ABSORPTION OF ELECTROMAGNETIC IRRADIATION IN ARRAYS OF CARBON NANOTUBES IN THE CUBTERAHERTZ RANGE

Agylych Atdayev, A. Danilyuk. S. Prischepa
Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus

I. INTRODUCTION

Magnetic nanocomposites consisting of non-contiguous ferromagnetic nanoparticles are intensively investigated nowadays. They are promising for the applications in the field of the information protection as well as for the creation of new spintronic elements of information processing. Properties of such nanocomposites can be tuned by the external magnetic field, spin-polarized current or by electromagnetic irradiation (EMI). As it has been demonstrated in numerous studies, magnetic nanocomposites based on carbon materials have non-trivial properties in the subterahertz frequency range [1]. Frequency dependencies of the permeability, transmission and reflection coefficients of EMI of carbon nanotube (CNT)-based nanocomposites in the subterahertz range are characterized by essential nonlinearities., which are determined by both the parameters of the carbon matrix and properties (impedance) of the interfaces between nanoparticles and CNT [2,3]. The combination of microwave parameters of the carbon matrix, ferromagnetic nanoparticles, and transition shells can lead to the appearance of quasiresonances, sharp dips or lifts of the transmission and reflection coefficients of EMI [2-4]. For the application of magnetic nanocomposites in subterahertz electronics, it is still necessary to solve not only the technological problems associated with their synthesis and reproducibility of properties, but also to reveal the features of the mechanism of absorption of EMP by such nanocomposites with respect to the concentration of ferromagnetic nanoparticles, their material parameters, impedance properties of transition shells, matrix, etc.

In this work, results of simulation of the absorbing properties of CNT array with iron nanoparticles are analyzed with respect to a number of parameters of the carbon matrix, nanoparticles and transition shell in the subterahertz frequency range. The main goal of the work is to identify the peculiarities of the absorption mechanism of EMI.

II. MODEL

Calculations of the transmission and absorption coefficients have been performed within the effective medium theory. The reflection coefficient (in dB) is expressed as [5]

$$R(\omega) = 20\log\left|\frac{Z(\omega) - Z_0}{Z(\omega) + Z_0}\right| \tag{1}$$

where $Z(\omega) = \sqrt{\mu_0\mu(\omega)/\varepsilon_0\varepsilon(\omega)}$ is the nanocomposite wave resistance; Z0 = 377 Ohm is the characteristic impedance of the plane wave in vacuum, ε0, μ0 are dielectric and magnetic constants, respectively, ε(ω), μ(ω) are complex permittivity and permeability of the nanocomposite, respectively, ω is cyclic frequency of EMI.

The transmission coefficient (the propagation coefficient) determines the screening efficiency and depends on the absorption, reflection and multiple reflection inside a nanocomposite and in dB is expressed as [5]

$$T(\omega) = 8{,}68\mathrm{Re}(\gamma) + 20\log\left|\frac{(Z_0 + Z)^2}{4Z_0 Z}\right| + 20\log\left|1 + \exp[-dRe(\gamma)]\,\frac{(Z_0 - Z)^2}{(Z_0 + Z)^2}\right| \tag{2}$$

where d is the nanocomposite thickness, $\gamma(\omega) = i\omega\sqrt{\mu_0\mu(\omega)\varepsilon_0\varepsilon(\omega)}$ is the propagation coefficient of EMI in the nanocomposite.

Impedance of the transition shells depends on the combinations of their considered passive elements, like capacitances C, resistances R and inductances L. In the considered nanocomposite in which arbitrary distribution of resistive, inductive and capacitive couplings is observed various types of connections between R, L, and C lead to different expressions for the impedance of the circuits of transition shells.

For the series circuit the impedance is equal to $Z_S = R + i[\omega L - (\omega C)^{-1}]$, for fully parallel circuit $Z_S = R^{-1} + i[\omega C - (\omega L)^{-1}\,]^{-1}$. Partially parallel and series-parallel circuits also could be realized.

The frequency dependences of ε(ω) and μ(ω) have been determined within the elaborated model of the EMI interaction with magnetic nanocomposite which takes into account both the microwave properties of the carbon matrix, ferromagnetic nanoparticles and impedance of interfaces [3,4]. It is based on the Braggeman approach for the randomly distributed nanoparticles embedded into the matrix. This approach was modified to take into account the impedance of transition shells and conductivity of the matrix.

