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The effect of correlation properties of inhomogeneities on plasma excitations in a metal

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Abstract. We theoretically investigate the manifestations of the non-monotonic character and anisotropic peculiarities of the correlation functions of the inhomogeneities in the dispersion law and damping of plasma waves. The following specific effects have been found: a change in the character of the modifications, dispersion law and damping for small wavenumbers; dependence of the plasma frequency shift on the direction of the wave propagation. We substantiate possibilities for developing the correlation spectroscopy of plasma waves which would enable us not only to measure a correlation radius of the inhomogeneities (this has been suggested earlier), but also to obtain information in the form of the correlation function.

1. Introduction

It is well known nowadays that, in such inhomogeneous media as amorphous alloys and microcrystalline solid solutions, together with the structural inhomogeneities of atomic size there exist some inhomogeneities having a size of several tens, hundreds and even thousands of ångströms. These inhomogeneities (they have various names such as middle-range order, large-scale inhomogeneities or long-wave correlations) are directly observed by electron optics methods [1, 2]. The importance of studying these inhomogeneities is because their nature remains vague in many respects. At the same time we know that they determine many of the most important characteristics of inhomogeneous materials.

One of the methods for studying these inhomogeneities is the investigation of dispersion law modifications caused by them and additional damping of different waves propagating in medium. For example, the study of the characteristic dispersion law modifications of spin waves (see [3] and the review in [4]) enabled the correlation radii of the structural inhomogeneities for many amorphous alloys in the region of about 100 Å to be found. Inhomogeneities of size 10–100 Å have been determined [5, 6] for a number of alloys by a neutron scattering method.

It is shown in theoretical work [7] that important information on the structure of the inhomogeneities could be obtained from an investigation of a dispersion law and damping of plasma waves. It follows from these papers that not only for spin waves (and elastic waves too [8]) but also for the dispersion law of plasma waves there must be a characteristic peculiarity in the vicinity of a wavenumber $k_c \sim r_c^{-1}$, where r_c is the

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correlation radius of the inhomogeneities. It is quite possible that the bend in the long-wave part of the plasma wave spectrum observed earlier [9, 10] is due to this effect. However, an insignificant number of experimental points in the long-wave part of the spectrum enables one to find only the lowest estimate for the correlation radius $r_c > 5$ Å. Unfortunately, experiments with the aim of investigating the correlation radii of the inhomogeneities on the basis of the effects described in [7] have not been made yet.

There is quite a different picture in the field of investigation of a law modification for spin waves. Here not only the possibility of determining the correlation radius but also information on the form of a correlation function of the inhomogeneities is now being considered [11, 12].

In order to excite the interest of the experimentors engaged in the study of plasma waves, we shall show that certain information about the form of a correlation function can also be obtained from the spectrum and damping of plasma waves.

2. Dispersion law of plasma waves

In [7] the problems of dispersion law modifications and damping of plasma waves have been considered in the following approximations. Let the inhomogeneities create a slowly varying ($ka \ll 1$, where k is a characteristic wavenumber and a is the lattice parameter) and a rather small random potential $V(\boldsymbol{r})$. Then the Hamiltonian of a semiclassical approximation has the form (see, e.g., [13])

$$\mathcal{H}(\boldsymbol{r}, \boldsymbol{p}) = \varepsilon(\boldsymbol{p}) + V(\boldsymbol{r}) \tag{1}$$

where $\varepsilon(\boldsymbol{p})$ is the dispersion law of conduction electrons in an ideal crystal.

The ground state of the conduction electrons in this approximation is described by the Fermi–Dirac distribution function

$$F_0(\boldsymbol{r}, \boldsymbol{p}) = A[\![\exp\{[\varepsilon - \varepsilon_F + V(\boldsymbol{r})]/k_B T\} + 1]\!]^{-1} \tag{2}$$

where A is a normalized constant, which is determined from the condition of the electron-number conservation, and ε_F is the Fermi energy of an ideal crystal. We now use the approximation of the quadratic dispersion law of the conduction electrons and approximate a derivative $\partial F_0/\partial \varepsilon$ by the Dirac δ-function. The propagation of a plasma wave will be described by a system of equations consisting of the kinetic equation, the Maxwell equations and a material equation. We linearize the kinetic equation representing a distribution function of the electrons in the form

$$F(t, \boldsymbol{r}, \boldsymbol{p}) = F_0(\boldsymbol{r}, \boldsymbol{p}) + \varphi(t, \boldsymbol{r}, \boldsymbol{p}) \tag{3}$$

