REFLECTIONLESS PROPAGATION OF ELECTROMAGNETIC WAVES IN INHOMOGENEOUS MAGNETOACTIVE PLASMA WITH SMALL SCALE STRUCTURES

E.S. Merkulov[1]*, N.S. Erokhin*[2]
[1]*I.A. Bunin Elets State University, Elets, Russia;*
[2]*Space Research Institute of RAS, Moscow, Russia*
E-mail: djorj_dyurua@mail.ru

It is considered the exactly solvable model of reflectionless electromagnetic wave propagation through the inhomogeneous magnetoactive plasma containing small scale structures of its density. The spatial profiles of wave vector, wave field amplitude, plasma dielectric permettivity have a local relationship. It is investigated their dependence on problem incoming parameters. It has been shown that under some choice of these parameters the spatial profiles of wave vector, wave field amplitude, plasma dielectric permettivity correspond to the magnetoactive plasma case. It has been shown that the plasma inhomogeneity spatial profiles are sensitive enough to incoming parameters variations.

PACS: 52.35.Mw

INTRODUCTION

There are now actively developing studies of the electromagnetic waves interaction with inhomogeneous media, in particular, the analysis of the ability of reflectionless wave resonant tunneling through the barriers by usage of exactly solvable models. These models allow us to study the wave processes in an environment where approximate methods are unsuitable because there are the small scale inhomogeneities of large amplitude. In addition, these exactly solvable models predict new effects that are of great interest for many practical applications: 1) the large increasing of efficiency of powerful electromagnetic radiation absorption and 2) research on the effectiveness of anti-reflection coatings and absorption ones for the radiowaves, the elaboration of radiothin coatings for antennas, 3) it is of grate interest to search for the optimal distribution of the dielectric constant on the antireflective layer thickness which will provide the minimum of reflectance or strong transmission of electromagnetic signals from the antennas covered with a layer of dense plasma. Moreover these investigations may provide the new methods for high density plasma heating by the electromagnetic waves.

BASIC EQUATIONS AND NUMERICAL CALCULATION RESULTS

Analysis of the interaction of electromagnetic waves with inhomogeneous media is based on the solutions of Helmholtz equation for the electromagnetic wave electric field $E(x,t) = F(x)\cdot\exp(i\omega t)$

$$d^2F/dx^2 + k_0^2\cdot\varepsilon_{ef}(x)\cdot F = 0. \qquad (1)$$

Here $k_0 = \omega/c$ is the vacuum wave number, $\varepsilon_{ef}(x)$ is the effective dielectric permettivity of the inhomogeneous plasma. In the case of plasma without the external magnetuic field $\varepsilon_{ef}(x)$ is determined by the spatial distribution of electron density/ So we have $\varepsilon_{ef}(x) = 1 - (\omega_{pe}/\omega)^2 < 1$, where ω_{pe} is the Langmuir frequency of plasma electrons. For further calculations it is convenient to intoduce the dimensionless spatial variable $\xi = k_0\cdot x$. In [2, 3], the exact solution of equation (1) is sought in the form of quasiclassical expression

$$F(x) = A \exp[i\,\Psi(\xi)]\,[1/p(\xi)]^{1/2},\ d\Psi/d\xi = p(\xi).$$

The first version of an exactly solvable model is

$$p(\xi) = \alpha / [A + B \sin(2\beta\xi)],\ W(\xi) = 1/[p(\xi)]^{1/2},$$
$$\varepsilon_f(\xi) = \beta^2 + (\alpha^2 - \beta^2)/[A + B \sin(2\beta\xi)]^2,$$

where W is the normalized wave electric field amplitude.

For the case of parameters choice $\alpha > \beta$, $\beta^2 > 1$ we take $\alpha = 1.7$, $\beta = 1.68$ and the parameter A is in the range (1.02…6). For A = 1.02 the graphs of $p(\xi)$, $W(\xi)$ are shown in Fig. 1,a and the graph of the effective dielectric permettivity $\varepsilon_f(\xi)$ is given in Fig. 1,b.

