DYNAMICAL BEHAVIOR OF BOSE-CONDENCED DIPOLE-ACTIVE PHONONS AND FROEHLICH PHOTONS IN BIOLOGICAL MEDIA

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Abstract. *A theoretical model is developed to discuss the dynamical behavior of Bose-condensed dipole-active phonons and internal Fröhlich photons under the action of the external coherent periodic pumping and damping of quasi-particles in biological media. It is shown that the system displays, under certain conditions, CW, periodic and chaotic behaviors. The nature of bifurcations and the stability of steady state solutions are analyzed in terms of the dependence on different parameters.*

Keywords: *millimeter waves, medical and biological applications, Bose-Einstein condensation*

I. Introduction

During recent years Electromagnetic Millimeter Waves (EMW) received considerable attention due to different medical and biological applications. EMWs correspond to the extremely-high-frequency band: from 30 to 300 GHz. This radiation can successfully be used in medicine as non-invasion physiotherapeutic method of treatment for various diseases. A large number of experimental data on the influence of EMWs on the biological objects have been accumulated (for reviews see [1-5]). Biological objects have an energetic spectrum of polarized fluctuations in range from 10^{11} to 10^{12} Hz. The nonlinear interaction of the polarized fluctuations and nonlinear connection of the polarized fluctuations with the solid system fluctuations may conduct to a meta-stable state, in which energy transforms into energy of the same kind as of the fluctuations. This transformation is named biological pumping. When exposed to an external energy source of electromagnetic fluctuations in a millimeter range length of the wave, the meta-stable state transitions and becomes the main state, which is proportional to the strength of the excitement of one type of dipole fluctuations.

One of the mechanisms on the relationship between the EHF radiation and biological membranes was proposed by H. Fröhlich in 1968 [6] and further developed in [7-10]. Frohlich's idea includes the following: biological systems have dipole oscillations in the frequency range from 100 up to 1000 GHz. The processes of metabolism within the cells transfer the energy to locally excited dipole oscillations (biological pumping). Under the influence of the radiation the metastable state can pass over to a normal state. In this case there appears "the gigantic dipole" which is a particular case of the coherent state of a biological object. Such oscillations can cover areas of biological membranes or parts of biomacromolecules (the analogue of the low-temperature condensation of the Bose gas).

In this paper we report studies on the dynamics of Bose-condensed dipole-active phonons and internal Fröhlich photons in biological media. We start in Section II with a description of the theoretical model and associated equations used to calculate the behavior of photons and phonons. The results of numerical calculations are presented and discussed in Section 3. Conclusions are given in Section 4.

II. Model and equations

Let consider a biological sample of length L under the influence of external pump P (see Fig.1). Under the influence of external pump the dipole-active phonons are created in the biological medium. The external pump comes from a millimeter wave generator of high frequency (e.g EHF-ND). The frequency of output power is within the range 42.2 - 61.2 GHz (λ=7.1 - 4.9 mm).

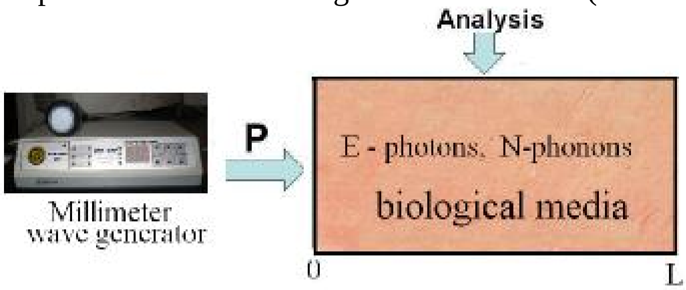

Figure 1. Schematic representation of investigated setup.

The general Hamiltonian that describes the interaction of Bose-condensed dipole active phonons has the form

$$H = \sum_{\vec{k}} \hbar\Omega a_{\vec{k}}^{+} a_{\vec{k}} + \frac{1}{8p}\sum_{\vec{k}} \int \left(e E_{\vec{k}}^{2} + m H_{\vec{k}}^{2} \right) dv_{\vec{k}}$$
$$+ \frac{1}{2V}\sum_{\vec{k}_1,\vec{k}_2,\vec{k}_1',\vec{k}_2'} g\left(\vec{k}_1 - \vec{k}_1'\right) d_{kp}\left(\vec{k}_1 + \vec{k}_2, \vec{k}_1' + \vec{k}_2'\right) a_{\vec{k}_1}^{+} a_{\vec{k}_2}^{+} a_{\vec{k}_1'} a_{\vec{k}_2'} - \sum_{\vec{k}} d_{\vec{k}} \left(E_{\vec{k}}^{+} a_{\vec{k}}^{+} + E_{\vec{k}}^{-} a_{\vec{k}} \right), \quad (1)$$

where ħΩ is the dipole-active phonon energy and, $E_{\vec{k}} = E_{\vec{k}}^{+} + E_{\vec{k}}^{-}$ and $H_{\vec{k}} = H_{\vec{k}}^{+} + H_{\vec{k}}^{-}$ are intensities of the electrical and magnetic fields. $E_{\vec{k}}^{+}\left(E_{\vec{k}}^{-}\right)$ and $H_{\vec{k}}^{+}\left(H_{\vec{k}}^{-}\right)$ are the positive-frequency (negative-frequency) parts of the variable electromagnetic field. $a_{\vec{k}}^{+}$ and $a_{\vec{k}}$ are the operators of creation and annihilation of the dipole-active phonons. e and m are the dielectric and magnetic permeabilities of the biological medium, $g\left(\vec{k}\right)$ is the phonon-phonon interaction constant and $d_{\vec{k}}$ is the dipole momentum of the transition into phonon state.