where $\varphi(t, \boldsymbol{r}, \boldsymbol{p})$ is a small addition to the equilibrium distribution function due to the electric field of the wave. Further we expand F_0 into a series up to quadratic terms in $V(\boldsymbol{r})$ and perform Fourier transformation with respect to $\boldsymbol{r}$ and t. As a result, one may obtain (for details see [7]) a bulky integral equation for a random scalar function $g(\boldsymbol{k}, \omega) \equiv \boldsymbol{k} \cdot \boldsymbol{j}$, where $\boldsymbol{k}$ is the wavevector of a plasma wave and $\boldsymbol{j}$ is the current density. The equation is averaged over the ensemble of random realizations of the inhomogeneities potential $V(\boldsymbol{r})$, assuming, for simplicity, that $\langle V(\boldsymbol{r})\rangle = 0$. Then the obtained correlators are decoupled in the first non-vanishing approximation of perturbation theory (Bourret approximation) in the parameter γ, which is a relative mean-square fluctuation of the potential $V(\boldsymbol{r})$:

$$\gamma = (\langle V^2(\boldsymbol{r})\rangle)^{1/2}/2\varepsilon_F. \tag{4}$$

As a result we obtain the dispersion law of plasma waves modified by the inhomogeneities in a general form

$$\omega^2 = \omega_p^2[1 + \tfrac{3}{5}q^2 - \gamma^2\mathcal{I}(q)]. \tag{5}$$

Here ω_p is the plasma frequency, $q = kv_F/\omega$ and $\mathcal{I}(q)$ represents a sum of four integrals dependent on the spectral density of the inhomogeneities.

At $\gamma = 0$ this expression is reduced to the unperturbed dispersion law of plasma waves corresponding to the long-wave approximation $ka \ll 1$, and consequently $q \ll 1$.

The corrections to the dispersion law caused by the inhomogeneities are of the order γ^2. However, there is one more parameter of smallness in the problem: q. The estimates made in [7] show that with an account of this parameter the corrections in (5) have a different order of smallness: γ^2/q_c^2, γ^2 and $\gamma^2 q^2$, where $q_c = k_c v_F/\omega_p \ll 1$ and k_c is the correlation wavenumber of the inhomogeneities.

When only the major term of the order γ^2/q_c^2 remains, we have for $\mathcal{I}(q)$ the following expression:

$$\mathcal{I}(q) = \frac{15}{q^2}\int \frac{(\boldsymbol{k}\cdot\boldsymbol{k}')^2}{k'^2}\frac{S(\boldsymbol{k}-\boldsymbol{k}')}{k'^2 - k^2}\,\mathrm{d}\boldsymbol{k}' \tag{6}$$

where $S(\boldsymbol{k})$ is the normalized spectral density of the inhomogeneities:

$$\langle V(\boldsymbol{k})V(\boldsymbol{k}_1)\rangle/\langle V^2\rangle = S(\boldsymbol{k})\delta(\boldsymbol{k} - \boldsymbol{k}_1). \tag{7}$$

The normalized correlation function of the inhomogeneities given by

$$K(r) = \langle V(\boldsymbol{x})V(\boldsymbol{x} + \boldsymbol{r})\rangle/\langle V^2\rangle \tag{8}$$

is related to the spectral density by a Fourier transformation, in accordance with the Wiener–Khintchin theorem for homogeneous random functions.

The integrated region in (6) embraces the whole space of the wavevectors, although in obtaining this expression a quadratic dispersion law of plasma waves valid only for small k is used as a zero approximation. It is justified by the fact that the integrals are effectively cut by the spectral density $S(\boldsymbol{k})$ for all values of $k \gg k_c$.

The real part of equation (6) determines the dispersion law modification, and its imaginary part determines damping of plasma waves due to scattering by the inhomogeneities.

