Transverse Plasma Resonance Mode in a Nonmagnetized Plasma and Its Practical Applications

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Abstract

It is shown that in the nonmagnetized plasma, besides longitudinal Langmuir resonance can exist the transverse plasma resonance. The resonance indicated can exist in the confined plasma. It is known that with the nuclear explosions the electromagnetic radiation in the very wide frequency band is observed, up to the radio-frequency range. And if the emission in field of light range can be explained by the emission of separate atoms, then emission in the region of radio-frequency band can be caused only by collective processes, which occur in the confined plasma. The use of transverse resonance makes it possible to create resonators and band-pass filters, and also lasers on the collective plasma oscillations. Transverse plasma resonance can be used also for the warming-up of plasma and its diagnostics. It is introduced the concept of magnetoelectrokinetic waves.

Keywords: plasma, resonance, Langmuir resonance, plasma resonance, cavity, laser

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1. Introduction

Until now, was considered that in the nonmagnetized plasma only one Langmuir resonance can exist. The processes, which characterize this resonance, are connected with a longitudinal change in the density of plasma. This resonance cannot emit electromagnetic waves lengthwise. It is known that with the nuclear explosions the electromagnetic radiation in the very wide frequency band is observed, up to the radio-frequency range. And if the emission in field of light range can be explained by the emission of separate atoms, then emission in the region of radio-frequency band can be caused only by collective processes, which occur in the confined plasma.

2. Electrodynamics of the Nonmagnetized Plasma

A large quantity of articles in the scientific journals and monographs [1,2,3,4] is devoted to the examination of electrodynamic processes in the plasma. In the publications indicated primary attention is paid to questions of physics of the magnetized plasma, and is only brief description of processes, proceeding in the nonmagnetized plasma. It is described only one Langmuir (plasma) resonance, which was known up to now. It should be noted that with the description of processes in the nonmagnetized plasma in the monographs indicated are terminological and systematic inaccuracies, which must be corrected.

Let us examine the plasmo-like medium, in which be absent the ohmic losses. Such plasma medium is superconductor or the very hot plasma, in which the ohmic losses can be disregarded. In this case the equation of motion of electron takes the form

$$m \frac{d \vec{V}}{dt} = e \vec{E}$$  \hspace{1cm} (1.2)

where m and e is a mass and electron charge, \( \vec{E} \) is tension of electric field, \( \vec{V} \) is speed of the motion of charge.

Taking into account that current density

$$j = ne \vec{V},$$  \hspace{1cm} (2.2)

we obtain from Eq. (2.2):

$$j_L = \frac{ne^2}{m} \int \vec{E} \, d \tau$$  \hspace{1cm} (2.3)

In Eqs. (2.2) and (2.3) the value \( n \) determines the charge density. After introducing the designation [5,6]

$$L_k = \frac{mn}{ne^2}$$  \hspace{1cm} (2.4)

Let us write down

$$j_L = \frac{1}{L_k} \int \vec{E} \, d \tau$$  \hspace{1cm} (2.5)

In this case the value \( L_k \) presents the specific kinetic inductance of plasmo-like medium. Its existence connected with the fact that charge, having a mass, possesses inertia properties. In spite of the obviousness of
this record of the density of inductive current, it was for the first time proposed in the work [7].

Pour on Eq. (2.5) it will be written down for the case of harmonics:

\[
\dot{j}_L = -\frac{1}{\omega L_k} E_0 \cos \omega t \quad (2.6)
\]

From Eqs. (6.5) and (6.6) it is evident that \( \dot{j}_L \) presents inductive current, since its phase is late with respect to the tension of electric field to the angle \( \frac{\pi}{2} \).

Maxwell equations for this case take the form

\[
\text{rot} \vec{E} = -\mu_0 \frac{\partial \vec{H}}{\partial t},
\]

\[
\text{rot} \vec{H} = \dot{j}_C + \dot{j}_L = \varepsilon_0 \frac{\partial \vec{E}}{\partial t} + \frac{1}{L_k} \int \vec{E} dt,
\]

(2.7)

where \( \varepsilon_0 \) and \( \mu_0 \) is dielectric and magnetic constant of vacuum, and the values \( \dot{j}_C \) and \( \dot{j}_L \) present respectively the bias current and conductivity. This form of writing of Maxwell equations taking into account the density of inductive current was for the first time proposed in work [7]. Further this question repeatedly was discussed in works [8-13].

