THE INTERACTION BETWEEN BROADBAND ELECTROMAGNETIC OSCILLATIONS AND PLASMA

I.K. Tarasov

National Science Center “Kharkov Institute of Physics and Technology”,
61108 Kharkov, Ukraine, E-mail: itarasov@ipp.kharkov.ua

The interaction between plasma and HF oscillations in a broad frequency range is studied. To introduce the HF power into plasma an active antenna array was used. This allowed varying the phase velocity of the wave disturbed in plasma by the lead-in system in a wide spectrum of values.

Obtained results may be used to develop new effective methods of plasma heating, drag currents creation, plasma acceleration, plasma flow controlling and instabilities suppression.

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INTRODUCTION

The results of our experimental study are based on the technical solution described earlier [1]. Commonly it is clear that a charged particle during its motion along the magnetic field axis interacts with the wave field in two ways depending on particle velocity and magnetic field intensity.

The first way represents a Cherenkov resonance between the wave and the charged particle. It takes place when the particle velocity is equal to the wave phase velocity $V_\varphi = \omega/k$. Here ω is the wave frequency and k is the wave number [2, 3].

Other way is a cyclotron resonance. This type of wave-particle interaction is usually observed when the wave frequency in the reference frame concerned with the moving particle is equal to ω_B or $n\omega_B$. Where $\omega_B = eB/mc$ is an electron cyclotron frequency and $n = 1,2,\ldots$ is an integer value, m and e are the electron mass and charge respectively and c is a speed of light. The energy transmission speed depends on two factors: the number of resonant particles and the width of resonance band in the space of phase velocities of the waves excited in plasma [4].

The system of a broadband spectrum HF-wave excitation and introduction into plasma volume allows us to generate oscillations with the frequency band and variation range dependent on the driver oscillator signal parameters. The oscillation phases at different exciters were also controlled [5, 6].

EXPERIMENTAL SETUP

The interaction between the wave and the particle was studied using the experimental setup (Fig.1) which represented a vacuum chamber placed into a longitudinal magnetic field. The field intensity was varying from 100 to 2000 Oe. Its longitudinal distribution represented the configuration of mirror trap with the corresponding mirror ratio 1/4.

The pressure in the chamber was held in the range between 10^{-4} and 10^{-6} Torr. The study was provided at a different working gases (H, He, N, Ar). The phase array was placed in the central area of the vacuum chamber. It was used as a source of the broadband electromagnetic oscillations. The plasma was created by coaxial HF-source placed at the one of the drift tube ends. The plasma was obtained by introducing of HF-power at the electron-cyclotron frequency into the working gas volume. The source was powered by 600W magnetron which worked continuously at the frequency $f = 2.45$ GHz. The density of created plasma was n = 2 – 5×10^{10} cm^{-3} and the temperature T= 20 eV. The diameter of the plasma column cross-section was D = 8 cm and the length was L = 150 cm.

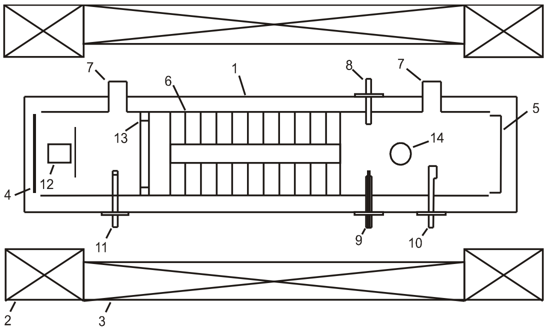

Fig.1. Schematic of the experimental setup: 1- vacuum chamber, 2,3 – magnetic field coils, 4 – collector, 5 – plasma source, 6 – drift tube, 7 – vacuum pumping, 8,11 – Langmuir probes, 9 – magnetic probe, 10,12 – electrostatic analyzers, 13 – Rogovsky coil, 14 – mobile electrostatic probes

A number of HF-field and plasma diagnostics were used. Two electromagnetic probes of different length were placed on a mobile carriage for measuring the HF-oscillations distribution along the magnetic field axis. Two double probes were located at the lateral windows of the vacuum chamber.

RESULTS AND DISCUSSION

HF-oscillations were excited in the active phased array which was driven by the signals of different forms. The spectra of the electromagnetic waves energy absorption in the plasma obtained from different working gases is shown on Fig.2. The comparative analysis of the own spectrum of the phased array and the spectra obtained in presence of plasma was provided. An average frequencies of the energy absorption bands corresponded to the ion cyclotron frequencies for a current working gas. As it is shown on Fig.2, the energy absorption takes place in a wide frequency ranges.