III.RESULTS AND DISCUSSIONS

Calculations have been performed to obtain the frequency dependences of complex permittivity and permeability of the magnetic nanocomposite and reflection R and transmission T coefficients. The absorption coefficient D was evaluated (in arbitrary units) as D=1-R-T.

In Figs. 1, 2 the calculated frequency dependences of the absorption coefficient for different parameters of circuits and type of connections are presented. Here we used the parameters obtained in [4]. Such quantities as volume fraction of nanoparticles (c=0.1), their diameter (a=40-50 nm), thickness of CNT array (d=300 nm), conductivity of CNT array (σ=120 Sm) are taken from Table 1 [4]. Varying was carried out by values characterizing the impedance of the transition shells, R, L, C. The obtained results can be divided into 2 groups. In the former the absorption coefficient increases monotonically and non-monotonically with frequency up to 0.5-0.6 depending on the nanocomposite parameters, Fig. 1. Such behavior is determined by the increase of the of the permeability and by corresponding decrease of the reflection and transmission coefficients. The absorption increase occurs due to the growth of magnetic losses [6].

The latter group of the results are characterized by a net decrease of the absorption down to negative values, Fig. 2. This means a certain amplification of the EMI. Such effect is related to the quasi resonances, net lifts or dips (drops) on the frequency dependences of the reflection and transmission coefficients as well as of the permeability [3,4]. In this work, it is demonstrated that, in the case of the abrupt drop of the permeability, which leads to the increase of the reflection and transmission coefficients, the abrupt decrease of the absorption coefficient down to the amplification of the EMI could be observed.

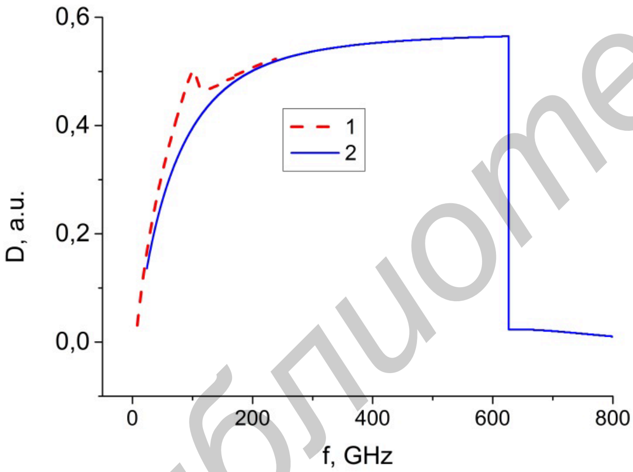

Figure 1 – Series – parallel circuit, R=0.05 Ohm, L=0.8×10^{-13} H, C=7.5×10^{-11} F (curve 1). Series circuit, R=0.008 Ohm, L=0.65×10^{-14} H, C=10^{-11} F (curve 2).

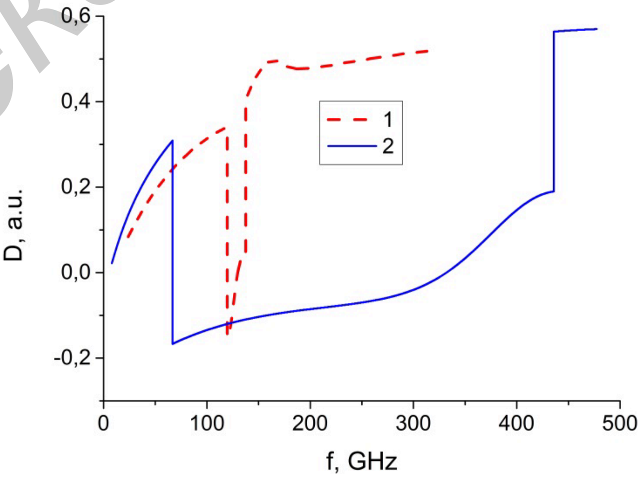

Figure 2 – Series circuit, R=0.01 Ohm, L =0.2 10^{-12} H, C=9 10^{-12} F (curve 1). Parallel circuit, R=0.01 Ohm, L =1 10^{-14} H, C=1 10^{-11} F (curve 2).

The increase of T occurs, as a rule, on 10-20 dB and is of resonance or quasi resonance type. At that the abrupt increase of R occurs up to almost 0 dB. Consequently, in the frequency range in which the abrupt growth of R and T coefficients happens, the amplification of EMI occurs as well. This effect corresponds to the significant increase of the reflectivity of EMI. Therefore, the amplification is apparently not significant. To increase the gain, it is necessary to look for such combinations of parameters in order to obtain amplification without significant growth of reflection, not to zero, but at least to -2 ..- 3 dB [6].