From Eq. (2.7) we obtain

\[
\text{rot} \text{rot} \vec{H} = \mu_0 \varepsilon_0 \frac{\partial^2 \vec{H}}{\partial t^2} + \frac{\mu_0}{L_k} \vec{H} = 0 \quad (2.8)
\]

For the case pour on, time-independent, equation (2.8) passes into the equation of London [14]

\[
\text{rot} \text{rot} \vec{H} = \frac{\mu_0}{L_k} \vec{H} = 0 \quad (2.9)
\]

where \( \lambda^2 = \frac{L_k}{\mu_0} \) is London depth of penetration.

It should be noted that in monograph [14] there is no equation (2.8), which characterizes the behavior of the nonmagnetized plasma in the variable fields, and equation for constant magnetic given only pour on (2.9).

Equation (2.7) indicates that neither dielectric nor magnetic of the permeability of the nonmagnetized plasma on frequency depend, but they are equal to the dielectric and magnetic constant of vacuum. Furthermore, this plasma characterizes one additional fundamental material parameter - specific kinetic inductance.

Equation (2.7) are accurate both for the constants and for the variables pour on. For the case of harmonics pour on \( \vec{E} = \vec{E}_0 \sin \omega t \) from (2.7) we obtain

\[
\text{rot} \vec{H} = \left( \varepsilon_0 \varepsilon_0 - \frac{1}{L_k} \right) \vec{E}_0 \cos \omega t \quad (2.10)
\]

The value in the brackets is the reactive plasma conductivity \( \sigma_X \), consequently

\[
\text{rot} \vec{H} = \sigma_X \vec{E}_0 \cos \omega t \quad (2.11)
\]

where

\[
\sigma_X = \varepsilon_0 \varepsilon_0 - \frac{1}{L_k} = \varepsilon_0 \varepsilon_0 \left( 1 - \frac{\omega^2}{\omega^2} \right) = \omega \varepsilon^*(\omega) \quad (2.12)
\]

Let us introduce the following designations

\[
\varepsilon^*(\omega) = \varepsilon_0 \left( 1 - \frac{\omega^2}{\omega^2} \right)
\]

where \( \omega^2 = \frac{1}{\varepsilon_0 L_k} \) is Langmuir frequency.

Then Eq. (2.17) can be rewritten

\[
\text{rot} \vec{H} = \omega \varepsilon^*(\omega) \vec{E}_0 \cos \omega t
\]

or

\[
\text{rot} \vec{H} = \omega \varepsilon^*(\omega) \vec{E}_0 \cos \omega t .
\]

In the literature in physics of plasma the value \( \varepsilon^*(\omega) \) is accepted to call the dielectric constant of plasma [1,2,3,4] depending on the frequency. Of this terminological and systematic error consists. In actuality the value \( \varepsilon^*(\omega) \) includes simultaneously the dielectric constant of vacuum and the specific kinetic inductance of plasma and it is determined by the equation

\[
\varepsilon^*(\omega) = \frac{\sigma_X}{\omega}
\]

where \( \sigma_X \) is the reactive plasma conductivity.

Is obvious that \( \sigma_X \) can be recorded, also, on other

\[
\sigma_X = \varepsilon_0 \varepsilon_0 - \frac{1}{L_k} = \frac{1}{\omega L_k} \left( \frac{\omega^2}{\omega^2} - 1 \right) = \frac{1}{\omega L_k} *, \quad (2.13)
\]

where

\[
L_k * = \frac{L_k}{\omega} \left( \frac{\omega^2}{\omega^2} - 1 \right) = \sigma_X \omega.
\]

Recorded thus value \( L_k * \) also includes and \( \varepsilon_0 \) and \( L_k \) and by analogy from \( \varepsilon^*(\omega) \) it can be named the inductance of plasma depending on the frequency.

