J. Plasma Fusion Res. SERIES, Vol. 2 (1999) 385–388

Some Aspects of Strong Langmuir Turbulence Driven by an Intense Relativistic Electron Beam

MASUZAKI Masaru, ANDO Ritoku, YOSHIDA Hiroshi, OOYAMA Shintarou, TANIGUCHI Shingo,
NITTA Mituhiro, NATSUME Ken-ichi, KAMADA Keiichi and KONDO Tomohiro
Department of Physics, Faculty of Science, Kanazawa University, Kanazawa 920-1192, Japan

(Received: 9 December 1998 / Accepted: 23 March 1999)

Abstract

Caviton fields driven by an intense relativistic electron beam (IREB) were probed with a weak low-energy electron beam. From spectra of high-power microwave radiation from beam electrons interacting with caviton fields it was found that the injected beam was modulated and the bunch length was about 5 mm. Relation among the turbulence, the radiation, the beam modulation, and the ratio of the beam density to the plasma density was studied.

Keywords:

strong Langmuir turbulence, intense relativistic electron beam, electron beam probing, high-power broadband microwave radiation, beam modulation

1. Introduction

Recently the strong Langmuir turbulence has attracted much attention theoretically, computationally and experimentally. In this state formation, collapse and burnout of cavitons, spatially localized lower-density volumes with large amplitude electrostatic waves trapped, are repeated by the nucleation process. This turbulence state can be driven by an intense relativistic electron beam (IREB) [1].

We have been carrying out experiments on the beam-driven strong Langmuir turbulence by injecting an IREB into an unmagnetized plasma. Previously we measured strong high frequency turbulent electrostatic fields using two optical diagnostic techniques; the Stark shift measurement and the plasma satellite method [2]. The former showed that strong fields of 50kV/cm or more with Gaussian distribution existed in the plasma, and that the dimensionless electrostatic energy density $W \sim 1.1$. From this result it was concluded that the plasma was in a strong Langmuir turbulence state. From the latter mean electric field in the plasma was obtained. From electric fields obtained from both methods, the strong field regions were found to occupy a few percent of the beam volume. The final scale of cavitons was estimated to be ~ 20 λ_D, λ_D being the Debye length. The plasma remained in the turbulence state about 30times of the IREB duration (~ 900ns) or longer after the IREB passed through the plasma.

We also observed energy spread and perpendicular velocity scattering of beam electrons due to interaction with caviton fields [3]. The measured results were analyzed using the theory of multidimensional transit-time interaction given by P.A. Robinson and D.L. Newman [4] and it was confirmed again that the plasma was in a strong Langmuir turbulence state.

High-power broadband microwave radiation was observed, too. The radiation was found to be from beam electrons interacting with the caviton fields [5,6]. The strong Langmuir turbulence state was a necessary condition, but not the sufficient one [7]. The radiation was emitted when the ratio of the beam density to the

---

Corresponding author's e-mail: masuzaki@plasma.s.kanazawa-u.ac.jp

plasma density, n_b/n_p, was between about 0.001 and 0.1 and it was strongest at about 0.01 [8].

This paper reports an attempt to measure strong turbulence electric fields using a weak probe electron beam, relation between high-power broadband microwave radiation and beam modulation, and relation among the strong Langmuir turbulence, microwave radiation, the IREB modulation, and ratio of the beam density to the plasma density, n_b/n_p.

2. Plasma and IREB

Figure 1 shows the experimental setup (for the observation of the microwave radiation). An unmagnetized plasma was produced in a stainless steel chamber of 16cm in diameter by discharging a pair of rail-type plasma guns set opposite to each other at z = 8.5cm, z being the distance from the anode of the IREB diode. Figure 2 shows n_p at z = 17.5cm as a function of τ, which is the delay time from the beginning of the gun discharge. An IREB, which was generated with a source capable of producing a pulse of 1.5MV, 30kA, and 30ns into a matched load, was injected through an anode of 20 μm thick titanium foil into the plasma at a selected τ. The injected IREB current was about 10kA and the energy of the beam electrons was 1.4MeV. The plasma diameter was typically 8cm and that of the IREB was typically 3cm. The chamber had two observation port at z = 17.5cm, and its inner wall was covered with an electromagnetic-wave absorber, Eccosorb AN.