The following correlation function and the spectral density corresponding to it were used to obtain estimates in [7]:

$$K(r) = \exp(-k_c r) \qquad S(\boldsymbol{k}) = k_c/\pi^2(k_c^2 + k^2)^2. \tag{9}$$

Rather bulky expressions were obtained for the spectrum and damping of plasma waves in a metal. In the limiting cases it follows from these expressions that

$$\left.\begin{aligned}(\omega'/\omega_p)^2 &= 1 + \tfrac{3}{5}q^2 - 5(\gamma^2/q_c^2)(1 - \tfrac{18}{5}u^2) \qquad k \ll k_c\\ \omega''/\omega_p &= 10(\gamma^2/q_c^2)u\end{aligned}\right\} \tag{10}$$

$$\left.\begin{aligned}(\omega'/\omega_p)^2 &= 1 + \tfrac{3}{5}q^2 - \tfrac{15}{4}(\gamma^2/q_c^2)(1/u^2) \qquad k \gg k_c\\ \omega''/\omega_p &= \tfrac{15}{2}(\gamma^2/q_c^2)(1/u).\end{aligned}\right\} \tag{11}$$

Here $u = k/k_c$, $\omega' = \mathrm{Re}\,\omega$, $\omega'' = \mathrm{Im}\,\omega$.

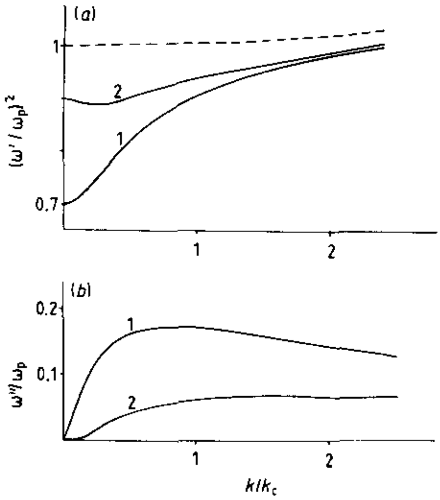

Figure 1. (*a*) Dispersion $(\omega'/\omega_p)^2$ and (*b*) damping ω''/ω_p of plasma waves ($\gamma^2 = 6 \times 10^{-4}$; $q_c = 0.1$): curves 1, for the monotonic correlation function (9); curves 2, for the correlation function (13): ---, dispersion curve in a homogeneous metal.

Figure 1 (curve 1) shows a modified dispersion curve $\omega'(k)$ and damping $\omega''(k)$ in detail. The damping has a maximum at $k = (\sqrt{3}/2)k_c$; in the vicinity of the same point there occurs a bend in the curve $\omega'(k)$.

It may be shown that the same modification is obtained for different isotropic and monotonic correlation functions: Gaussian, Karman, etc. Some deviations are only in the numerical coefficient. Using different functions, one should take into account the renormalization of the correlation radii, which is determined by comparing 'correlation volumes' for different correlation functions [14]:

$$V_c = (4\pi/3)r_c^3 = \int K(r)\,\mathrm{d}\boldsymbol{r}. \tag{12}$$

3. Non-monotonic correlation functions

The conclusions and estimates of [7] and of the previous section were obtained on the basis of the isotropic, monotonically decreasing correlation functions $K(r)$ of the inhomogeneities. They also correspond to isotropic and monotonically decreasing spectral densities $S(\boldsymbol{k})$. The various types of the inhomogeneity in the solids are described by these functions. For example, they describe frozen heat fluctuations of density, deformations, etc.

However, there are some inhomogeneities which can only be described by the correlation functions of another type. It is shown in [11, 12] that there are a number of physical effects which can lead to one and the same result: the formation of inhomogeneities whose spectral density has a tendency to decrease not only at $k \to \infty$ but also at $k \to 0$. For example, the effect of disintegration of supersaturated solid solutions leads to this tendency. As a result of such disintegration some deviations in density of different signs are observed for small volumes of material. In [12] these deviations were called 'Krivoglaz's spatial pulses', after a researcher who first turned his attention to this case [15]. The process of rejection of samples with randomly formed quasi-homogeneous parts of large size (the so-called 'quality filter'; see [12]) leads to the same tendency.

Finally, the process of natural or artificial formation of the quasi-periodic structures (superlattices) results in this tendency.

$S(k)$ vanishing at $k = 0$ corresponds to a limiting case of manifestation of the tendency for $S(k)$ to decrease. Such $S(k)$ and the correlation functions $K(r)$ corresponding to them (they cross the abscissa axis once or more times) were called in [11] functions of the second type. The functions lead to pronounced differences in the laws of damping of spin [11] and elastic [8] waves, in comparison with the laws corresponding to monotonically decreasing functions (functions of the first type). Thus, from a study of spin and elastic waves, one not only can find a correlation radius of the inhomogeneities but also can establish the type of the correlation function describing these inhomogeneities.