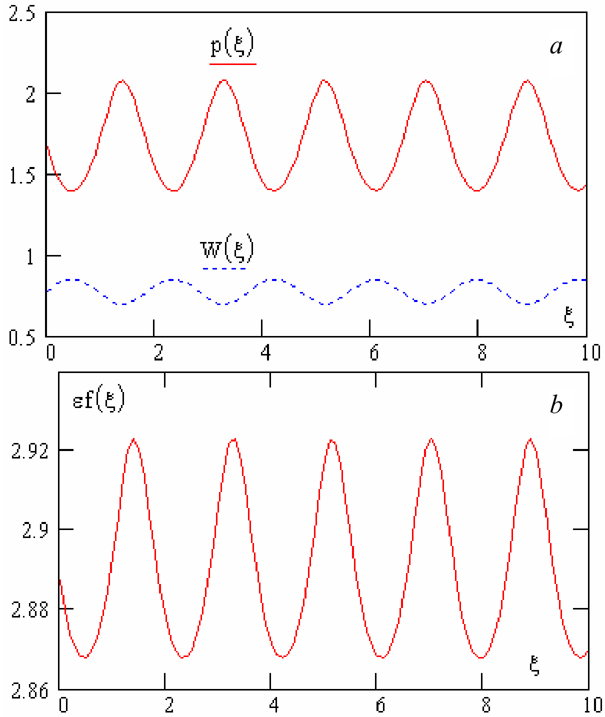

Fig. 1. Plotts of $p(\xi)$ and $W(\xi)$(a); Graph of $\varepsilon_f(\xi)$ (b)

In this case we have max p = 2.076, min p = 1.392, max W = 0.847, min W = 0.694, max $\varepsilon_f(\xi)$ = 2.923, min $\varepsilon_f(\xi)$ = 2.868.

Thus for values of parameter A close to 1 the variations of effective dielectric permettivity $\varepsilon_f(\xi)$ and the normalized amplitude of wave $W(\xi)$ are small but the variation of the dimensionless wave vector is close to 50%.

In another case A = 6 with $\alpha = 1.7$, $\beta = 1.68$ graphs of $p(\xi)$, $W(\xi)$ are presented in Fig. 2,a and the graph of the effective dielectric permettivity $\varepsilon_f(\xi)$ is given by Fig. 2,b.

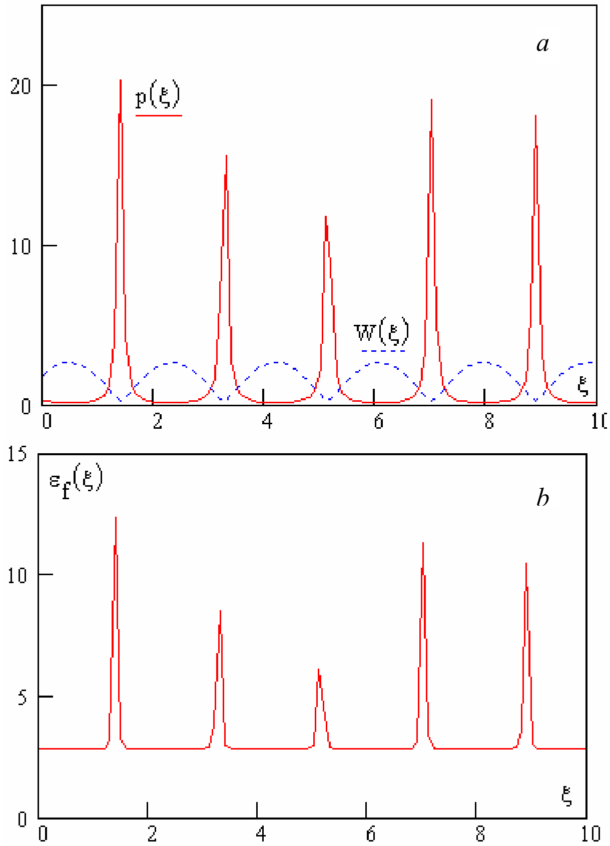

Fig. 2. Plotts of $p(\xi)$ and $W(\xi)$ (a). Graph of $\varepsilon_f(\xi)$ (b)

In this version, we have:

max p = 20.257, min p = 0.143,
max W = 2.648, min W = 0.222,
max $\varepsilon_f(\xi)$ = 12.421, min $\varepsilon_f(\xi)$ = 2.823.

Ratio $W_{max}(\xi)/W_{min}(\xi) = 11.96$, $p_{max}/p_{min} = 141.66$, max $\varepsilon_f(\xi)$/min $\varepsilon_f(\xi)$ = 4.4. Thus in an inhomogeneous plasma the strong splashes are observed like soliton type of both wave vector and the effective dielectric constant in the layers where the plasma parameters are close to those for the upper hybrid resonance.

Note that in the plasma sheet the effective dielectric permettivity is positive. So the opaque (in the classic view) regions are absent. This opaque regions corresponds to the choice of the parameter A corresponding to the case of strongly inhomogeneous magnetized plasma.

Consider the case $0 < \alpha < \beta$ for $\alpha = 1.7$, $\beta = 1.72$ with the values of parameter A are in the following range (1.02…6). In this case we obtain max p = 2.076, min p = 1.392, max W = 0.847, min W = 0.694, max $\varepsilon_f(\xi)$ = 2.913, min $\varepsilon_f(\xi)$ = 2.856. Graphs of $p(\xi)$, $W(\xi)$ are shown in Fig. 3 and the graph of effective dielectric permettivity $\varepsilon_f(\xi)$ is given in Fig. 3,b. As we can see, for small differences in the parameters α, β and if A is close to unity as in the previous case the variation of effective permittivity $\varepsilon_f(\xi)$, the normalized amplitude of wave $W(\xi)$ are small enough but the variation of dimensionless wave vector is close to 49%.