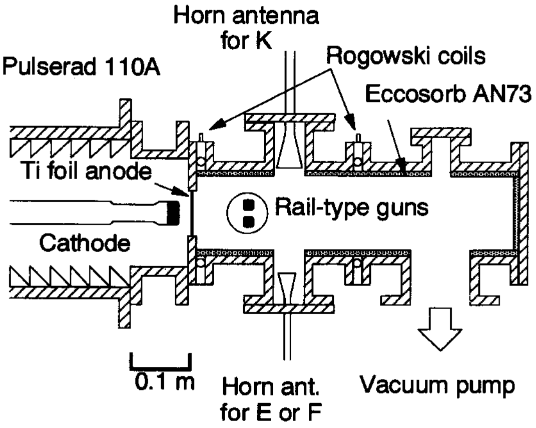

Fig. 1 Experimental set up (for radiation measurement).

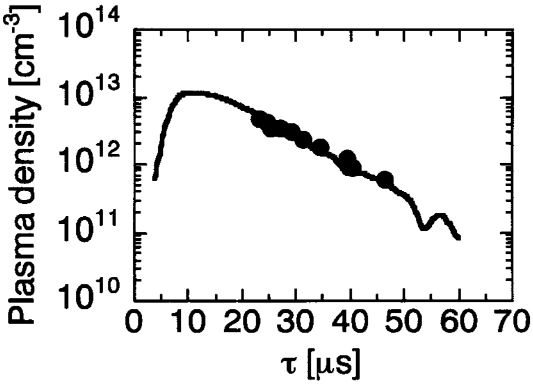

Fig. 2 The plasma density at z = 17.5cm as a function of τ.

3. Weak Beam Probing into Caviton Fields

In order to investigate further the strong Langmuir turbulence state after the IREB passed through the plasma, we began an attempt to study strong turbulence electric fields by measuring scattering of a weak low-energy electron beam (probe beam) injected across the plasma. Rough estimation is done on the scattering angle of the probe beam due to caviton fields. It is based on the data obtained in a previous experiment [2] that the strong field regions occupy a few percent of the plasma-beam volume and that the typical field strength is 50kV/cm. The deflection angle is estimated to be from –3.3 to 3.3 deg. for probe beam energy of 50keV.

Figure 3 shows the experimental setup. A probe beam (50kV, ~ 50mA, 150ns) produced using an electron gun was injected across the plasma at z = 30.5cm. Beam pattern on an observation fluorescent screen was photographed. Figure 4 shows the beam patterns observed when $n_p \sim 1.0 \times 10^{-10}$cm^{-3} at z = 30.5cm. The figure in each pattern is the delay time of the probe beam injection from the injection time of the

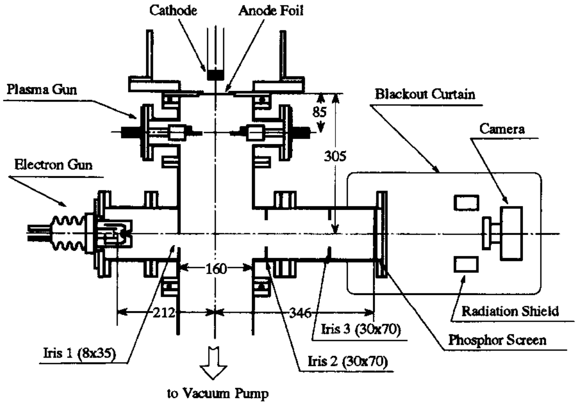

Fig. 3 The experimental set up for weak beam probing.

