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

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On the basis of an exactly solvable model of 1D-Helmholtz equation it is considered reflectionless propagation of transverse electromagnetic wave of circular polarization through a chiral inhomogeneous isotropic plasma with small-scale structures of high amplitude. Considered spatial profiles of plasma-dielectric chiral environment characterized by a number of free parameters that determine the characteristic scales of these structures, the spatial profile of the wave vector and wave field, the modulation of the dielectric permettivity etc. The model parameters are corresponding plasma without a magnetic field but with a small addition of chiral component (circular polarization of wave is provided by chirality). Numerical calculations of the spatial profiles for the wave number, the wave amplitude, the dielectric permettivity of chiral plasma have been performed. For some choice of the model parameters the wave number profile corresponds to the increase of the wave amplitude in the center of plasma layer. Variants are possible when the dielectric permettivity in its minimum is negative one and the chiral plasma contains sufficiently broad areas of opacity. Profiles of the dielectric permettivity and the wave vector can be qualitatively similar.

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INTRODUCTION

Study of exactly solvable models of the electromagnetic waves interaction with inhomogeneous and nonstationary environments is of interest for many applications, for example, to increase the effectiveness of antireflection coatings and absorption one in the radioranfe frequencies, radio-fairing design for antennas, to explain the mechanism of radiation escape from sources in astrophysics and in the search for the optimal distribution of dielectric permettivity which may privide the effective transfer of electromagnetic signals through layers of dense plasma (the trans-illumination of wave barriers).

In essence, it is the effect of resonant tunneling of electromagnetic waves through a structured environment which may includes layers of plasma opacity. In other words, in this case there is a coordination characteristics of the electromagnetic wave and the inhomogeneous plasma layer.

We present the results of research on the exact linear solution describing the reflectionless transmission of electromagnetic waves through a chiral isotropic plasma with small-scale structures of high amplitude. The analysis of the spatial profiles of the wave number, the normalized amplitude of the wave and the dielectric permettivity of the plasma, depending on the initial parameters of an exactly solvable model.

THE MODEL BASIC EQUATIONS AND NUMERICAL CALCULATION RESULTS

To facilitate further analysis, we introduce now the dimensionless coordinate along the direction of electromagnetic wave propagation $\xi = \omega x/c$, the wave vector $p(\xi) = c\,k(x) / \omega$ and the normalized amplitude of the electric field of the wave $W(\xi) = 1/[p(\xi)]^{1/2}$. The solution for the wave field having a frequency ω is sought as

$$E(x,t) = F(x) \exp(i\,\omega\,t),$$

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

According to the Helmholtz equation in an exactly solvable model should be the following relation between the wave vector and the dielectric permettivity of plasma

$$\varepsilon(\xi) = [p(\xi)]^2 - [p(\xi)]^{1/2}\, d^2\, \{[1/p(\xi)]^{1/2}\}/ d\xi^2.$$

In our exactly solvable model of the wave vector is defined by $p(\xi) = \alpha/[A + B \sin(2\,\beta\,\xi)]$, where α, β, $B = (A^2 - 1)^{1/2}$, $A > 1$ are parameters of the problem. Then, from the Helmholtz equation, we obtain an expression for the dielectric permettivity of the plasma:

$$\varepsilon(\xi) = \beta^2 + (\alpha^2 - \beta^2)/[A + B \sin(2\,\beta\,\xi)]^2.$$

Here we consider the choices of initial parameters of the problem where $\varepsilon(\xi) <1$ corresponding to a plasma without a external magnetic field but with a small addition of chiral (the circular polarization of electromagnetic waves provide by the chirality).

For the case $\alpha < \beta$ we have

$$\min \varepsilon(\xi) = \beta^2 + (\alpha^2 - \beta^2)\cdot(A + B)^2,$$

$$\max \varepsilon(\xi) = \beta^2 + (\alpha^2 - \beta^2)/(A + B)^2.$$

Consequently, the condition $\max \varepsilon(\xi)< 1$ with $\beta <1$ automatically for all $A > 1$. If $\beta > 1$, then there is a restriction on the following type of the parameter A $(A + B)^2 < (\beta^2 - \alpha^2)/(\beta^2 - 1)$.