The Eqs. (2.12) and (2.16) are equivalent and we with the identical success can assert that the plasma is characterized by the not frequency-dependent dielectric constant \( \varepsilon^*(\omega) \), but by the frequency-dependent kinetic inductance \( L_k * \).

With the use of the parameters \( \varepsilon^*(\omega) \) and \( L_k * \) equation (2.10) it is possible to rewrite

\[
\text{rot} \vec{H} = \omega \varepsilon^*(\omega) \vec{E}_0 \cos \omega t \quad (2.14)
\]

or

\[
\text{rot} \vec{H} = \frac{1}{\omega L_k * \omega} \vec{E}_0 \cos \omega t \quad (2.15)
\]

Equations (2.14) and (2.15) are also equivalent.

Thus, the parameter \( \varepsilon^*(\omega) \) is not dielectric constant, although has its dimensionality. The same relates also to \( L_k * \).

It is easy to see that

\[
\varepsilon^*(\omega) = \frac{\sigma_X}{\omega}, \quad L_k * (\omega) = \frac{1}{\sigma_X \omega}.
\]
These equations determine physical sense and designation of the parameters $\varepsilon^*(\omega)$ and $L_k^*(\omega)$.

To use $\varepsilon^*(\omega)$ and $L_k^*(\omega)$ for finding the energy according to the formulas

$$W_E = \frac{1}{2} \varepsilon E_0^2$$

and

$$W_j = \frac{1}{2} L_k j_0^2$$

is cannot. Work [15] gives the equation, which makes it possible to calculate the energy, accumulated in the nonmagnetized plasma, with the presence in it of variable electrical pour on with the use of the parameter of $\varepsilon^*(\omega)$

$$W = \frac{1}{2} \left[ \frac{\omega}{\omega^2} \right] \varepsilon E_0^2$$

(2.16)

However equation is given without what or substantiation, and is simple ugdano. Actually, if we in Eq. (2.16) substitute the value $\varepsilon^*(\omega)$, then we will obtain

$$W_\Sigma = \frac{1}{2} \varepsilon_0 E_0^2 + \frac{1}{2} \frac{1}{\omega^2} L_k^2 E_0^2 = \frac{1}{2} \varepsilon_0 E_0^2 + \frac{1}{2} L_k j_0^2$$

(2.17)

This is the correct result, which indicates that the total energy, accumulated in the nonmagnetized plasma with the presence in it of variables pour on, is included energy of electrical pour on energy of kinetic electron motion. In work [15] this special feature of Eq. (2.16) is not examined

The same result is obtained, after using the equation

$$W_\Sigma = \frac{1}{2} \varepsilon_0 E_0^2$$

Figure 1. The two-wire circuit, which consists of two ideally conducting planes

If we line short out at a distance $z$ and to connect to it the source of the direct current of $I$, then the energy, stored up in the magnetic field of line, will be written down

$$W_H = \frac{1}{2} \mu_0 H^2 a b z = \frac{1}{2} L_H I^2$$

since $H = \frac{I}{b}$, we will obtain

$$L_H = \mu_0 \frac{a z}{b}$$

where $L_H$ is the summary inductance of line.

The value $L_H = \mu_0 \frac{a}{b}$ is the running inductance of line, and $\mu_0 \frac{a}{b}$ corresponds to the specific inductance of medium, in this case of vacuum.

The specific energy of magnetic field will be written down

$$W_H = \frac{1}{2} \mu_0 H^2$$

Subsequently for the larger clarity of the obtained results, together with their mathematical idea, we will use

$$W_{\Sigma E} = \frac{1}{2} \varepsilon_0 E^2 a b z = \frac{1}{2} C_{\Sigma E} U^2$$

where $E = \frac{U}{a}$ is tension of electric field in the line.

The value

$$C_{\Sigma E} = \varepsilon_0 \frac{b z}{a}$$

represents the total capacitance of the line, where $C_E = \varepsilon_0 \frac{b}{a}$ linear of the capacity of line, and $\varepsilon_0$ is dielectric constant of vacuum.