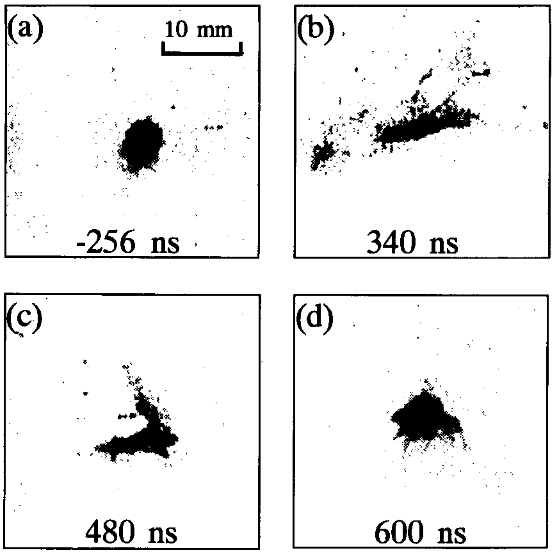

Fig. 4 Photographs of probe beam patterns on the observation fluorescent screen.

IREB. Scattering is seen even about 600ns after the IREB passed through the plasma. This experimental result supports the previously obtained conclusion that the plasma remained in a strong Langmuir turbulence state after the IREB passed through the plasma [2]. In this state the background incoherent waves may be energy reservoir for caviton formation. Further study is needed to clarify this point.

4. Microwave Radiation and Beam Modulation

We observed radiation spectra radially (Fig.1) using a 3-ch. filter-bank spectrometer, a 5-ch. heterodyne spectrometer, and a 3-ch. filter-waveguide-combination spectrometer. These spectrometers covered frequency range of 18–140GHz. Frequency range and center frequency of each channel are given in Table 1. Typical spectrum is shown in Fig. 5. It is nearly flat or slightly increasing with frequency up to about 40GHz and declines steeply at the higher frequency side. The radiation was relativistically beamed with an angle of about 10° to the chamber axis (the detail will be published elsewhere). This angle agrees roughly with the angle of 7° for the radiation from a single beam electron interacting with the caviton field, calculated under the assumption that the caviton field is of dipole type and the dipole moment is parallel to the beam direction [9]. The radiation spectrum of a single beam electron interacting with caviton field extends to the angular frequency $\omega = 2\gamma^2 c/D$, where γ is the relativistic factor, c is light speed, and D is the caviton size [9]. For high-power radiation the IREB should be modulated [10]. As shown in the Fig. 5 (a), we fit to the observed spectrum a curve calculated using the radiation spectrum of a single beam electron interacting with cavitons having parallel dipole moment and assuming Gaussian spectral function for the beam modulation. Here we assumed that the phase velocities of waves equal the beam velocity. From this spectral function the symmetric spatial beam distribution of Gaussian shape is obtained as shown in Fig. 5 (b). The bunch length is estimated to be 5mm. This value coincides roughly with the wavelength of the beam-plasma instability which is believed to be the origin of the turbulence.

Table 1 Center Frequency and band width of each channel.

Band	Freqency range [GHz]	Center frequency [GHz]
K	18-26.5	22.25
Ka	26.5 - 40	33.25
U	40 - 60	50
E-1	68 - 72.2	70.1
E-2	72.2 - 76.5	74.35
E-3	76.5 - 81	78.75
E-4	80.7 - 85.7	83.2
E-5	85.5 - 90	87.75
F-1	90 - 117 (140)	103.5
F-2	117 - 140	128.5

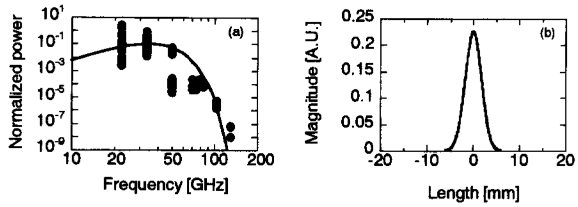

Fig. 5 (a) Typical radiation spectrum with a Gaussian fit curve taking account of a single particle spectrum. (b) The spatial beam distribution from the fitted curve.

