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On the nonlinear light scattering in a dielectric nanocompozite

Khvedelidze Leonardo Levanovich

PhD in Engineering

Ak. Tsereteli State University, Kutaisi

Multiform Educational-Research center "Kavkasia 2010". Zestafoni, Georgia

The paper discusses possibility of the light beam propagation in a dielectric nanocomposite. The appropriate physical model is given and appropriate conclusions are made. The obtained results are interesting in terms of application in nanomedicine, which requires further research in this area based on results of relevant experiments.

Key words: Dielectric nanocomposites, nanomedicine, model, nanomaterials.

Introduction

In recent decades, scientists have discovered new properties of nanomaterials. Nanocomposites are becoming more and more widely usable in various fields of technics and technologies. Active research into the medical application of nanocomposites, which will be crucial for humanity in the nearest future is currently underway. Due to all above mentioned factors, intensive research of nanotechnologies and nanomaterials is one of the main determinants of the development of modern medicine, which is also of great importance for the future of mankind.

This paper discusses one possible application of the possibility of nonlinear light scattering in dielectric nanocomposites in nanomedicine. An appropriate physical model is given, which fits well with the data in the literature and is essential for the further research. The obtained results are essential in terms of the application of dielectric nanocomposites and nanomaterials in nano-biomedicine.

Theoretical model

As it’s known, heat is transfered chaotically within a solid, as a result of the oscillation of the atoms and molecules constituting the body. The propagation of such oscillations is convenient to consider as the propagation of particles of a linear spectrum - phonons. Sound - is also the propagation of oscillation, but the corresponding waves have the direction of a propagation. The unified mechanism of propagation is revealed in the fact that in macroscopic bodies the coefficient of heat transfer and the speed of sound are proportional to each other [1,2]. This issue is very relevant for many branches of technics and technology, including the development and use of biomedical materials.

Let's use a general phenomenological assessment to assess the thermal conductivity [2;3]:

$$\lambda = \alpha V l, \quad (1)$$

Where:

- λ - is the thermal conductivity of the composite, (W/(m.k));
- V - is the characteristic velocity of the heat transfer particles in the sample. The heat transfer is a phonon for which the characteristic velocity is equal to the velocity of the sound in the material, (m/sec);
- l - is the length of the free path of the phonons, (m);
- α - is the volumetric heat-acoustic coefficient, which is proportional to the phonon concentration (J / m^2K),
- k_B - is the Boltzmann constant, and characterizes the volume at which the ballistic motion of phonons is transformed into chaos. It’s obvious that this volume is proportional to l^3 and,

$$\alpha = k_B(Cl^3),$$

where:

C - is a dimensionless value and equal to one.

In order to study the given issue, first let's turn to the issue of heat transfer during the irradiation of a nanocomposite, which is one of the principal issues for practical purposes.

As it is well known, heat in solid bodies is transferred chaotically as a result of the oscillation of atoms and molecules that make up the body. The propagation of such oscillations is convenient to consider as the propagation of particles of a linear spectrum - phonons.

The paper [1] discusses the bond state of solitons in the graphene waveguide. In particular, based on the theoretical foundations of quantum mechanics, electrons were considered in terms of coulomb interactions within quantum formalism framework. The electronic system Hamiltonian was even represented within the Hubbard model framework [1,2,4].

In the work [1] we have discussed connected state of solitary waves in graphene waveguide. Particularly, based on the theoretical basis of quantum mechanics, the electrons were discussed within quantum formalism, taking into consideration Coulomb's inverse-square law. As for the electronic system hamiltoniana was represented within Hubbard model [1-3]:

$$H = \sum_{j\Delta\sigma}^{t_p} a_{j\sigma}^{+} a_{j+\Delta\sigma} + U\sum_j a_{j\sigma}^{+} a_{j\sigma} a_{j-\sigma}^{+} a_{j-\sigma} + h.c. \quad (1)$$

Where $a_{j\sigma}^{+}$; $a_{j\sigma}$ is the operator of electrons' emergence and disappearance in J knot with the spin σ, t_p- is the integral saltus, which is d

In this work, discussable diel etermined overlapping wave functioning neighboring knots, Δ-is the vector of electrons bond in neighboring knots, U- is electron Coulomb repel energy, which are situated in one spin.ectric and magnet features and Callipers for the considered system, Maxvel's equations,

$$\vec{E} = -\frac{1}{c}\frac{\partial \vec{A}}{\partial t}$$

shall have the following expression: [1,4]:

$$\frac{\partial^2 \vec{A}_k}{\partial t^2} - \frac{1}{c^2}\frac{\partial^2 \vec{A}_k}{\partial t^2} + \frac{4\pi}{c}\vec{j}_k - \frac{4\pi}{c}\frac{\partial \vec{P}_k}{\partial t} = 0. \quad (2)$$

Here $\vec{A}_k$ is vector-potential, which conforms to electromagnetic field in graphene's K-th layer, and is considered to have the following expression: $\vec{A}_k = (0,0,A_k(x,t))$; $\vec{j}_k$ is electric current, which streams in the graphene's K-th layer with electromagnetic field and neighboring graphene's layer.