Using Heisenberg motion equation for operator $a_{\vec{k}}$, the equation of the positive frequency component of the electromagnetic field and the polarization of the biological media in the slowly varying envelope approximation we obtained the following system of nonlinear differential equations that fully describes the dynamic evolution of Frohlich millimeter electromagnetic field and the inner Bose-condensed phonons

$$\frac{dY_1}{dt} = -s\, Y_1 - (\Delta - w_0) Y_2 + 2 a\, g\, Y_3 + a \left\{ 2g\,[d - n\left(Y_3^2 + Y_4^2\right)] - 1 \right\} Y_4 + P, \quad (9)$$

$$\frac{dY_2}{dt} = -s\, Y_2 + (\Delta - w_0) Y_1 + 2 a\, g\, Y_4 - a \left\{ 2g \left[d - n\left(Y_3^2 + Y_4^2\right) \right] - 1 \right\} Y_3, \quad (10)$$

$$\frac{dY_3}{dt} = -a Y_2 - Y_3 - \left[d - n\left(Y_3^2 + Y_4^2\right) \right] Y_4, \quad (11)$$

$$\frac{dY_4}{dt} = a Y_1 + \left[d - n\left(Y_3^2 + Y_4^2\right) \right] Y_3 - Y_4. \quad (12)$$

We introduced in (9)-(12) phenomenologically terms, which take into account the damping of the internal field and the amplitude of the external electromagnetic field. The system of nonlinear differential equations (9)-(12) is the basis for considering the possibility of formation of different temporal structure in the system of Bose-condensed dipole-active phonons and internal Fröhlich photons under the action of the external coherent periodic pumping and damping of quasi-particles in biological media.

III. Results and discussions

This section concerns the behavior of a Bose-condensed dipole-active phonons and internal Fröhlich photons. We begin our investigations considering the detuning δ as parameter to be varied. Figure 2 illustrates typical time traces (left), phase portraits (center) and the power spectra (right) of a system of phonons and photons under the variation of the detuning δ. For small enough detuning the system show CW operations (see Fig.2a). When the detuning is increased to δ=12 periodic self-pulsations arise in the system and the phase trajectory goes to a stable limit cycle with time and one frequency is present in the power spectrum. Thus moving from δ=5 to δ=12 we crossed the Hope bifurcation. When the value of detuning is increased to δ=18 the period doubling bifurcation is reached (see Fig. 2c). Chaotic behavior appears if the detuning is increased enough (see Fig. 2 d). Thus, we suppose that the cascade of period-doubling bifurcations corresponding to the transition of the system to the dynamic-chaos regime is present in the system.

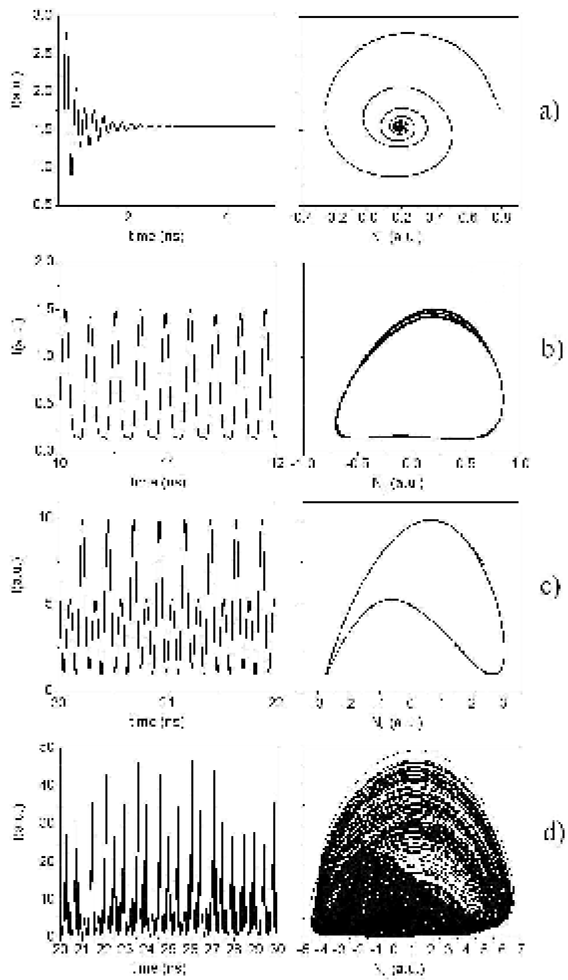

Figure 2. Time traces of the intensity of internal Fröhlich photons (left), phase portrait (right) for different values of detuning δ (a) δ=5, (b) δ=12, (c) δ=18, (d) δ=25.

Thus, our numerical estimates suggest that CW, self-pulsations and chaotic behaviors in the system of photons and phonons in biological systems under the influence of EMW can indeed be observed. Note that these chaotic self-oscillations, which occur because of the instability of the stationary states, are one more example of the formation of temporal structures in nonlinear dynamical systems. In addition to dynamic optical turbulence, spatial turbulence can develop and ‘‘order-chaos’’ and ‘‘chaos– order’’ structures can emerge.

IV. Conclusion

We have carried out an investigation of the dynamics of a Bose-condensed dipole-active phonons and internal Fröhlich photons under the influence of different parameters. The results presented in this paper show that under appropriate conditions such system is capable of generating different behaviors such as CW, periodic, or chaotic behaviours. Finally, we believe that our work provides a good basis for future study and, in particular, provides some pointers for more detailed investigations of phonons and photons and their applications in biology and medicine.

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VI. References

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