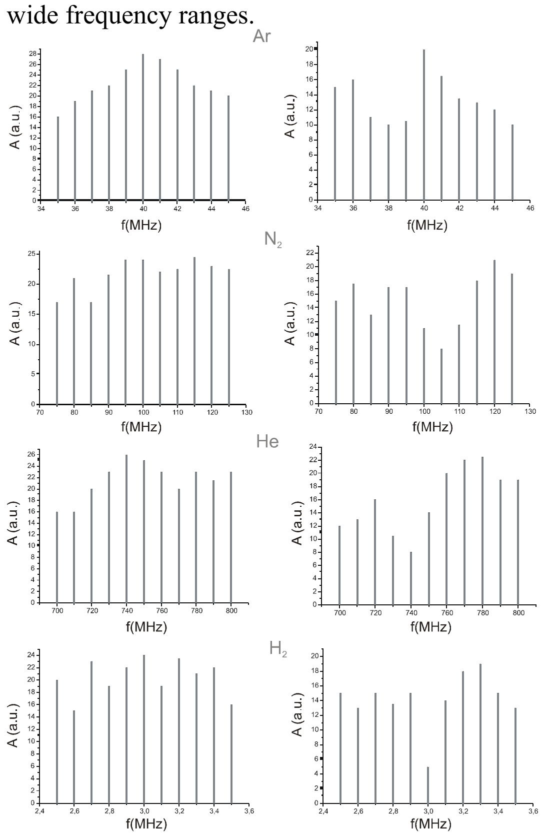

Fig.2. Absorption spectra for different working gases. At the left side - the spectra without a working gas. At the right - the spectra obtained in presence of the working gas

During the pulse excitation of broadband oscillations spectrum the currents of ions and electrons were measured (Fig.3). The plasma density was also obtained together with signals from the magnetic probe.

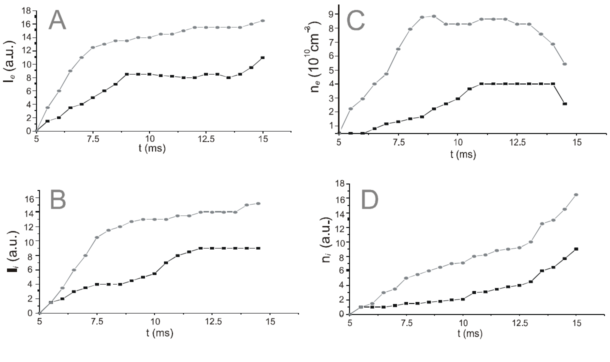

Fig. 3. Temporal dependencies of electron current (A), ion current (B), electron density (C), ion density (D) for broad (gray line, circles) and narrow (black line, rectangles) spectra of the introduced oscillations

The introduction of HF-power in the plasma generated a corresponding response. The observations of such response at both narrow and wide HF spectra with the same values of introduced power were made (Fig.4) the measurements of plasma density, temperature and integrated luminescence together with X-ray output are presented.

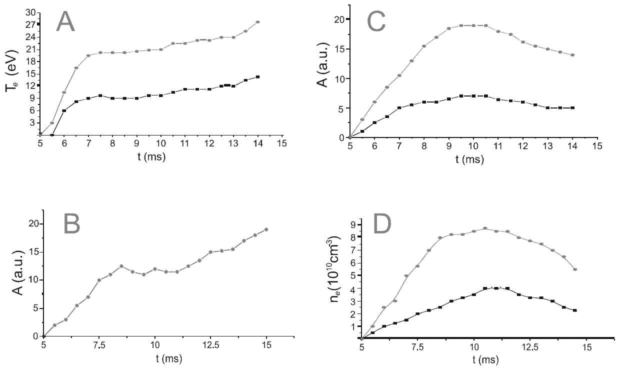

Fig.4. Temporal dependencies of electron temperature (A), x-ray output (B), integral luminescence (C), electron density (D) for broad and narrow spectra of the introduced waves

A couple of oscillograms, presented on Fig.5, demonstrate the possibility of using the active phased array for creating a running wave in the confined plasma. The phase velocity of such running wave was determined by switching on of separate oscillators along the array. The collector current on was dependent on the running wave phase velocity (Fig.5).

