Electrical and shielding properties of epoxy resin filled with Ni-C and Co-C core-shell nanoparticles

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INTRODUCTION

A small size, higher surface area, scalability, and several other favorable attributes of nanomaterials have made them the most profitable materials in recent years. Among all of the types of nanomaterials the special kind called "core–shell"nanomaterials are getting a lot attention since have the properties which are synergistic among the core and shell and exhibit new properties owing to the interactions between the core and the shell. Core-particles are multi-interface in nature and can generate significant interfacial polarization loss and would help in generating multiple scattering/reflections among an individual nanostructure which helps in effective electromagnetic waves attenuation. Such advantageous and tailorable structure and properties have also advanced these materials as a emergent materials for multifarious applications in, for instance, bionanotechnology, enhanced optical devices, tailored magnetic devices, storage materials, etc.

The aim of this study is to investigate the electrical and microwave absorbing/shielding properties of epoxy composites filled with metal(Ni,Co)-carbon core-shell particles in the frequency range (1-67) GHz.

METHODS of PREPARATION and INVESTIGATION

Preparation of CMs via: Ultrasonic dispersing of core-shell particles-epoxy resin(L285) mixture with subsequent curing. The content of Me-C core particles was fixed at 60wt%. (Me-C) core-shell particles are globular agglomerates (300-600nm), which consist of spherical particles of much smaller diameter (is near 25-75 nm).

DC resistivity was measured by two-probes method, shielding properties and complex permittivity and permeability spectra were derived from S-parameters measured by scalar network analyzers (R2-65 and R2-67) and Keysight PNA N5227A vector network analyzer using the transmission–reflection method in the frequency range of 1–67 GHz.

RESULTS

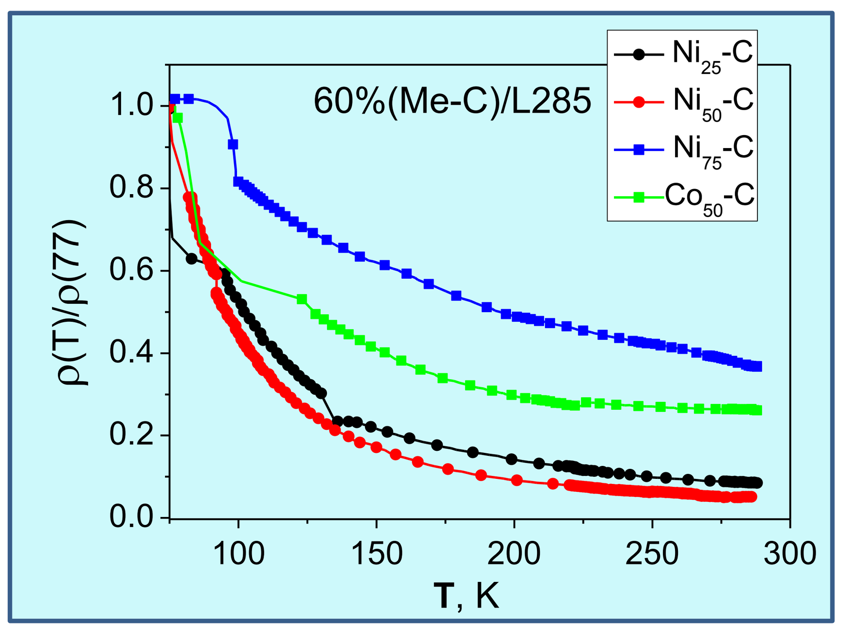

Fig. 2. Temperature dependence of normalized resistivity of composites 60 wt.% Me_x-C/epoxy(L285)

Composite	ρ_{293}, Ω×m	ρ_{293}/ρ_{77}
60 wt.%(Ni_{25}-C)/epoxy	$7.8\cdot10^3$	0.085
60 wt.%(Ni_{50}-C)/epoxy	19.2	0.051
60 wt.%(Ni_{75}-C)/epoxy	2.1	0.37
60 wt.%(Co_{50}-C)/epoxy	$8.9\cdot10^2$	0.26