If $\alpha > \beta$ we have

$$\min \varepsilon(\xi) = \beta^2 + (\alpha^2 - \beta^2)\cdot(A - B)^2,$$

$$\max \varepsilon(\xi) = \beta^2 + (\alpha^2 - \beta^2)\cdot(A + B)^2.$$

This shows that the $\max \varepsilon(\xi) < 1$ if the following conditions on the parameters are fulfilled

$$(A + B)^2 < (1 - \beta^2)/(\alpha^2 - \beta^2),\ \beta^2 < \alpha^2 < 1.$$

The graphs $W(\xi)$, $p(\xi)$, $\varepsilon(\xi)$ for case $\alpha < \beta$ if condition $(A + B)^2 < (\beta^2 - \alpha^2)/(\beta^2 - 1)$ is fulfilled are shown in Fig. 1 in the case of problem incoming parameters choice $\alpha = 0.7$, $\beta = 0.9$, $A = 3$. As we can see the dielectric permettivity of the plasma is less than one, there are also areas of plasma opacity (the classical pouint of view) where $\varepsilon(\xi) < 0$. A fairly deep modulation wave vector $p(\xi)$ and the normalized amplitude of the wave $W(\xi)$. There are narrow splashes of $p(\xi)$, $\varepsilon(\xi)$ in some subslayers of inhomogeneous plasma.

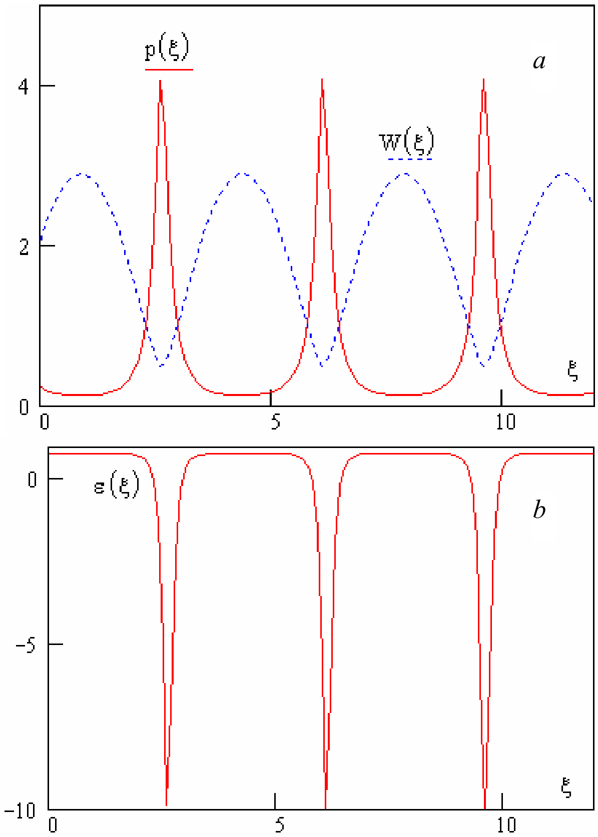

Fig. 1. The graphs of W(ξ), p(ξ)(a). The graph ε (ξ)(b)

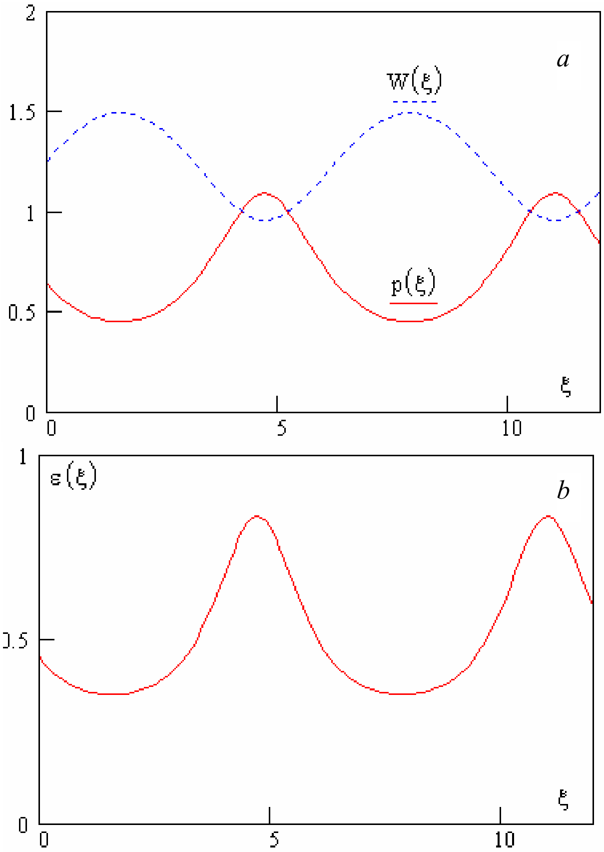

Fig. 2. The graphs of W(ξ), p(ξ)(a). The graph ε(ξ) (b)

The graphs of W(ξ), p(ξ), ε(ξ) for the case $\alpha > \beta$ if the condition $(A + B)^2 < (1 - \beta^2)/(\alpha^2 - \beta^2)$, $\beta^2 < \alpha^2 < 1$ is fulfilled are shown in Fig. 2 in the case of problem parameters choice $\alpha = 0.7$, $\beta = 0.5$, $A = 1.1$. According to Fig. 2, the opacity regions of the inhomogeneous plasma are absent, the modulation of the wave vector is of the order of 69%. The minimum and maximum values of the dielectric permettivity of the plasma are equal to min ε(ξ) = 0.3489, max ε(ξ) = 0.8327.