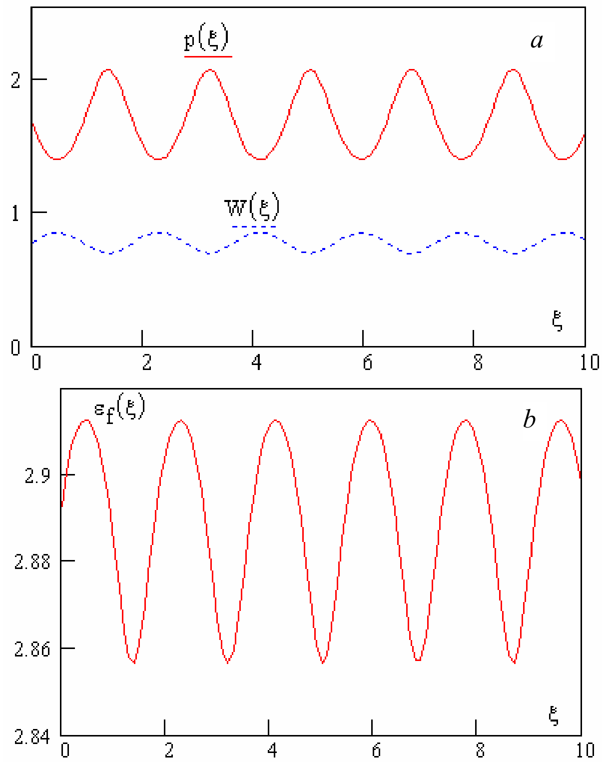

Fig. 3. Plotts of $p(\xi)$ and $W(\xi)$ (a). Graph of $\varepsilon_f(\xi)$ (b)

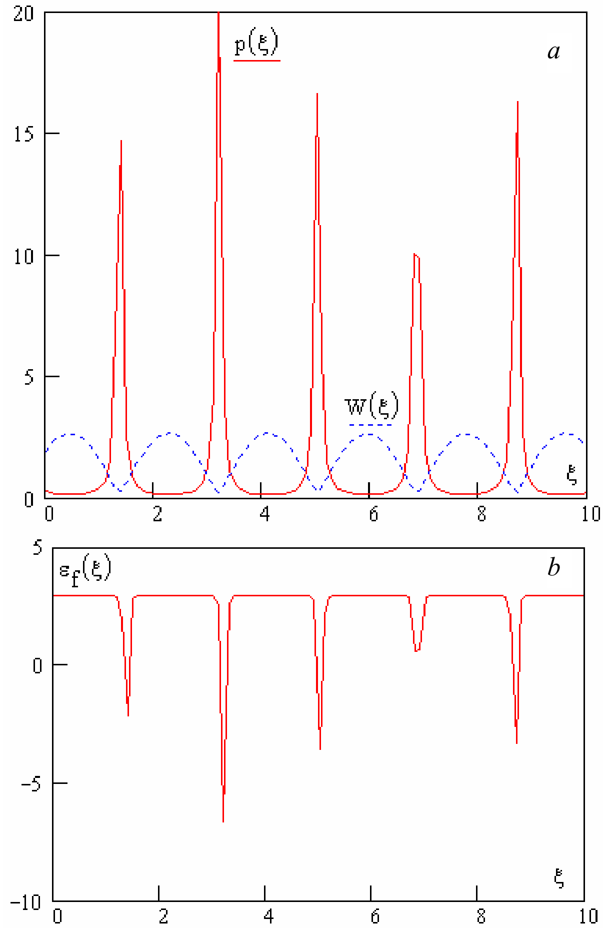

Fig. 4. Plotts of $p(\xi)$ and $W(\xi)$ (a). Graph of $\varepsilon_f(\xi)$ (b)

The increasing of parameter A leads to an increase in wave amplitude and wave vector. If we take A = 6 we obtain max p = 20.257, min p = 0.143, max W = 2.648, min W = 0.222, max $\varepsilon_f(\xi)$ = 2.958, min $\varepsilon_f(\xi)$ = - 6.754. Graphs of $p(\xi)$, $W(\xi)$ are shown in Fig. 4,a and the graph of the effective dielectric constant $\varepsilon_f(\xi)$ is given in Fig. 4,b. When A ≥ 3.4 for the dielectric constant $\varepsilon_f(\xi)$ there are regions of opacity where $\varepsilon_f(\xi) < 0$. This regions correspond to the case of reflectionless propagation of electromagnetic waves in a strongly inhomogeneous magnetized plasma with layers of opacity in which $\varepsilon_f(\xi) < 0$.

