Green's functions of polaritons in a medium with zero-mean inhomogeneous coupling parameter

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Abstract

Dynamic susceptibilities (Green's functions) of the interacting electromagnetic waves $G_e^*(\omega)$ and optical phonons $G_u^*(\omega)$ in a medium with zero-mean inhomogeneous coupling parameter have been considered. The calculation was performed using a self-consistent approximation for the two stochastically interacting wave fields. It is shown that on the tops of the resonance maxima of the imaginary parts of the Green functions the fine structure is formed: a minimum (dip) on the top of $G_e^*(\omega)$ and narrow maximum (peak) on the top of $G_u^*(\omega)$. With increasing the correlation wavenumber of inhomogeneities $k_c$ (i.e., with decreasing the size of inhomogeneities), the width of the peak on $G_u^*(\omega)$ decreases, and two resonance maxima in the function $G_e^*(\omega)$ are formed. Because of the large difference in the speeds of light and optical phonons, the fine structure of the polaritons is manifested itself more clearly and saved to a much larger values of $k_c$, than for the studied earlier crossing resonance of spin and elastic waves.

1. Introduction

The phenomenon of crossing resonance between two wave fields of different physical nature in a homogeneous medium is well studied. The crossing resonance occurs at the intersection of dispersion curves of these fields and...
leads to lifting of the degeneracy of frequencies at this point. Coupled oscillations of various physical nature are formed in this area of the strong interaction (polaritons (Kittel’ (1978)), magnetoelectric wave (Akhiyezer et al. (1967)), and so on). In this paper, we consider the interaction between electromagnetic waves and transverse optical phonons, which results in the formation of coupled oscillations - polaritons. The crossing resonance between the waves in ionic crystals usually occurs in the long-wavelength range (the wavelength is much larger than the lattice parameters), where the main role plays the Coulomb energy. Thus, we can consider the crystal as a continuous medium and use a macroscopic description. The crossing resonance leads to the formation of the gap in the dispersion relation of waves: electromagnetic waves cannot propagate in the frequency range \( \omega_l < \omega < \omega_r \), where \( \omega_l \) and \( \omega_r \) are the frequencies of transverse and longitudinal optical phonons.

The dispersion law of waves in the range of the crossing resonance in an inhomogeneous medium was studied in Ignatchenko, Deich (1994) and Deich, Lisiansky, (1996). The research was conducted for the extremely inhomogeneous model of interaction of two wave fields when the coupling parameter between the fields is a random function of the coordinates with zero mean value. In this case, the interaction between the fields is due only to spatial fluctuations in this parameter. The study in Ignatchenko, Deich (1994) and Deich, Lisiansky, (1996) was carried out in the framework of the Bourret approximation (Bourret (1962)) (single scattering of waves from inhomogeneities). In Ignatchenko, Polukhin (2013), the dynamic susceptibilities (Green’s functions) of the coupled spin and elastic waves in the crossing resonance range in an inhomogeneous medium with zero mean value of the coupling parameter between the fields were considered. The study was conducted with an approximate into account the processes of multiple scattering of waves from the inhomogeneities. The calculation was performed in the framework of self-consistent approach, taking into account all the diagrams with nonintersecting lines correlations in expansions of the Green functions (Migdal (1958), Kraichnan (1961)).

The objectives of the work are: (i) to investigate the dynamic susceptibilities (Green's functions) of coupled electromagnetic waves and transverse optical phonon (polaritons) in a medium with the zero-mean inhomogeneous coupling parameter between them and (ii) to take into account the processes of multiple scattering of waves from the inhomogeneities in the framework of self-consistent approximation.

2. The system of equations for the Green’s functions

We consider a model of an ionic crystal, in which only the dipole moment \( d_i(\mathbf{x}) \) is non-uniform (Deich, Lisiansky, (1996)). The vector \( \mathbf{x} \) determines the position of the dipole moment, and the index \( i \) takes the values of \( x, y, \) and \( z \). The function \( d_i(\mathbf{x}) \) can be represented as

\[
d_i(\mathbf{x}) = \langle d_i \rangle + \langle \Delta d_i \rangle \rho(\mathbf{x}),
\]

where \( \langle d_i \rangle \) and \( \langle \Delta d_i \rangle \) determined the mean value and root mean square (rms) fluctuation of the coupling parameter between the wave fields, respectively, \( \rho(\mathbf{x}) \) is the centered \( (\langle \rho \rangle = 0) \) and normalized \( (\langle \rho^2 \rangle = 1) \) random function of coordinates (angle brackets denotes the average over the ensemble of random functions \( \rho \)). In a media with inhomogeneous coupling parameter between the waves, the average value of which is equal to zero, we have

\[
\langle d_i \rangle = 0, \quad \langle \Delta d_i \rangle \mathbf{x}, \quad \delta_{ij} < \rho(\mathbf{x})\rho(\mathbf{x}'),
\]

\[
< \rho(\mathbf{x})\rho(\mathbf{x}') > = K(\mathbf{r}),
\]

where \( K(\mathbf{r}) \) is the correlation function, \( \mathbf{r} = \mathbf{x} - \mathbf{x}' \), \( \delta_{ij} \) is the Kronecker delta. Since in our model \( \langle d_i \rangle = 0 \), the interaction of two wave fields caused only by stochastic fluctuations in these fields.

The system of the Dyson equation for the averaged Green's functions of electromagnetic waves \( \mathbf{G}_k^e \) and optical phonons \( \mathbf{G}_k^p \) in \( k \) - space has the form
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