As a result of conducted discussion and appropriate calculating in the work [1] was accepted the following expression for the current compactness and the graphene waveguide systems:

$$j_k = -en_0\sum_l D_l \sin\left(\frac{le}{c}A_k(t)\right), \quad (3)$$

$$D_l = \sum_{s=1}^{m}\int_{-\pi/a}^{\pi/a} dpB_{ls}\cos(lp)\frac{\exp\left(-{\varepsilon_s(p)}/{k_B(T)}\right)}{1+exp\left({\varepsilon_s(p)}/{k_B(T)}\right)}, \quad (4)$$

As a result of appropriate changes Sine-Gordon equation was accepted.

In addition, there is mentioned, signal inversion is observed from a moment. Furthermore, inverted signal amplitude, practically, remains the same.

Taking into consideration that it is possible to receive nanocomposites with the use of graphene as well, which could be characterized by dielectric features, therefore, we shall further discuss the falling of the plane electromagnetic wave on the flat surface of nanocomposite.

It's known that for calculation concrete physical features of separate nanomaterial as a whole system, can be difficult, because they consist of various particles, which match the quantum mechanics laws. It is also known, that the optical features of quantum mechanical system are related to spectrum features of energy carriers' energetic state: to electrons and holes. Currently, it could be regarded to be confirmed, that optical and electrophysical features are essentially different from capacitance sample features, which is connected to energetic spectrum variation [5-8].

It is possible to determine quantum state of nanoparticle according to current electromagnetic radiation spectrum. If we compare current spectrum of nanocomposites consisted of various size of nanoparticles, it is possible to calculate general features of the ongoing processes at this time. If we regard, that number of nanoparticles N are not too big and plain electromagnetic wave fall on it, the wave vector of which lays in plane (x; y) then transmission coefficient will have the following expression while the beam of light normally falls on the plane surface, which is placed perpendicular to the x-axis, for the conductivity coefficient the expression can be recorded as follows [9]:

$$T(\omega;N) = \frac{(1-R^2)^2 \cdot \exp(-\beta L)}{1+R^2 \cdot \exp(-2\beta L)}; \quad (5)$$

Where β- is the coefficient of extinction, R- light beam reflection coefficient near the border of layer, which as a rule, is less than 1 during the experiment, L- is the distance which goes through the nanocrystal composite.

Coefficient of extinction in the approach of unit diffusion can be expressed through unit volume diffusion $\sigma^z(\omega;a)$ cross of nanocomposite

$$\beta(\omega;a) = [\sigma^a + \sigma^s(\omega;a)] + \alpha^m(\omega);$$

Where $\alpha^m(\omega)$- is the coefficient of reflection weakened with matrix, a-is the characterized size of nanoparticle. In case of such orientation of nanocomposite scatter cross $\sigma^s(\omega,a)$ and absorption cross $\sigma^a(\omega,a)$ in laboratory coordinate system can be found through unit volume component of composite $\chi_{zz}(\omega,a)$ [9,10]:

$$\sigma^a(\omega,a) = \frac{4\pi\omega}{c} Im\chi_{zz}(\omega,a)$$

$$d\sigma^z(\omega,a) = \frac{\omega^4}{c^4} |\chi_{zz}(\omega,a)|^2 sin^2\theta d\Omega; \quad (6)$$

Where θ- is the angle between scatter and electrical wave's electric intensity vectors, and c is the speed of light.

In the work [11] is given expression for cross in absorption line.

$$\sigma_a = \frac{4\pi\omega N a^2}{c\hbar} F(I)\left[G_1 S_1 arctg\left(\frac{\Delta\omega_1 \Gamma_n F(I)}{\Gamma_n^2 + F^2(I)\cdot\Delta\omega_n\cdot(\Delta\omega_n + \Delta\omega_1)}\right) + G_2 S_2 arctg\left(\frac{\Delta\omega_2 \Gamma_n F(I)}{\Gamma_n^2 + F^2(I)\cdot\omega_n\cdot(\Delta\omega_n - \Delta\omega_2)}\right)\right] \quad (7)$$

Where G_1 and G_2 are density of condition, and $\Delta\omega = \omega - \omega_n$; $F(I) = \sqrt{\frac{I_s}{I+I_s}}$. In these expressions S_1 and S_2 are determined as the medium value of particle form-factor consequently are located in upper and lower zones for transmission to $S_{ng}(I)$.

