Photonic Crystal Application for Microwaves Output Induced by the Beam-Plasma Instability in the Absence of Ions

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Abstract: *In this paper we propose the application of photonic crystal structure for amplification of microwave oscillations in relativistic electron beam induced by the beam-plasma instability in the absence of ions. Previously, it has been shown that interaction between the electron beam and charged high-dense electron plasma represents a mechanism for microwaves generation in the range of 18-40 GHz depending on beam current and energy. From this point of viewpoint application of photonic crystal as an output electrodynamical structure seems to be a prospective way to gain the amplitude of longitudinal space-charge waves in the electron beam. So, this study aims at the model development and numerical particle-in-cell simulation of the described microwave system to consider its efficiency gain by means of photonic crystal.*

Keywords: relativistic electron beam; photonic crystal; beam-plasma instability; microwaves.

Introduction

Beam-plasma instability is an important fundamental phenomenon intensively studied both theoretically and experimentally [1,2]. This phenomenon consists in the longitudinal oscillations of space charge and electromagnetic field while the intensive electron beam pierces the drift chamber filled with neutral plasma [3]. The beam-plasma instability finds an application for microwave generation and amplification [4] and beam-plasma discharge excitation techniques [5]. Recently the researchers have considered the beam-plasma instability in the presence of ion background that provided quasi-neutrality of the beam-plasma system and the appearance of the restoring force acting on the disturbed plasma electrons.

In their previous studies, Dubinov and colleagues [6,7] have shown the interesting phenomena – they have observed the excitation of beam-plasma instability in the absence of ions when the intensive electron beam interacts with the additional electron beam performing the squeezed state which acts as a high-dense charged plasma. The last plays role of such a nonlinear active media for development of space-charge oscillations [8,9]. Due to interaction between travelling high-energy electron beam and squeezed state of the additional electron beam it is possible to excite longitudinal space-charge waves under the development of convective beam-plasma instability in the absence of ions. Notable, that the excited space-charge oscillations lie in the higher range of the microwave electromagnetic spectrum (about 18-40 GHz). The problem is that the electromagnetic waves induced by space-charge oscillations are characterized by extremely low amplitudes.

At the same time one of the actively developed areas of modern electronics is related with the research of different artificial metamaterials, namely photonic crystals. Many recent studies both theoretical and experimental show attractive properties of this metamaterial, namely its capacity to concentrate electromagnetic energy and to direct electromagnetic energy flow [10-13]. Such idea to combine classical configurations of different microwave devices with photonic crystal has been stated by Prof V.G. Baryshevsky and his colleagues in their work [14]. Moreover, it has been shown recently that introduction of photonic crystal output structure into the classical construction of axial vircator demonstrates sufficient power increase due to the efficient extraction of microwaves and proper interaction with passing beam [15].

Thus, in this work we suggest a new scheme of microwave device where the induced space-charge oscillations are amplified be means of interaction of electron beam with photonic crystal modes. In the framework of numerical 3D particle-in-cell simulation we have estimated characteristics of output radiation, namely efficiency, power level and frequency properties.

Model and Results

The scheme of proposed microwave device is similar to one described in [6] (Fig.1,a). Here, two hollow electron beams are injected in two-section cylindrical drift space with different chamber radius, divided by metal grid. The inner beam performs the squeezed state and does not leave the first chamber while the outer one travels through the whole drift space. Interaction between these beams in the first chamber leads to the development of beam-plasma instability which appears in excitation of small-amplitude longitudinal space-charge waves. While the outer beam leaves the first chamber and pieces photonic crystal structure, located in the second chamber these small-amplitude waves become amplified under interaction with eigenmodes of photonic crystal (Fig.1,b).

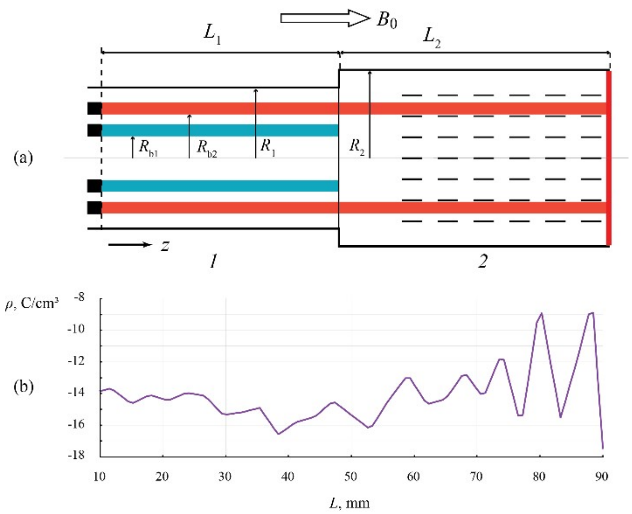

Figure 1. (a) The sketch of the suggested microwave device scheme; (b) Dependency of space-charge density on longitudinal coordinate *z*

One can see that the presence of photonic crystal positively affects the space-charge oscillations. The described approach on excitation and amplification of electron beam oscillations could be considered as a promising way to generate electromagnetic signal in the upper range of microwave spectrum.

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