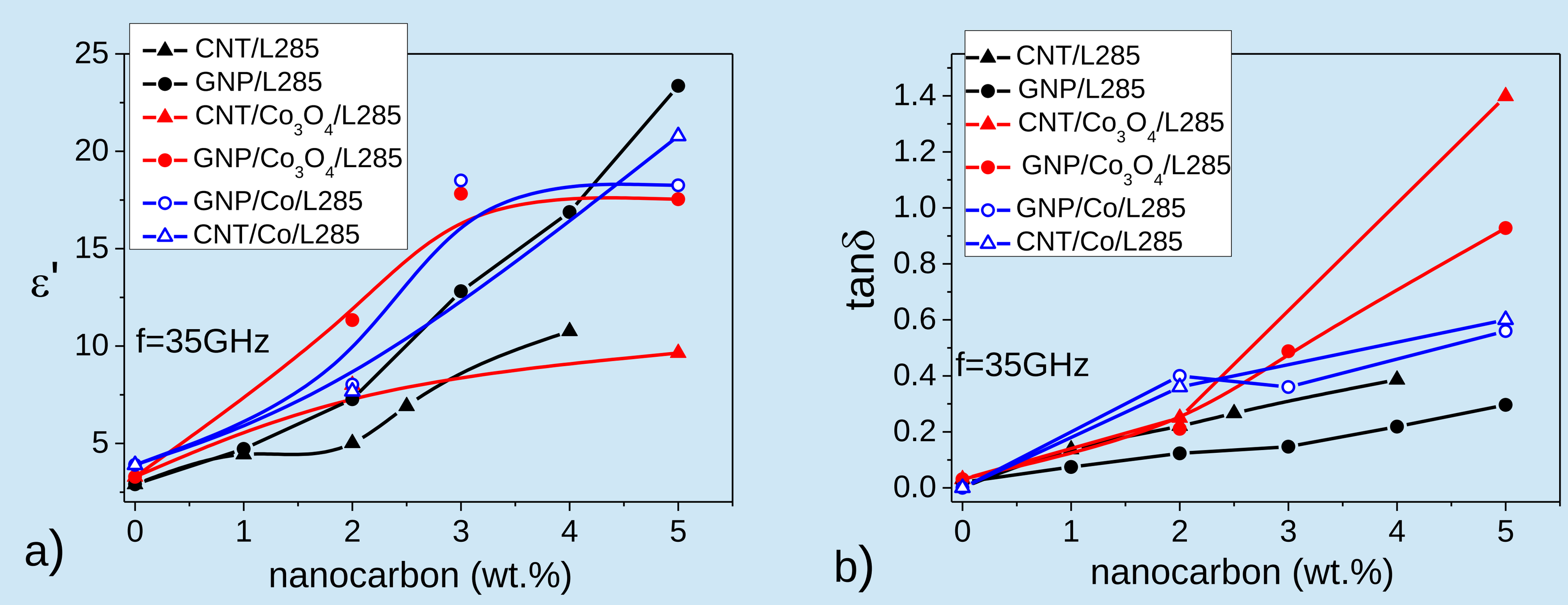


Fig.3 Permittivity (a) and dielectric loss tangent (b) of nanocarbon/Co(Co_3O_4)/epoxy composites versus nanocarbon content at f=35 GHz