In this paper we shall show that this information may, in principle, be obtained from the experimental investigation of plasma waves.

As modelling we take the simplest correlation function of the second type [11]:

$$K_1(r) = (1 - k_c r/3)\exp(-k_c r) \qquad S(k) = 4k_c k^2/3\pi^2(k_c^2 + k^2)^3. \tag{13}$$

Since the correlation function changes its sign, there must be a modulus $K_1(r)$ in (12) when determining the correlation volume V_c. The calculation of integral (6) with this correlation function leads to a bulky expression whose real and imaginary parts are shown in figure 1 (curves 2). In the limiting case $k \ll k_c$ we have

$$\begin{aligned}(\omega'/\omega_p)^2 &= 1 + \tfrac{3}{5}q^2 - \tfrac{5}{3}(\gamma^2/q_c^2)(1 + \tfrac{18}{5}u^2) \\ \omega''/\omega_p &= \tfrac{80}{3}(\gamma^2/q_c^2)u^3\end{aligned} \tag{14}$$

In another limit $k \gg k_c$ both the dispersion and the damping are described, as before, by the corresponding expressions (11); only ω'' takes a factor $\frac{2}{3}$.

Inhomogeneities of the second type, as well as those of the first type, lead to a decrease in the plasma frequency. However, from a comparison of (10) and (14) it is seen that the modification $\omega'(0)$ is three times smaller in this case. In the dispersion law the type of correlation function reveals itself at $k < k_c$. The strongest deviations are obtained for $k \ll k_c$. In this region, inhomogeneities of the second type result not in an increase but in a decrease in the coefficient before k^2 in the dispersion law for small k. For

$$10\gamma^2/q_c^4 > 1 \tag{15}$$

the coefficient may even change sign. This case is shown in figure 1. One should note that the inequality (15) does not violate the principal inequality of the perturbation theory used here: $\gamma^2/q_c^2 \ll 1$ as $q_c^2 \ll 1$.

For correlation functions of the second type for $k \ll k_c$ there is also a modification of the exponent of k in the law of damping of plasma waves (from $\omega'' \sim k$ to $\omega'' \sim k^3$). This effect is similar to that calculated earlier for the modification of the law of damping of spin waves caused by both the fluctuations of anisotropy [16] (from $\omega'' \sim k$ to $\omega'' \sim k^3$) and the fluctuations of exchange and magnetization [11] (from $\omega'' \sim k^5$ to $\omega'' \sim k^7$).

Thus, the modelling of inhomogeneities of the correlation functions of the first and second types result in different modifications in the spectrum and damping of plasma waves. The experimental observation of the anomalous dispersion in the long-wave part of the spectrum for plasma waves or evidence of its absence would allow us to draw a conclusion about the degree to which the correlation properties of the inhomogeneities are close to the first or second type. A similar conclusion can be drawn from the investigation of damping, if we can only manage to separate the contribution from the mechanism discussed.

In [11, 12] a class of spectral densities of rather a general form is considered; these are classified with respect to index n:

$$S_n(k) \sim k^{2n} S_0(k) \tag{16}$$

where $S_0(k)$ is any monotonically (and sufficiently rapidly) decreasing function and $2n$ is the order of zero of the function $S_n(k)$ at $k = 0$. The index $n = 0$ corresponds to monotonically decreasing functions (functions of the first type), and the indices $n > 0$ to different functions of the second type.

The damping of plasma waves for this class of functions for the limiting cases of small and large k has the forms

$$\omega''/\omega_p \sim (\gamma/k_c)^2 \begin{cases} k^{2n+1} & k \ll k_c \\ 1/k & k \gg k_c. \end{cases} \tag{17}$$

With the increase in n of the correlation function the power k in the law of damping of plasma waves increases for small k. For large k the law k^{-1} does not change for arbitrary n; only the numerical coefficient changes. Thus, the damping of plasma waves obeys common regularities obtained for the damping of spin [11] and elastic [8] waves.

4. Anisotropic correlations

In the previous sections we have analysed the cases when the inhomogeneities possess the isotropic 'form' and, consequently, are described by the isotropic functions of the first and second types. For the majority of 'natural' inhomogeneous media this model is quite valid. However, there are such cases when, either purposefully or naturally, anisotropic inhomogeneities are induced in the medium. Then a question arises: will anisotropy of the correlation properties of the inhomogeneities be revealed in a modification of the plasma wave frequency?