Let us write down efficient potential electric field energy

$$W_E = \frac{1}{2} \varepsilon_0 E^2$$
the method of equivalent diagrams. It is evident that with
an increase in \( z \), \( C_{\Sigma} \) and \( L_{\Sigma} \) they increase, therefore the
section of the line of the long \( dz \) can be represented in the
form the equivalent diagram, shown in Figure 2a.

If we in open-circuit line place the plasma, charge
carriers in which can move without the losses, and pass
through the flow line \( I \), then charges they will stock
kinetic energy. Since the transverse current density in this
line is determined by the equation

\[
\frac{b dz}{a}
\]

Figure 2. a - the equivalent the schematic of the section of the two-wire
circuit; \( b \) - the equivalent the schematic of the section of the two-wire
circuit, filled with plasma without the losses; a - the equivalent
the schematic of the section of the line, filled by the dissipative plasma

\[
j = \frac{I}{b z} = n e V
\]

that summary kinetic energy of all moving charges will be
written down

\[
W_{k \Sigma} = \frac{1}{2} \frac{m}{n e^2} a b z \left( \frac{1}{a} - \frac{m}{n e^2} \frac{a}{b z} I^2 \right)
\]

Is fulfilled also the equation

\[
W_{k \Sigma} = \frac{1}{2} L_{k \Sigma} I^2,
\]

where \( L_{k \Sigma} \) - complete kinetic inductance of line. Consequently

\[
L_{k \Sigma} = \frac{m}{n e^2} \frac{a}{b z}
\]

Thus, the value

\[
L_k = \frac{m}{n e^2}
\]

the role of the specific kinetic inductance of this medium
plays.

We already previously introduced this value in another
manner (see Eq. (2.4)).

Equation (3.2) is obtained for the case of the direct
current, when current distribution is uniform.

From Eq. (3.1) is evident that in contrast to and of the
value of with an increase in it does not increase, but it
decreases. Connected this with the fact that with an
increase in a quantity of parallel-connected inductive
elements grows. The equivalent the schematic of the
section of the line, filled with the plasma, in which there
are no losses, it is shown in Figure 2b. Line itself in this
case will be equivalent to parallel circuit with the lumped
parameters \( C = \frac{\varepsilon_0 b z}{a} \) and \( L = \frac{L_k a}{b z} \).

But if we calculate the resonance frequency of this
outline, then it will seem that this frequency generally not
on what sizes depends, actually

\[
\omega_p^2 = \frac{1}{C L} = \frac{1}{\varepsilon_0 L_k} = \frac{n e^2}{\varepsilon_0 m}
\]

Is obtained the very interesting result, which speaks,
that the resonance frequency macroscopic of the resonator
examined does not depend on its sizes. Impression can be
created, that this is plasma resonance, since. The obtained
value of resonance frequency exactly corresponds to the
value of this resonance. But it is known that the plasma
resonance characterizes longitudinal waves in the long
line they, while occur transverse waves. In the case
examined the value of the phase speed in the direction of
is equal to infinity and the wave vector

\[
\vec{k}_z = 0
\]

This result corresponds to the solution of system of equations (2.7)
for the line with the assigned configuration (Figure 1). From Eqs. (2.8) known result [1,2,3,4]. In this case the
wave number is determined by the equation

\[
k_z^2 = \frac{\omega_p^2}{c^2} \left( 1 - \frac{\omega_p^2}{\omega^2} \right)
\]

and the group and phase speeds

\[
\chi_g^2 = c^2 \left( 1 - \frac{\omega_p^2}{\omega^2} \right)
\]

\[
\chi_p^2 = c^2 \left( \frac{1}{1 - \frac{\omega_p^2}{\omega^2}} \right)
\]

where \( c = \left( \frac{1}{\mu_0 \varepsilon_0} \right)^{1/2} \) is speed of light in the vacuum.

In this plasma the phase speed of electromagnetic wave
is equal to infinity. Consequently, at each moment of time
depend on distribution and currents in this line uniform and
it does not depend on the coordinate, but current in the
planes of line in the direction of is absent. Consequently,
current in the planes of line in the direction \( z \) is absent.
This, from one side, it means that the inductance of will
not have effects on electrodynamic processes in this line,
but instead of the conducting planes can be used any
planes or devices, which limit plasma on top and from below.