5. Turbulence, radiation, IREB modulation, and density ratio

We measured, at z = 30.5cm and varying τ (n_p), the perpendicular velocity scattering as a measure of the turbulence [3], the sum of the radiation power in K, Ka and U bands, and the excited power in a waveguide pickup due to a small portion of the beam traversing

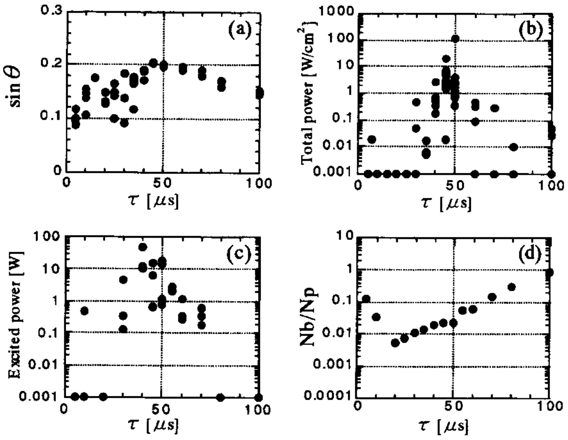

Fig. 6 (a) The weighted mean of sine of the perpendicular scattering angle of IREB electrons, (b) total power of the radiation, (c) power radiated into the waveguide pickup by a small portion of the beam traversing it as a measure of the beam modulation, and (d) n_b/n_p.

across the waveguide (WR-42) as a measure of the beam modulation [11]. The density ratio n_b/n_p was also measured. Figure 6 shows the result. For IREB electrons to emit radiation it is necessary that the plasma is in a strong Langmuir turbulence state, and that the beam is modulated. The radiation was maximized at n_b/n_p around 0.02. One of problems to be solved is mechanism of the beam modulation including its relation to the strong Langmuir turbulence.

6. Concluding Remark

When cavitons burn out the field energies are transferred to plasma electrons and nonthermal high energy tail should appear. Now we are preparing to measure this high energy tail after the IREB passes through the plasma by using a differential electrostatic energy analyzer.

References

[1] P.A. Robinson, Rev. Mod. Phys. **69**, 507 (1997).
[2] M. Yoshikawa, M. Masuzaki and R. Ando, J. Phys. Soc. Jpn. **63**, 3303 (1993).
[3] H. Koguchi, M. Masuzaki, R. Ando and K. Kamada, J. Phys. Soc. Jpn. **67**, 1273 (1998).
[4] P.A. Robinson and D.L. Newman, Phys. Fluids B **2**, 3120 (1990).
[5] M. Masuzaki, R. Ando, A. Yoshimoto, M. Ishikawa, M. Yoshikawa, K. Kitawada, H. Morita and K. Kamada, *Proc. of the 8th Int. Conf. on High-Power Particle Beams*, Novosibirsk: World Scientific, 1991, Vol. 2, p. 683.
[6] M. Masuzaki, R. Ando, M. Yoshikawa, H. Morita, J. Yasuoka and K. Kamada, *Proc. of the 9th Int. Conf. on High-Power Particle Beams*, Washington, DC: NTIS, 1992, Vol. 2, p. 1227.
[7] M. Yoshikawa, M. Masuzaki, R. Ando and K. Kamada, J. Phys. Soc. Jpn. **65**, 2081 (1996).
[8] R. Ando, M. Masuzaki, H. Morita, K. Kobayashi, M. Yoshikawa, H. Koguchi and K, Kamada, J. Phys. Soc. Jpn. **65**, 2518 (1996).
[9] J.C. Weatherall, Phys. Rev. Lett. **60**, 1302 (1988).
[10] G. Benford and J.C. Weatherall, Phys. Fluids B **4**, 4111 (1992).
[11] H. Yoshida, M. Masuzaki, S. Ooyama, R. Ando, and K. Kamada, to be published.