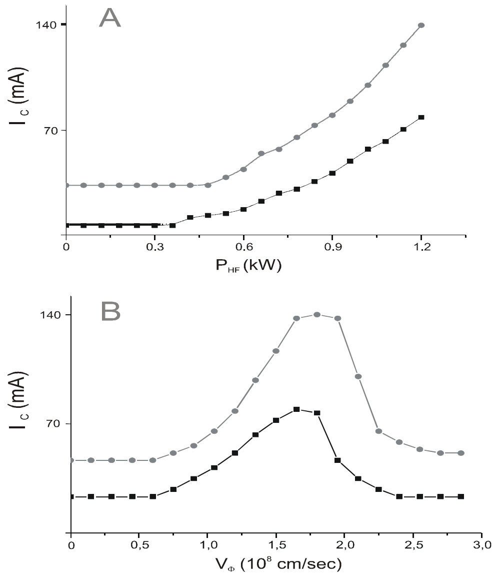

Fig.5. The dependence of the collector current on the introduced power and phase velocity for both broad (gray line, circles) and narrow (black line, rectangles) spectra of the introduced oscillations

Fig.6 demonstrates the dynamics of the plasma ions velocity distribution. Here we consider the escaping the trap in a transverse direction. When the frequency band was ~10% of the carrier frequency value the form of the velocity distribution was changing. The location of observed deformation was different depending on the average frequency.

At low frequencies the left side of the velocity distribution exhibited a peculiarity. As the frequency was growing the deformation area was shifting to the right side (Fig.6) of the velocity distribution. The deformation character was also different. It may be a plateau, or an additional peak, or oscillatory perturbations.

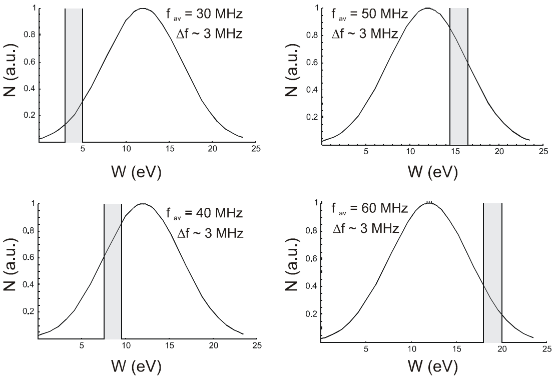

Fig.6. The groups of interacting ions for different average frequencies (the spectrum width ~ 3 MHz)

CONCLUSIONS

The using of the active phased array in a broadband frequency range near the ion cyclotron frequency allows to generate a broadband oscillations in plasma.

An interaction between the plasma and the broadband oscillations permits to affect on the working gas (or mixture of gases).

A comparative analysis of the oscillograms reflecting the dynamics of electron temperature, density, integral luminescence, x-ray radiation of plasma allows to conclude that HF-power with a broad oscillation spectrum introduced into plasma affects on it effectively than those with narrow spectrum.

The frequency range variation provides an interaction between the groups of particles with different velocities. This allows to use the broadband HF-power introduction for heating and cooling of plasma.

Finally an opportunity of the current generation was demonstrated. The current was generated in plasma in the running wave mode.

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ВЗАИМОДЕЙСТВИЕ ШИРОКОПОЛОСНЫХ ЭЛЕКТРОМАГНИТНЫХ КОЛЕБАНИЙ С ПЛАЗМОЙ

И.К. Тарасов

Изучается взаимодействие плазмы с высокочастотными колебаниями в широком диапазоне частот. Для введения высокочастотной мощности в плазму использовалась активная антенная решетка. Это позволило варьировать фазовую скорость и частоту волны, возбуждаемой в плазме, в широком диапазоне величин.

Полученные результаты могут быть использованы для разработки новых эффективных методов нагрева плазмы, создания токов увлечения, контролирования плазменных потоков и подавления неустойчивостей.

ВЗАЄМОДІЯ ШИРОКОСМУЖНИХ ЕЛЕКТРОМАГНІТНИХ КОЛИВАНЬ ІЗ ПЛАЗМОЮ

І.К. Тарасов

Вивчається взаємодія плазми із високочастотними коливаннями у широкому діапазоні частот. Для введення високочастотної потужності у плазму використовувалась активна антенна решітка. Це дозволило змінювати фазову швидкість і частоту хвилі, яка збуджується у плазмі, у широкому діапазоні величин.

Отримані результати можуть бути використані для розробки нових ефективних методів нагріву плазми, створення токів захоплення, контролювання плазмових потоків і придушення нестійкостей.