From Eqs. (3.3), (3.4) and (3.5) is evident that at the point of \( \omega = \omega_0 \) occurs the transversal resonance with the infinite quality. The fact that in contrast to the plasma, this resonance is transverse, will be one can see well for the case, when the quality of this resonance does not be equal to infinity. In this case \( k_z \neq 0 \) and in the line will be extended the transverse wave, the direction of propagation of which will be perpendicular to the direction of the motion of charges. The examination of this task was begun from the examination of the plasma, limited from two sides by the planes of long line. But in the process of this examination it is possible to draw the conclusion that the frequency of this resonance generally on the dimensions of line does not depend. It means, resonance has infinite quality, \( Q \). In this case, when the quality of this resonance does not be equal to infinity, \( Q \neq \infty \), and, using near the conductivity of the index \( \mu \), it is possible to draw the conclusion that the frequency of this resonance generally on the dimensions of line does not depend. It means, resonance has infinite quality, \( Q \). In this case, when the quality of this resonance does not be equal to infinity, \( Q \neq \infty \), and, using near the conductivity of the index \( \mu \),

\[
W_{E,H,j} = \frac{1}{2} \varepsilon_0 j_0 E^2_0 + \frac{1}{2} \mu_0 H^2_0 + \frac{1}{2} L_j j_0^2
\]

Thus, for finding the total energy, by the prisoner per unit of volume of plasma, calculation only fields \( E \) and \( H \) it is insufficient.

At the point \( \omega = \omega_0 \)

\[
W_H = 0, W_E = W_k,
\]

i.e. magnetic field in the plasma is absent, and plasma presents macroscopic electromechanical resonator with the infinite quality, \( Q \) corresponding at the frequency.

Since with the frequencies \( \omega > \omega_0 \), the wave, which is extended in the plasma, it bears on itself three forms of the energy: electrical, magnetic and kinetic, then this wave can be named electromagnetic kinetic wave. Kinetic wave represents the wave of the current density of \( \mathbf{E} \), \( \mathbf{H} \) and \( j \). This wave is moved with respect to the electric wave the angle \( \pi/2 \).

If losses are located, moreover completely it does not have value, by what physical processes such losses are caused, then the quality of plasma resonator will be finite quantity. For this case of Maxwell equation they will take the form

\[
\begin{align*}
\rho \omega &= -\mu_0 \frac{\partial \mathbf{H}}{\partial t}, \\
\rho \omega &= \sigma_{\rho,ef} \mathbf{E} + \sigma_0 \frac{\partial \mathbf{E}}{\partial t} + \frac{1}{L_k} \int \mathbf{j} dt.
\end{align*}
\]

The presence of losses is considered by the term \( \sigma_{\rho,ef} \mathbf{E} \), and, using near the conductivity of the index \( \sigma_0 \), it is thus emphasized that us does not interest very mechanism of losses, but only very fact of their existence interests. Let us examine the method of measuring \( \sigma_{\rho,ef} \). For measuring should be selected the section of line by the length, whose value is considerably lower than the wavelength in the plasma. This section will be equivalent to outline with the lumped parameters

\[
\begin{align*}
C &= \varepsilon_0 \frac{b z_0}{a}, \\
L &= L_k \frac{a}{b z_0}, \\
G &= \sigma_{\rho,ef} \frac{b z_0}{a},
\end{align*}
\]

where \( \sigma \) is conductivity, connected in parallel \( C \) and \( L \).

The conductivity \( G \) of this outline is determined by the equation

\[
G = \frac{1}{Q_{\rho}} \sqrt{\frac{C}{L}}
\]

where \( Q_{\rho} \) is quality of the resonator.

From where, taking into account (3.8 - 3.10), we obtain
\[ \sigma_{p,ef} = \frac{1}{Q_p} \sqrt{\frac{\varepsilon_0}{L_k}} \] 

(3.10)

consequently, measuring its own quality of plasma resonator, it is possible to determine \( \sigma_{p,ef} \).