Taking into consideration (5) expression to (7) expression shall be accepted expression for an optical radiation with dielectric nanocomposite and absorption in a layer of ω_n with central frequency:

$$T(\omega, N, I) \approx exp\left(-L\frac{4\pi\omega N}{c\hbar} DF(I)\right); \quad (8)$$

Where the following marking are proposed:

$$D = a^2(G_1 S_1)\cdot arctang\left(\frac{\Delta\omega_1 \Gamma_n F(I)}{\Gamma_n^2 + F^2(I)\cdot\Delta\omega_n\cdot(\Delta\omega_n + \Delta\omega_1)}\right) + a^2(G_1 S_1)\cdot arctg\left(\frac{\Delta\omega_1 \Gamma_n F(I)}{\Gamma_n^2 + F^2(I)\cdot\Delta\omega_n\cdot(\Delta\omega_n - \Delta\omega_2)}\right) \quad (9)$$

Discusion and analysis

From the discussion given above, it can be seen that the magnitude of the light conduction coefficient in the dielectric nanocomposite according to equation (9) essentially depends on the intensity of the laser radiation field (I). This relationship has the minimum point (I_p), in which the conduction coefficient is minimal for certain parameters and the given radiation of the composite. However, when shifting from a value of I_p to a large or small side, there is a small radiation limiting effect according to the intensity scale. The conduction spectrum profile is generally asymmetric with respect to the central frequency value due to the difference in $\Delta\omega_1$ and $\Delta\omega_2$ frequencies.

The paper [13] provides figures of nanocomposites from which it can be seen that the depth of the absorption band strongly depends on the magnitude of the intensity and the size of the nanoparticles. However, for solid dielectric nanocomposites, the orientation of the nanoparticle along the field requires a high intensity of radiation. It should also be noted that the conductivity coefficients behavior for solid and liquid matrices are the same at high intensities. In this case, the value of the conduction coefficient at the central frequency is equal:

$$T(I) = \exp\left(-L\frac{4\pi\omega_n N}{c\hbar\Gamma_n}a^2(GS_n)_{g=n}(\Delta\omega_1 + \Delta\omega_2)\cdot F^2(I)\right). \quad (11)$$

As the intensity increases, this equation exponentially tends to 1, it does it faster with the larger nanoparticle size, $\Delta\omega_1 + \Delta\omega_2$, and value of the GS.

Conclusion

The issue discussed in this paper is interesting for solving different types of practical tasks. The appropriate solution to the problem of nonlinear light scattering in a dielectric nanocomposite is obtained. It should be noted that the discussed task allows to further specify the possibilities of using dielectric nanocomposites and nanomaterials in biomedicine. It is also possible to modify the model under consideration, which should be carried out according to further experimental studies.

The obtained results from Fig. 10 shows, that in a system in which the dipole-dipole interaction of the nanoparticle can no longer be neglected, the magnitude of this interaction will strongly depend on the intensity that will take the maximum value in fairly weak fields $(I \approx I_p)$. This peculiarity should be taken into account when studying the optical properties of similar composites, as well as when designing real devices in bionanomedicine which work is based on this property.

As it is well known, many materials of biological origin (proteins, bacteria, etc.) can be considered as nanoparticles, and at same the time particles are dielectric. In this regard, the question arises about the existence of nonlinear low-threshold optical radiation in the biological environment, which is also interesting in terms of specifying possible effects.

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Ak. Tsereteli State University, Kutaisi

Multiform Educational-Research center “Kavkasia 2010”. Zestafoni 2000.

Bibilashvili street N5, Georgia

Leonardo Khvedelidze. PhD-Engineering Sciences

Sammary

The paper discusses the possibility of using nonlinear light scattering in dielectric nanocomposites in nanomedicine. An appropriate physical method is proposed, which allows to clarify some essential issues related to its possible use for practical purposes. The issue posed is considered in terms of the basic regularities of quantum physics, which is essential for the practical application of the results obtained. However, results obtained in solving the task under consideration are interesting in terms of application in nanomedicine, which is essential in general, as well as in terms of the practical application of nanomaterials and nanotechnologies. Relevant conclusions are made, which allows the issues discussed and results obtained to be taken into account for further research, which is also essential.