Absorptive properties of multilayered composite structures

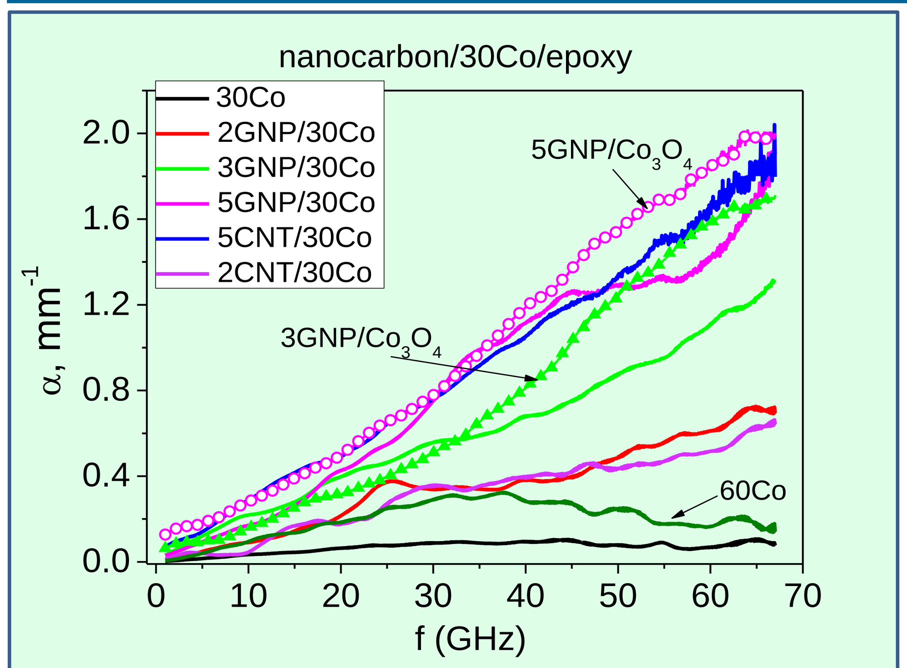


Fig. 4. EMR attenuation constant α for nanocarbon/Co_3O_4/epoxy composites

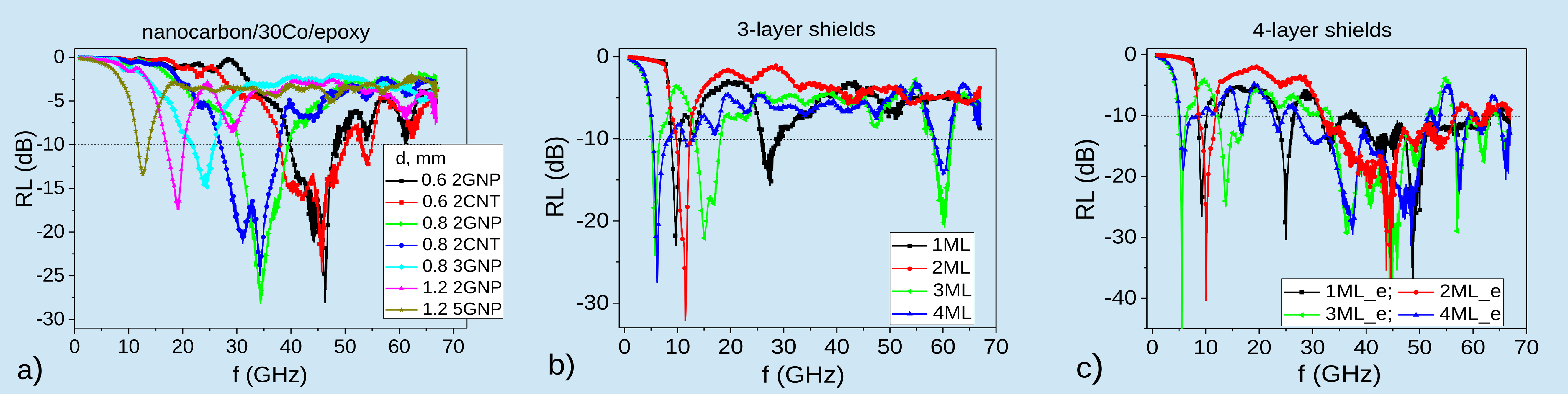


Fig. 5. Modeled reflection loss *RL* for single (a), 3-layered (b) and 4-layered (c) samples based on nanocarbon/magnetic filler/epoxy composites

CONCLUSIONS

- A comparative study of microwave electromagnetic properties of multicomponent epoxy composites (CMs) with nanocarbon and magnetic fillers (Fe, Co and Co_3O_4 particles) was performed.
- A significant increase of permittivity in three-phase CMs compared to two-phase ones is caused by the presence of a large number of the additional conductive magnetic particles acting as "artificial dipoles", the formation of microcapacitor network of conductive nanocarbon and magnetic particles and contribution of interfacial polarization.
- The observed enhancement of EMR attenuation index α in nanocarbon/magnetic/epoxy CMs is a result of i) polarization and charge accumulation at the interphase boundaries; ii) significant multiple reflection and scattering of EM waves due to the mismatch of wave impedances at the boundaries of different phases; iii) arising of additional magnetic losses due to magnetic fillers.
- The modeling of reflection loss *RL* of multi-layered structures composed of three-phase composite layers showed good microwave absorptive properties. For example, the 4-layered composite structures based on GNP/Co_3O_4/epoxy layers showed a more pronounced reflection loss $|RL|$=(30-32) dB and absorption bandwidth (24-25 GHz) for sample thickness of 2.5-2.7 mm.
- Much better microwave absorption properties of the multi-layered structures compared with the uniform single composite layer can be ascribed to the improved impedance matching with free space and the addition of interior interfaces.

Layer number*	4	3	2	1
CM layers based on GNP/30Co_3O_4/epoxy				
1ML	epoxy	2GNP	3GNP	5GNP
Layer thickness, mm	0	0.6	0.6	0.5
1ML_e	1.0	0.6	0.6	0.5
2ML	epoxy	2GNP	3GNP	5GNP
Layer thickness, mm	0	0.5	0.5	0.5
2ML_e	1.0	0.5	0.5	0.5
CM layers based on nanocarbon/30Co/epoxy				
3ML		60Co	3GNP	5GNP
Layer thickness, mm	0	1.49	0.66	1.35
3ML_e	1.0	1.49	0.66	1.35
4ML	epoxy	60Co	2CNT	5CNT
Layer thickness, mm	0	1.42	0.9	1.20
4ML_e	1.0	1.42	0.9	1.20

* The numbering of layers begin from the last layer