For the series RLC circuit a narrow dip to the negative region on the frequency dependence of the absorption coefficient is observed, see curve 1 in Fig. 2. In the case of parallel circuit this dip become valley-like. This is due to the presence of the extended region in which the reflection and transmission coefficients increase. The reason for this is an abrupt decrease of the permeability of the nanocomposite and, consequently, the decrease of the magnetic losses. In the adjacent frequency ranges in which positive values of the of the absorption coefficients are observed (+0.2 and greater) the permeability is significantly larger and R and T coefficients are less.

In the frequency ranges of negative D the EMI can be absorbed intensively. Such kind of materials could be perspective for the application of devices for information protection as well as for optical connections for integrated circuits. The latter could substitute copper conductors in the subterahertz frequency range and avoid parasitic losses and overheating.

IV. CONCLUSIONS

In summary, it has been established that at some certain parameters of a CNT-based nanocomposite consisting of ferromagnetic nanoparticles and transition shells and characterized by a resonant circuit in the subterahertz frequency range, the significant absorption could occur. At frequency change this absorption could be transformed to the amplification of EMI.

REFERENCES

[1] F. Qin, C. Brosseau. J. Appl.Phys. 111, 061301 (2012). 2. V.A. Labunov, A.L. Danilyuk, A.L. Prudnikava et al. J. Appl. Phys. 112, 024302 (2012).
[2] A. Atdaev, A.L. Danilyuk, V.A. Labunov et al. Semiconductors 50, 1702 (2016).
[3] A. Atdayev, A.L. Danilyuk, S.L. Prischepa. Beilstein J. Nanotechnol. 6, 1056 (2015).
[4] A. Davalos, A. Zanette, Fundamentals of Electromagnetism. Springer Verlag, Berlin, 1999.
[5] A.V. Avramchuk, M.M. Kasperovich, N.A. Pevneva et al. J. Appl. Spec. 83, 225 (2016).

METHOD OF ACCELERATED MODELING OF MICROSTRIP ANTENNA ARRAY CHARACTERISTICS USING CUDA TECHNOLOGY

V. Kizimenko
Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus

I. INTRODUCTION

Currently, a large number of articles are devoted to modeling antennas with the use of Graphics Processing Units (GPU) and parallel computing architecture CUDA. At the same time, the main difficulty is the limited amount of video memory of video cards and its higher cost compared to conventional memory. The calculation is possible only for relatively small tasks and antenna arrays with a small number of radiating elements. One of the first papers on the use of video cards for solving electrodynamics problems was the article [1]. The implementation of the finite time difference method (FDTD) for the GPU in the Brook language was described. Modeling the process of electromagnetic wave propagation in free space on the GPU was 12 times faster than on the CPU. The paper [2] describes the implementation of the Method of Moments (MoM) on the GPU for 3D wire structures. Results of numerical modeling of a helical wire antenna with a cylindrical reflector are presented. The results obtained by the authors are in good agreement with the results obtained during the simulating a similar structure in the FEKO software. Compared with the option of the method for the CPU, an 8-fold reduction in the calculation time was achieved. Given the size of the video memory (896 MB) of the GTX 275 card used in the simulation, the maximum size of the input impedance matrix, available for calculation is 7500 × 7500 elements. In work [3] results of modeling of a single rectangular microstrip radiator by MoM method with reduction of the calculation time in 17 times are presented. The calculated characteristics of reflection coefficient are in good agreement with the results obtained using the software for electromagnetic modeling ADS-Momentum. Simulation with a sufficient degree of accuracy is possible for arrays with a number of elements less than ten. Article [4] is devoted to consideration of basic ideas on parallelization of the traditional finite element method (FEM). The main difficulty in this case is the intensive data exchange between blocks of code. To solve this problem, it is proposed to divide the original matrix into submatrices and group the elements within them in degrees of freedom. The results of comparison of the simulation time of the 7x7 monopole antenna array with 5,242,996 unknowns on a computer with a Xeon W3520 processor and Tesla C2050 accelerators are presented. Acceleration of simulation time using two accelerators was 5.37, using four – 5.5 times. It can be seen that due to the growth of data exchange, the increase in the number of video cards does not give a corresponding increase in computing performance: the low speed of copying data into video memory is an additional