Let the inhomogeneities be described by an anisotropic correlation function of the first type in the following form:

$$K(r) = \exp[-k_1^2(x^2 + y^2) - k_2^2 z^2] \tag{18}$$

i.e. the spatial fluctuations, which depend on the direction, are characterized by different correlation radii $r_1 \sim k_1^{-1}$ and $r_2 \sim k_2^{-1}$. At $k_1 > k_2$ the inhomogeneities stretch along the axis $z (r_2 > r_1)$ and in the limiting case $k_2 \to 0$ represent 'needles', which are homogeneous along the axis z. At $k_1 < k_2$ the inhomogeneities are flattened $(r_2 < r_1)$, and in the limiting case $k_1 \to 0$ they form homogeneous layers in the x–y plane. The properties of the layers vary randomly only along the axis z.

The anisotropic correlation function (18) corresponds to the anisotropic spectral density

$$S(k) = \exp[-\tfrac{1}{4}(\kappa^2/k_1^2 + k_z^2/k_2^2)]/8\pi^{3/2} k_1^2 k_2. \tag{19}$$

Integration of equation (6) with this spectral density in a general form results in various mathematical difficulties. Therefore, we consider the limiting case $k = 0$, which (for the functions of the first type) corresponds to a maximal value of the dispersion law modification in the isotropic material.

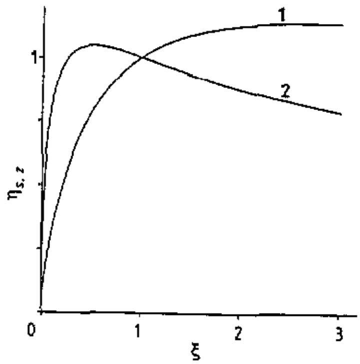

Figure 2. Dependence of the functions η_z (curve 1) and η_s (curve 2) on the anisotropy coefficient ξ for the correlation function of the inhomogeneities.

At $k = 0$ the integral (6) is solved exactly, and for the plasma frequency shift from its value in an ideal crystal we obtain the expression

$$\Delta_{s,z}(k_1, k_2) = (\omega_{s,z} - \omega_p)/\omega_p = -(5\gamma^2/4q_e^2)\eta_{s,z}(\xi). \tag{20}$$

Here the indices s and z correspond to oscillations whose electric field is polarized perpendicularly or along the axis z: $q_e = k_e v_F/\omega_p$, where $k_e = (k_1^2 k_2)^{1/3}$ is the effective correlation wavenumber of the inhomogeneities. This number remains constant when the form of the inhomogeneities, i.e. their anisotropy parameter $\xi = k_2/k_1$ changes, but there are no changes in the correlation volume $V_c \sim k_e^{-3} = k_1^{-2}k_2^{-1}$.

The functions $\eta_{s,z}(\xi)$ depend only on the anisotropy parameter ξ and are the same when the correlation volume changes:

$$\eta_s = (3\xi^{2/3}/4\alpha^2)\begin{cases}[(\alpha^2+1)/\alpha]\tanh^{-1}\alpha - 1 & \xi \leqslant 1 \\ 1 - [(1-\alpha^2)/\alpha]\tan^{-1}\alpha & \xi \geqslant 1\end{cases} \tag{21}$$

$$\eta_z = (3\xi^{2/3}/2\alpha^2)\begin{cases}1 - [(1-\alpha^2)/\alpha]\tanh^{-1}\alpha & \xi \leqslant 1 \\ [(1+\alpha^2)/\alpha]\tan^{-1}\alpha - 1 & \xi \geqslant 1\end{cases} \tag{22}$$

where $\alpha^2 = |1 - \xi^2|$; equation (22) was first obtained in [17].

Of physical interest may be the different functional dependences. For example, if we are interested in the dependence of $\Delta_{s,z}$ on the 'form' of the inhomogeneities, and their correlation volume does not change, q_e remains constant, and the dependence of $\Delta_{s,z}$ on the anisotropy parameter ξ is completely determined by the dependence of $\eta_{s,z}$ on ξ.

The functions $\eta_{s,z}$ vanish both at $\xi \to 0$ and at $\xi \to \infty$ (at $\xi \ll 1$, $\eta_s \sim -\xi^{2/3}\ln\xi$, $\eta_z \sim \xi^{2/3}$, and, at $\xi \gg 1$, $\eta_{s,z} \sim \xi^{-1/3}$) and reach a maximum at the points $\xi = 0.51$ and $\xi = 2.72$, respectively (figure 2). At $\xi = 1$ (isotropic inhomogeneities), $\eta_{s,z} = 1$ and $q_e = q_c$.