Using Eqs. (3.6) and (3.10) we will obtain

\[ \text{rot} \vec{E} = -\mu_0 \frac{\partial \vec{H}}{\partial t}, \]

\[ \text{rot} \vec{H} = \frac{1}{Q_p} \sqrt{\frac{\varepsilon_0}{L_k}} \vec{E} + \varepsilon_0 \frac{\partial \vec{E}}{\partial t} - \frac{1}{L_k} \int \vec{E} \cdot \vec{dt}. \] 

(3.11)

The equivalent schematic of this line, filled with dissipative plasma, is represented in Fig 2B.

Let us examine the solution of system of equations (3.11) at the point of, in this case, since

\[ \varepsilon_0 \frac{\partial \vec{E}}{\partial t} + \frac{1}{L_k} \int \vec{E} \cdot \vec{dt} = 0 \]

we obtain

\[ \text{rot} \vec{E} = -\mu_0 \frac{\partial \vec{H}}{\partial t}, \]

\[ \text{rot} \vec{H} = \frac{1}{Q_p} \sqrt{\frac{\varepsilon_0}{L_k}} \vec{E}. \] 

(3.12)

The solution of this system of equations is well known [5]. If there is an interface between the vacuum and the medium, whose parameters are determined by equations (3.12), then the surface impedance of medium is written

\[ Z = \frac{E_{lg}}{H_{lg}} = \sqrt{\frac{\omega \mu_0}{2\sigma_{p,ef}}} (1 + i) \]

where \( \sigma_{p,ef} = \frac{1}{Q_p} \sqrt{\frac{\varepsilon_0}{L_k}} \).

The wave, which exits into the depths of the medium, diminishes according to the law \( e^{-\frac{z}{\delta_{p,ef}}} \cdot e^{-i \frac{z}{\delta_{p,ef}}} \), phase speed in this case it is determined by the equation of

\[ v_p = \omega \sigma_{p,ef} \]

where of \( \delta_{p,ef}^2 = \frac{2}{\mu_0 \omega \sigma_{p,ef}} \) - effective depth of penetration of field into the plasma. The obtained equations characterize wave process in the plasma. For good conductors of \( \frac{\sigma_{ef}}{\omega \varepsilon_0} \gg 1 \) and then wavelength in this medium of

\[ \lambda_p = \frac{2\pi \delta}{\omega} \]

is considerably less than wavelength in the free space. Subsequently of us it will interest the case, when at the point \( \omega = \omega_p, \lambda_p \gg \lambda_0, v_p \gg v_0 \).

The examination of the electrodynamic properties of plasma is carried out nontraditionally. We not at all introduced this concept as the frequency dependent dielectric constant of plasma. This made possible to understand, that \( \varepsilon^*(\omega) \) is purely mathematical, but not physical concept, and that the dielectric constant of plasma on frequency does not depend, but is equal to the dielectric constant of vacuum. From other side, this approach gave to us the possibility to understand, what energy processes occur in the plasma, and what forms of energy in it are stocked and are extended.

4. Practical Results

Since with the aid of the plasma can be created macroscopic single-frequency resonator, this resonator can be used for development and creating the new class of electrokinetic lasers. This resonator can be also used as band-pass filter.

With the sufficiently great significances of \( Q_p \) energy of magnetic fields on at the resonance frequency considerably less than kinetic energy of the current carriers and energy of electrostatic pour on. Furthermore, the phase speed in this resonator under specific conditions can be considerably more than the speed of light. Therefore, with the excitation of transverse plasma resonance it is possible to place

\[ \text{rot} \vec{E} = 0, \]

\[ \frac{1}{Q_p} \sqrt{\frac{\varepsilon_0}{L_k}} \vec{E} + \varepsilon_0 \frac{\partial \vec{E}}{\partial t} + \frac{1}{L_k} \int \vec{E} \cdot \vec{dt} = j_{CT}, \]

(4.1)

where \( j_{CT} \) is density of strange currents.