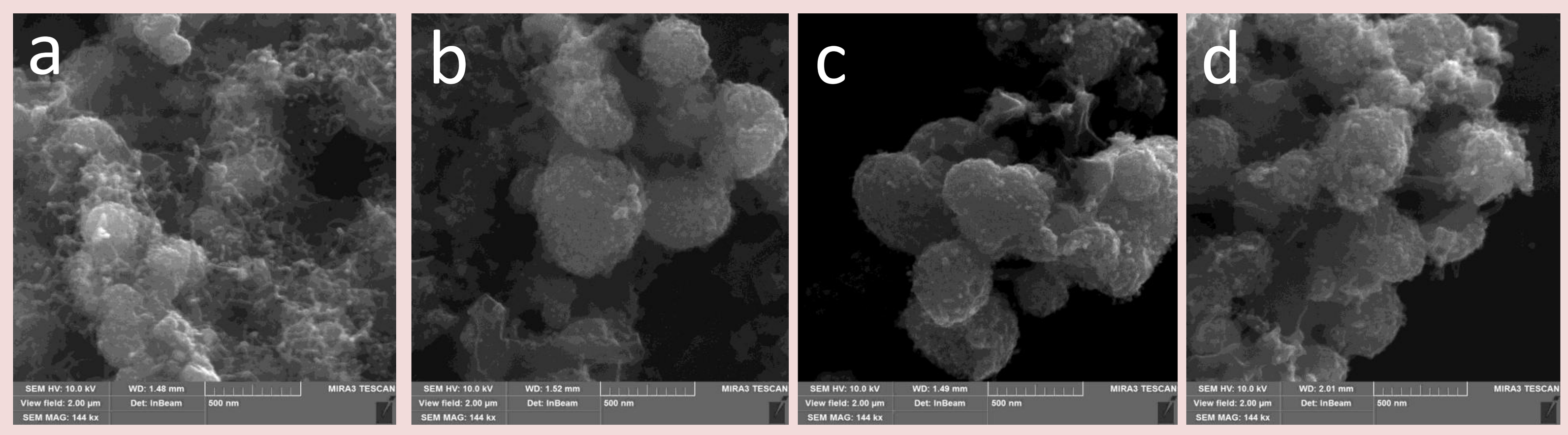

Fig.1. SEM-images of core-shell particles: a) (Ni_{25}-C), b) (Ni_{50}-C), c) (Ni_{75}-C), d) (Co_{50}-C)

EMR reflection *R*, absorption *A*, transmission *T* indices and EMR shielding efficiency SE_T were determined using the measured S-parameters:

$$R=|S_{11}|^2,\ \ T=|S_{12}|^2,\ \ A=1-|S_{11}|^2-|S_{12}|^2,$$

$$A_{eff}=A/(1-R),\ \ SE_T=10\lg\left(|S_{21}|^2\right) \qquad (1)$$

The experimental dependence of permittivity ε_r^* and permeability μ_r^* versus frequency were derived from S-parameters using Nicolson-Ross method.

The EMR attenuation index α describes the microwave absorptive ability of the material and is a function of the electrodynamic parameters of the material:

$$\alpha=\mathrm{Re}[\gamma], \qquad (2)$$

where $\gamma=i\cdot k_0\cdot\sqrt{\varepsilon_r^*\mu_r^*}$ is the propagation constant, $k_0=2\pi/\lambda$.