It is seen that the plasma oscillations polarized in different directions have different values of $\Delta_{s,z}$. Therefore, there is a major possibility of estimating the anisotropy of the correlation function of the inhomogeneities from experimental research on plasma waves. It follows from figure 2 that the larger value of the renormalized frequency always corresponds to a larger correlation radius of the inhomogeneities. For the strongly anisotropic inhomogeneities (infinitely thin 'layers' and 'needles') the plasma frequency modification decreases considerably in comparison with the effect caused by the isotropic inhomogeneities of the same correlation volume.

Of great interest may also be the dependences of $\Delta_{s,z}$ on k_1 and k_2 when the correlation volume is changeable. For example, for a fixed correlation radius r_1 and an unlimited increase in $r_2(k_2 \to 0)$ the inhomogeneities take the form of a needle-shaped structure, which is homogeneous along the axis z with a finite 'diameter' of the needles. For fixed r_2 and an increase in $r_1(k_1 \to 0)$ the inhomogeneities tend to a laminated structure (with a finite 'layer' thickness), which is homogeneous in the x–y plane. In both limiting cases all the expressions for $\Delta_{s,z}$ diverge, except those for Δ_z at $k_2 \to 0$. This divergence is due to the following reasons. In a general case all the effects caused by the inhomogeneities are proportional to $V_c^{2/3}$ and the functions $\eta_{s,z}$ depend only on the anisotropy ξ. In the isotropic medium the increase in the correlation radius leads to an increase in V_c, except for $\eta_{s,z} = 1$. For anisotropic inhomogeneities, on an increase in one of the correlation radii and when the value of another is constant, the correlation volume also increases, but the functions of the form of the inhomogeneities $\eta_{s,z}$ decrease. As a result, the divergence $\Delta_{s,z}$ becomes less (at $k_1 \to 0$, $k_2 =$ constant, we have $\Delta_{s,z} \sim (k_1 k_2)^{-1}$ and, at $k_1 =$ constant, $k_2 \to 0$, $\Delta_s \sim k_1^{-2} \ln(k_1/k_2)$) or disappears totally ($\Delta_z \sim k_1^{-2}$, at $k_1 =$ constant, $k_2 \to 0$). Thus, the effect of increasing the correlation volume is predominant in all three cases discussed above. Only in one case is this effect counterbalanced by that of the form of the inhomogeneities.

For simplicity we discuss the tendency towards divergence of all the expressions in perturbation theory at $V_c \to \infty$ for isotropic inhomogeneities. When the increase in r_c is unlimited ($k_c \to 0$), the isotropic spectral density $S(k)$ tends to a Dirac function $\delta(k)$. Correspondingly, each of the random realizations becomes a constant independent of the coordinates. Averaging in the calculation of any physical characteristic is performed over the ensemble where every member represents a spatially inhomogeneous medium, the parameters of the medium differing from those of another member of the ensemble by a random value. It is clear that this average has no physical sense as it is not equal to a corresponding average in volume for any of the members of the statistical ensemble under consideration; at $k_c \to 0$ the system loses the property of spatial ergodicity. The real situation for each member of the ensemble is quite trivial; there will be neither a dispersion law modificaton nor a damping of waves. Only a renormalization of ω_p by a finite value, which is different for each of the ensemble's members, will occur.

5. Conclusion

Broadening the class of the correlation functions modelling inhomogeneities (in comparison with the simplest monotonically decreasing correlation functions used in [7]) has led to the following results.

Correlation functions of the second type, as well as those of the first type, result in a modification of (bend in) the dispersion curve for plasma waves in the vicinity of the characteristic wavenumber of the inhomogeneities: $k_c \sim r_c^{-1}$. However, the character of the modification is different; functions of the second type may even lead to the appearance of negative dispersion in the region of long waves, and it is impossible when the functions of the first type are applied.

The laws of damping are quite different for the first and second types of function (also true for functions of the second type with a different value of index n (see (17)).

These results are, in the main, analogous to those obtained earlier for a dispersion law modification and damping of spin [11, 16] and elastic [8] waves, using correlation functions of the second type. In particular, the dependence of the law of damping on the index n is in general regular for all kinds of wave; an exponent $2n$ is added to all power laws known for the first type of function in the region of small k. The primary distinctive characteristic for plasma waves has a larger difference between the modifications of the dispersion law because of the functions of first and second types than those for spin and elastic waves.