Differentiating (4.1) on the time and after dividing into \( \varepsilon_0 \) we will obtain

\[ \omega_p^2 \vec{E} + \frac{\omega_p}{Q_p} \frac{\partial \vec{E}}{\partial t} + \frac{\partial^2 \vec{E}}{\partial t^2} = \frac{1}{\varepsilon_0} \frac{\partial j_{sd}}{\partial t}. \]

(4.2)

If we (4.2) integrate over the surface of normal to the vector \( \vec{E} \) and to designate

\[ \Phi_E = \int \vec{E} \cdot d\vec{S}, \]

where \( \Phi_E \) is the electric flux.

And further we will obtain

\[ \omega_p^2 \Phi_E + \frac{\omega_p}{Q_p} \frac{\partial \Phi_E}{\partial t} + \frac{\partial^2 \Phi_E}{\partial t^2} = \frac{1}{\varepsilon_0} \frac{\partial I_{sd}}{\partial t}. \]

(4.3)

where \( I_{sd} \) is strange current.

Equation (4.3) is the equation of harmonic oscillator with the right side, characteristic for the two-level laser [17]. If the source of excitation is absent, then we deal concerning “cold” laser resonator, in which the fluctuations attenuate exponentially

\[ \Phi_E(t) = \Phi_E(0) e^{i \omega_p t} \cdot e^{-\frac{t}{2Q_p}}, \]

i.e. the macroscopic electric flux of will oscillate with the frequency, relaxation time in this case is determined by the equation

\[ \tau = \frac{2Q_p}{\omega_p}. \]
If resonator is excited by strange currents, then this resonator presents band-pass filter with the resonance frequency to equal plasma frequency and the pass band

\[ \Delta \omega = \frac{\omega_p}{2\Theta_p}. \]

Another important practical application of transverse plasma resonance is possibility its use for warming-up and diagnostics of plasma. If the quality of this resonator is great, which can be achieved at moderate concentrations of plasma and its high temperature, then in this resonator can be obtained the high levels of electrical pour on, and it means high energies of charge carriers.

Plasma the resonator examined is not difficult to coordinate with the line of communications. The equivalent resistance of resonator at the point \( \omega = \omega_p \) will be written down

\[ R = \frac{1}{G} \frac{a Q_p}{b \sqrt{\frac{L_k}{\varepsilon_0}}}. \]

if \( b = b_L \), then matching condition they take the form

\[ \frac{a L_k}{b z_0} \frac{\mu_0}{\varepsilon_0} = 1. \]

This one should remember that selected the length of the resonator \( z_0 \) should be from the condition \( z_0 << \frac{\lambda}{\omega} \).

With the creation on the basis of the plasma resonator of different devices can arise the need for the agreement of this resonator with the free space. It is obvious that in this case must be observed the condition

\[ \sqrt{\frac{\mu_0}{\varepsilon_0}} = \frac{a Q_p}{b z_0} \sqrt{\frac{L_k}{\varepsilon_0}} \]

or

\[ \frac{a Q_p}{b z_0} \sqrt{\frac{L_k}{\mu_0}} = 1. \]

Transverse plasma resonance can be used also for the warming-up of plasma and its diagnostics. The effectiveness of warming-up is defined by the fact that the losses in the high-temperature plasma are small, and, therefore, can be achieved the high quality of resonator and as consequence the high values of electrical pour on in the Ger. The resonance indicated can be used for purposes of diagnostics of plasma for density measurement of free charge carriers.

5. Conclusion

It is shown that in the nonmagnetized plasma, besides longitudinal Langmuir resonance, with satisfaction of the specified boundary conditions, can exist the transverse plasma resonance. It is known that with the nuclear explosions the electromagnetic radiation in the very wide frequency band is observed, up to the radio-frequency range. And if the emission in field of light range can be explained by the emission of separate atoms, then emission in the region of radio-frequency band can be caused only by collective processes, which occur in the confined plasma. The use of transverse resonance makes it possible to create resonators and band-pass filters, and also lasers on the collective plasma oscillations. Transverse plasma resonance can be used also for the warming-up of plasma and its diagnostics. Is introduced the concept of magnetoelectrokinetic waves.

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