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Laboratory modelling of microwave bursts in the inner magnetosphere of the Earth

S. Golubev, D. Mansfeld and M. Viktorov
Institute of Applied Physics of Russian Academy of Sciences, Nizhny Novgorod, Russia (gol@appl.sci-nnov.ru / Fax: +7-831-4366086)

Abstract

In the present paper we discuss the use of a mirror-confined plasma of the electron cyclotron resonance (ECR) discharge for modeling of burst processes in the inner magnetosphere of the Earth associated with the implementation of the plasma cyclotron maser. Heating under the ECR conditions allows to create two-component plasma which is typical for the inner magnetosphere of the Earth. We investigate the regime of cyclotron maser, which is realized in the absence of a permanent source of nonequilibrium particles in a decaying plasma.

1. Introduction

Interaction of electromagnetic waves and charged particles under the electron cyclotron resonance (ECR) conditions is the base of many phenomena observed in space and laboratory plasmas. The most interesting demonstration of such interaction is the generation of bursts of stimulated electromagnetic radiation by "superthermal" particles of nonequilibrium magnetized plasma due to the development of the cyclotron instabilities. So, cyclotron instability of whistler waves is implemented in the magnetic flux tubes (for example, in the Earth's magnetosphere) filled with a dense cold plasma containing a small addition of energetic electrons with anisotropic distribution function. As a result of the instability development resonant particles give energy to the waves then fall into the loss cone in the velocity space and leave the magnetic trap [3]. These processes determine the energetic particles population of radiation belts of the Earth and planets, explain the origin of powerful choral ELF-VLF emissions in the Earth's magnetosphere. The other type of instabilities is observed in a rarefied plasma ($\omega_{pe} < \omega_{ce}$) when the density of hot plasma component is comparable or even greater than the density of cold plasma [2, 4]. Under these conditions electromagnetic waves at frequencies close to the electron cyclotron frequency are effectively excited in a direction nearly perpendicular to the ambient magnetic field. Apparently, intense bursts of auroral kilometric radiation of the Earth (frequencies from 50 to 600 kHz) and decameter radio emission in the magnetosphere of the Jupiter (frequencies from 3 to 30 MHz) are generated under such conditions [1, 5]. The present paper is devoted to the laboratory modeling of such instabilities.

2. Experimental results

The experiments were conducted in a decaying plasma of the ECR discharge sustained by powerful millimeter-wave gyrotron radiation (frequency 37.5 GHz, power 100 kW, pulse duration up to 1 ms) under the ECR conditions in the magnetic mirror trap. Heating under the ECR conditions allows to create two-component plasma which is typical for the inner magnetosphere of the Earth. In out experiments we can create plasma containing cold dense component (N_e, T_e) with an isotropic velocity distribution, and less dense component of hot electrons (N_h, T_h) with anisotropic distribution function (with a predominance of the transversal to the magnetic field momentum as compared to the longitudinal one). Parameters of the initial plasma were $N_e \sim 10^{13}\,\text{cm}^{-3}$, $N_h \sim 5 \cdot 10^{10}\,\text{cm}^{-3}$, $T_e \sim 300\,\text{eV}$, $T_h \geq 10\,\text{keV}$. During the plasma decay after ECR heating switch-off when the plasma density becomes low enough, so that the electron plasma frequency is much less than the electron cyclotron frequency, the development of cyclotron instabilities is possible. In such plasma, instability development is determined by the substantial difference in the lifetimes of the trapped hot and cold plasma components. Density of the cold plasma component decreases rapidly after the ECR heating switch-off, thus creating conditions for the excitation of waves propagating across the magnetic field.

In the experiments we studied the dynamic spectrum and the intensity of stimulated electromagnetic radiation from the plasma with the use of broadband horn antenna with a uniform bandwidth in the range from 2 to 20 GHz and the oscilloscope Tektronix MSO72004C (analog bandwidth 20 GHz, time resolution 10 ps). Using a pin-diode detector we measured precipitations of energetic ($\geq$ 10 keV) electrons from the trap ends with time resolution $\sim$ 1 ns.

After ECR heating switch-off with a delay of $\sim$ 500 μs the instability was detected as series of quasi-periodic broadband pulses of electromagnetic radiation in a direction perpendicular to the ambient magnetic field and synchronous precipitations of energetic electrons from the trap. In Fig.1 typical signals of hot electrons current (a), electric field of the excited wave (b), and its dynamic spectrum (c) are shown.

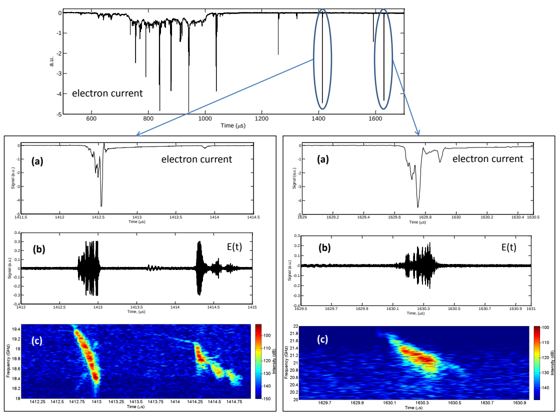

Figure 1: Typical signals of (a) hot electrons current, (b) electric field of the excited wave and (c) its dynamic spectrum. ECR heating is on at zero time and switched-off at 1 ms.

3. Summary and Conclusions

The generation of bursts of electromagnetic radiation can be associated with the explosive development of the cyclotron instability of the extraordinary wave at the fundamental electron cyclotron harmonic as a result of the resonant interaction of the electrons with the extraordinary wave propagating in a rarefied plasma in the direction perpendicular to the ambient magnetic field. We have to note that in a dense plasma, immediately after the ECR heating switch-off, cyclotron instability of these modes do not develop (up to $\sim$ 500 μs) because of the depression of cyclotron radiation [6]. Self-consistent nonlinear model of the plasma cyclotron maser explained all the characteristic features of the behavior of nonequilibrium plasma.

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