CONCLUSIONS

The above performed analysis of reflectionless interaction of electromagnetic wave with a strongly inhomogeneous magnetoactive plasma containing subwavelength structures of large amplitude results to the following conclusions.

On the basis of exactly solvable one-dimensional model the reflectionless interaction of electromagnetic waves with inhomogeneous structures of the wide plasma layer is studied.

In the problem considered there are three independent parameters α, β, A which determine the thickness of heterogeneous sublayers, their number and the depth of modulation of effective dielectric permettivity in the inhomogeneous magnetoactive plasma.

The increasing of parameter A leads to an increase of the amplitude of wave, the wave vector as well as variations in the effective dielectric permettivity. It was revealed that in the case of parameters choice when $0 < \alpha < \beta$ and for $A \geq 3.4$ the opaque regions of inhomogeneous magnetoactive plasma are appearing.

Note also the possibility of generation of soliton wave field splashes during the electromagnetic wave resonance tunneling. Inhomogeneity of the plasma sheet can be quite harsh one on the scale of vacuum wavelength.

The approach developed can be useful for a number of applications, in particular, for the plasma diagnostics and the dense plasma heating by powerful electromagnetic waves.

REFERENCES

1. V.L. Ginzburg, A.A. Rukhadze. *Electromagnetic waves in plasmas*. Moscow: "Nauka". 1970, 207 p.
2. A.B. Shvartsburg. Dispersion of electromagnetic waves in stratified and non-stationary media (exactly solvable models) // *Physics-Uspekhi.* 2000, v. 170, p. 1297.
3. B.A. Lagovskyi. Absorbing and Antireflecting continuously ingomogenous coatings for electromagnetic waves // *Radiotekhnika i Elektronika.* 2006, v. 51, № 1, p. 74-83 (in Russian).
4. N.S. Erokhin, V.E. Zakharov. On nonlinear transillumination of wave barriers for electromagnetic radiation in inhomogeneous plasma // *Doklady Physics*. 2007, v. 52, № 9, p. 332.
5. S.V. Nazarenko, F.C. Newell, V.E. Zakharov. Communication through plasma sheaths via Raman (three waves) scattering process // *Physics of Plasmas*. 1994, v. 1, № 9, p. 2827.
6. A.A. Zharov, A.L. Kotov. About nonlinear according of electromagnetic waves with plane plasma layer // *Fizika Plazmy*. 1984, v. 10, № 3, p. 615 (in Russian).
7. A.N. Kozurev, A.D. Piliya, V.I. Fedorov. Propagation of lowerhybrid finite amplitude waves // *Physics of Plasmas*. 1979, v. 5, p. 322.

Article received 11.04.2013.

БЕЗОТРАЖАТЕЛЬНОЕ РАСПРОСТРАНЕНИЕ ЭЛЕКТРОМАГНИТНЫХ ВОЛН В НЕОДНОРОДНОЙ МАГНИТОАКТИВНОЙ ПЛАЗМЕ С МЕЛКОМАСШТАБНЫМИ СТРУКТУРАМИ

Е.С. Меркулов, Н.С. Ерохин

Рассмотрена точно решаемая модель безотражательного распространения электромагнитной волны в неоднородной магнитоактивной плазме с мелкомасштабными структурами плотности. В модели пространственные профили волнового вектора, амплитуды волны и диэлектрической проницаемости плазмы имеют локальные связи. Исследована их зависимость от исходных параметров задачи. Показано, что при некотором выборе этих параметров пространственные профили волнового вектора, амплитуды волны и диэлектрической проницаемости соответствуют магнитоактивной плазме. Обнаружена существенная чувствительность указанных профилей к вариациям параметров задачи.

БЕЗВІДБИТКОВЕ ПОШИРЕННЯ ЕЛЕКТРОМАГНІТНИХ ХВИЛЬ У НЕОДНОРІДНІЙ МАГНІТОАКТИВНІЙ ПЛАЗМІ З МІЛКОМАСШТАБНИМИ СТРУКТУРАМИ

Є.С. Меркулов, М.С. Єрохін

Розглянута точно розв’язувана модель безвідбиткового поширення електромагнітної хвилі в неоднорідній магнітоактивній плазмі з мілкомасштабними структурами густини. В моделі просторові профілі хвильового вектора, амплітуди хвилі та діелектричної проникності плазми мають локальні зв’язки. Досліджена їх залежність від вихідних параметрів задачі. Показано, що при деякому виборі цих параметрів просторові профілі хвильового вектора, амплітуди хвилі та діелектричної проникності відповідають магнітоактивній плазмі. Виявлена суттєва чутливість указаних профілів до варіацій параметрів задачі.