Anisotropy of the correlation function results in a difference in the dispersion law modification for plasma waves propagating in different directions.

Thus, there are possibilities for developing a new method of investigating disordered media (correlation spectroscopy of plasma waves) based on the experimental study of the dispersion law modification and damping of plasma waves. The method would enable one to measure the correlation radii and mean square fluctuations of the electric potential in a medium, in analogy with the procedure of measuring similar parameters of spin systems by correlation spin-wave spectroscopy [4]. In principle, the method allows one to obtain more detailed information on the inhomogeneities: to determine what type (first or second) the correlation functions describing the inhomogeneities is, to find the orientation of the axis of anisotropy and to estimate the value of anisotropy for the anisotropic inhomogeneities. The method of correlation spectroscopy of plasma waves has its own sphere of application both in the range of wavenumbers of the inhomogeneities, and in the media studied. In this sense the method discussed and other methods of correlation spectroscopy of inhomogeneities (spin wave, optic and elastic) are not competing but complementary.

References

[1] Yudin V V, Timakova G P, Matokhin A V, Dolzhikov S V and Yudina L A 1983 *Fiz. Tverd. Tela* **25** 1953

[2] Labutin V Yu, Nefedov V I, Makogina E I, Yudina L A and Yudin V V 1986 *Poverkhnost* **12** 95

[3] Ignatchenko V A and Iskhakov R S 1977 *Zh. Eksp. Teor. Fiz.* **72** 1005 (Engl. Transl. 1977 *Sov. Phys.–JETP* **45** 526; 1978a *Zh. Eksp. Teor. Fiz.* **74** 1386 (Engl. Transl. 1978 *Sov. Phys.–JETP* **47** 715); 1978b *Zh. Eksp. Teor. Fiz.* **75** 1438 (Engl. Transl. 1978 *Sov. Phys.–JETP* **48** 726)

[4] Ignatchenko V A and Iskhakov R S 1985 *Physics of Magnetic Materials, Proc. 2nd Int. Conf. on Physics of Magnetic Materials (Jadwisin, 17–22 September 1984)* Part 1—Invited Papers (Singapore: World Scientific) pp. 527–50

[5] Wolny J, Freltoft T and Lebech B 1989 *Acta Phys. Pol.* A **76** 127

[6] Antonov A V, Isakov A I, Kuznetsov S P, Meshkov I V, Perekrestenko A D and Shelagin A V 1984 *Fiz. Tverd. Tela* **26** 1585

[7] Ignatchenko V A, Mankov Yu I and Rakhmanov F V 1981 *Zh. Eksp. Teor. Fiz.* **81** 1771 (Engl. Transl. 1981 *Sov. Phys.–JETP* **54** 939); 1982 *Fiz. Tverd. Tela* **24** 2292 (Engl. Transl. 1982 *Sov. Phys.–Solid State* **24** 1301)

[8] Deich L I, Ignatchenko V A 1987 *Fiz. Tverd. Tela* **29** 825

[9] Bross H 1978 *Phys. Lett.* **64A** 418

[10] Manzke R 1980 *J. Phys. C: Solid State Phys.* **13** 911

[11] Ignatchenko V A and Iskhakov R S 1988 *Fiz. Metal. Metalloved.* **65** 679

[12] Ignatchenko V A and Iskhakov R S 1990 *Fiz. Metall. Metalloved.* **9** 5

[13] Lifshitz I M, Azbel M Ya and Kaganov M I 1971 *Elektronnaya teoriy metallov (Electron theory of metals)* (Moscow: Nauka) p 15

[14] Ignatchenko V A and Iskhakov R S 1984 *Preprint* 268F, Institute of Physics, Siberian Branch of the Academy of Sciences of USSR, Krasnoyarsk

[15] Krivoglaz M A 1961 *Voprosy Fiz. Metall. Metalloved.* **13** 17

[16] Bogomaz I V and Ignatchenko V A 1986 *Preprint* 363F, Institute of Physics, Siberian Branch of the Academy of Sciences of USSR, Krasnoyarsk; 1989 *Fiz. Metal. Metalloved.* **67** 866

[17] Rakhmanov F V 1984 *Thesis* Kirensky Institute of Physics, Krasnoyarsk