Similar results are obtained for other choices of the problem incoming parameters.

CONCLUSIONS

The results of the analysis performed can be summarized as the following.

On the basis of an exactly solvable linear model it is investigated the reflectionless transmission of electromagnetic waves through a heterogeneous chiral plasma containing subwavelength structures of large amplitude. The model contains three free parameters which may be changing. So it results to significantly change of the profile of dielectric permettivity of the plasma. It can contain layers of opacity.

Plasma layer width can vary considerably (tens, hundreds, or more times). Nevertheless the reflectionless transmission of electromagnetic waves remains.

Conditions on the problem parameters under which an exactly solvable model describes the chiral plasma in an external magnetic field are obtained.

In our model there is a local ratio of the wave vector and the dielectric permettivity of the plasma. Qualitative profile of the dielectric permettivity ε(ξ) is similar to the profile of the wave vector p(ξ).

The described method of analysis of electromagnetic waves reflectionless propagation through inhomogeneous chiral plasma is of greate interest, in particular, for the task of coordinating the plasma characteristics and the incident electromagnetic wave in a vacuum, which can dramatically improve the efficiency of tunneling of electromagnetic radiation in the layers of plasma resonances with aim of their heating. In addition, it is important also for the transmission of electromagnetic signals from the ground to the ionosphere, for the diagnosis of inhomogeneous plasma, for the correct interpretation of experimental data on the emission spectra of astrophysical objects and the Sun also.

Note that the resonant tunneling of electromagnetic waves through inhomogeneous plasma layers can be studied by taking into account cubic nonlinearity due to the ponderomotive force of electromagnetic radiation pressure. This question will be considered in future work.

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БЕЗОТРАЖАТЕЛЬНОЕ РАСПРОСТРАНЕНИЕ ЭЛЕКТРОМАГНИТНЫХ ВОЛН В НЕОДНОРОДНОЙ ХИРАЛЬНОЙ ПЛАЗМЕ С МЕЛКОМАСШТАБНЫМИ СТРУКТУРАМИ

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На основе точно решаемой модели одномерного уравнения Гельмгольца рассмотрено безотражательное распространение поперечной электромагнитной волны циркулярной поляризации через хиральную неоднородную изотропную плазму с мелкомасштабными структурами высокой амплитуды. Рассмотренные пространственные профили плазмодиэлектрического хирального окружения характеризуются большим числом свободных параметров, что определяют характерные масштабы этих структур, пространственного профиля волнового вектора и поля волны, модуляции диэлектрической проницаемости и т. п. Модельные параметры соответствуют плазме без магнитного поля, но с малой добавкой хиральной компоненты (циркулярная поляризация волны обеспечена хиральностью). Выполнены численные расчеты пространственных профилей волнового вектора, амплитуды волны и диэлектрической проницаемости хиральной плазмы. Для некоторого выбора модельных параметров профиль волнового числа соответствует увеличению амплитуды волны в центре плазменного слоя. Возможны варианты, когда диэлектрическая проницаемость в ее минимуме отрицательна и хиральная плазма содержит достаточно широкие области непрозрачности. Профили диэлектрической проницаемости и волнового вектора могут быть качественно подобными.

БЕЗВІДБИТКОВЕ ПОШИРЕННЯ ЕЛЕКТРОМАГНІТНИХ ХВИЛЬ У НЕОДНОРІДНІЙ ХИРАЛЬНІЙ ПЛАЗМІ З МІЛКОМАСШТАБНИМИ СТРУКТУРАМИ

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Розглянуто на основі точно розв'язуваної моделі одновимірного рівняння Гельмгольца безвідбиткове поширення поперечної електромагнітної хвилі циркулярної поляризації через хиральну неоднорідну ізотропну плазму з мілкомасштабними структурами високої амплітуди. Розглянуті просторові профілі пламоводіелектричного оточення характеризуються великою кількістю вільних параметрів, що визначає характерні масштаби цих структур, просторового профілю хвильового вектора та поля хвилі, модуляції діелектричної проникності та таке інше. Модельні параметри відповідають плазмі без магнітного поля, але з малою додатковою хиральною компонентою (циркулярна поляризація хвилі забезпечена хиральністю). Виконано числові розрахунки просторових профілів хвильового вектора, амплітуди хвилі та діелектричної проникності хиральної плазми. Для деякого вибору модельних параметрів профіль хвильового числа відповідає збільшенню амплітуди хвилі в центрі плазмового шару. Можливі варіанти, коли діелектрична проникність в її мінімумі негативна і хиральна плазма вміщує досить широкі області непрозорості. Профілі діелектричної проникності та хвильового вектора можуть бути якісно подібними.