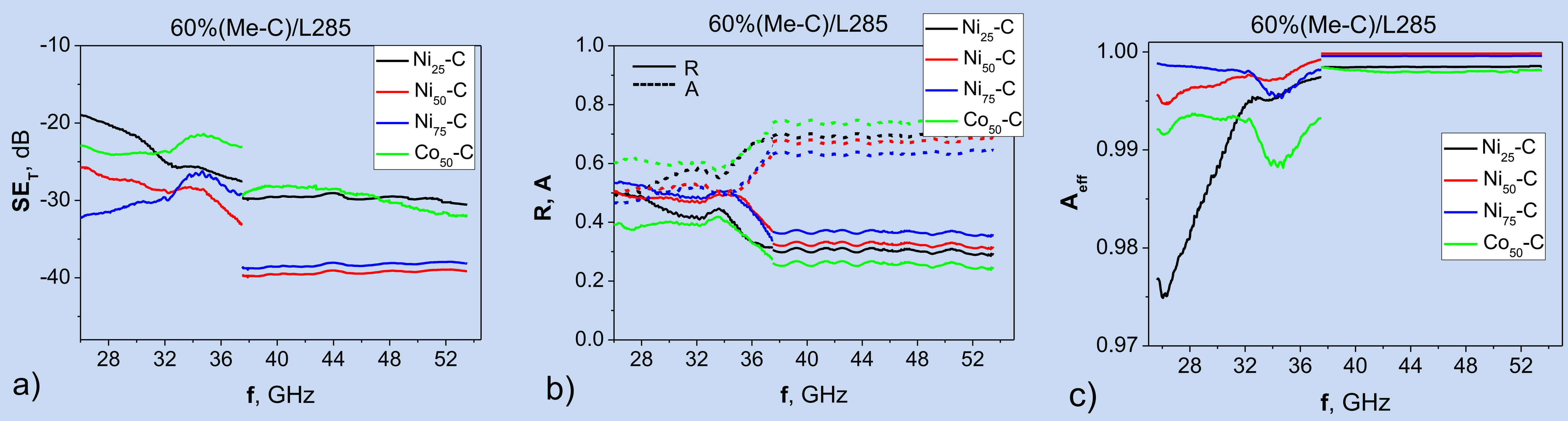

Fig. 3. Shielding efficiency SE_T (a), EMR reflection *R*, absorption *A* (b) and effective absorption indices for 60 wt.% (Me_x-C)/epoxy CMs versus frequency.

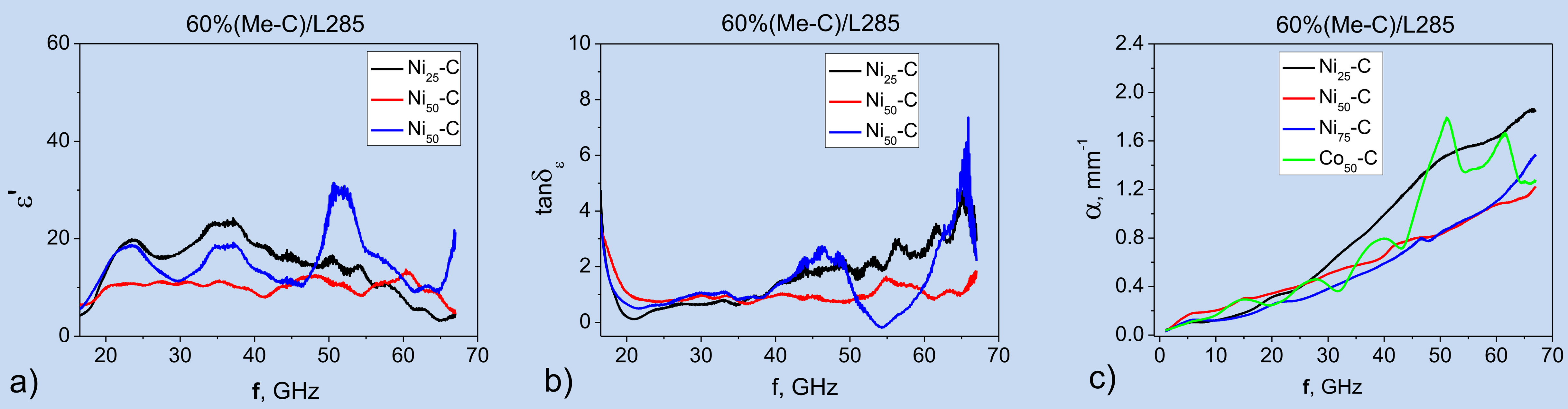

Fig. 4. Permittivity (a), $\tan_e$ and EMR attenuation coefficient for 60 wt.% (Me_x-C)/epoxy CMs versus frequency. Permeability $\mu^*\approx1+i\cdot0.2$ for (Ni_{25}-C)/epoxy and $\mu^*\approx1.2+i\cdot0.01$ for (Ni_{50-75}-C)/epoxy in the frequency range 15-67 GHz

CONCLUSIONS

- It was found that electrical resistivity of (Ni-C) core shell/epoxy composites was decreased at increase of Ni content in core-shell structure and displays the activation behavior versus temperature.
- The observed sufficient increase of EMR shielding efficiency ($|SE_T|$=32-40 dB at sample thickness 2.2 mm) in K_a- and V-band for epoxy CMs with higher Ni content in core-shell (Ni-C) correlates with increased DC electrical conductivity of these composites compared with other CMs. The studied (Me-C)/epoxy CMs showed a good EMR absorptive properties (the effective absorption index A_{eff}=0.999 at *f*=65 GHz) that can be related to the enhanced dielectric and magnetic losses in CMs.
- The comparatively high value of EMR attenuation coefficient α is related to high values of permittivity, $\tan\delta_\varepsilon$ and additional magnetic loss due to magnetic nature of metal particles.