Development of Phosphor Screen Having "Gridded Energy Analyzer" for Two-Fluid Nonneutral Plasma Experiments

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A new type of fluorescent screen with a gridded energy analyzer is proposed. This new method clearly has an advantage of clarifying both space distribution of number density and particle energy simultaneously. The fluorescent screen has three potential grids in front of it. Using the set of grids, the particle energy is analyzed. The preliminary data show that the potential grids have successfully analyzed the energy of the injected electrons. The fluorescent screen seems to emit visible light even after the number of electrons is somewhat reduced by the potential grids.

Keywords: a fluorescent screen, a gridded energy analyzer, particle flux measurement, nonneutral plasma, the Malmberg trap, the Beam Experiment Upgrade

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1. Introduction

The measurement of two-dimensional (2D) distributions of particle flux Γ using a fluorescent screen has been intensively used, and the image data appeared on the screen is usually recorded with a CCD camera that captures the whole image of the 2D distribution of the light emitted from the fluorescent screen. In fact, the method of using the CCD has been applied for the measurement of $\Gamma(x, y)$ of pure electron plasmas in a liner device [1, 2], and recently, the CCD is used for detecting soft x-ray emitted from hot plasmas [3, 4].

Regarding the method of analyzing particle energy of plasmas, on the other hand, the most popular one is so called "Faraday cup" which has been applied in many plasma experiments [5]. In the Faraday cup, a set of metallic meshes is usually contained. And, to the meshes, individual electric potential are externally applied in order to form a potential distribution inside the Faraday cup. Generally, one of the individual potential is variable and used as the retarding potential to analyze the energy of the incident particles.

The above two methods work well. However, there is no report on the instrument which has both functions of the two methods simultaneously. Actually, since the innovative instrument is one of passive methods, it is strongly required to be installed for basic plasma experiments such as the two-fluid plasma experiments planned on the BX-U machine (Beam Experiment Upgrade) [6].

In this contributed paper, we have proposed a new instrument which possesses functions of both the fluorescent screen and the gridded energy analyzer. This new method clearly has an advantage of clarifying both space distribution of number density and particle energy simultaneously. The outline of this paper is as follows: In Sec. 2, the design of the instrument is described. Subsequently, in Sec. 3, a preliminary result from a test experiment is shown. Finally, a summary is given in Sec. 4.

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2. Design of the Proposed Instrument

The proposed instruments is consists of a fluorescent screen and three potential grids. In this chapter, we explain them.

2.1 Fluorescent screen

Fluorescent screen measurements are generally categorized into two groups, according to what type of the emitted light is utilized for plasma diagnostics; one is called as "*the reflection light method*" in which the light reflected from the fluorescent screen is obtained. The other is called as "*the transmitted light method*" in which the transmitted light is observed from the backside of the fluorescent screen. The instrument proposed here is one of transmitted light methods. Thus, obviously, the layer of the fluorescent screen must be thin enough in order to obtain substantial visible light. In experiments on BX-U, the fluorescent screen will be used to observe what the two-dimensional distribution of the measured particle flux (both electrons and ions) is and how it evolves in time. However, the typical value of the particle energy on BX-U is about several 10 eV, which is too small to cause the fluorescent screen emit enough visible light. Therefore, the charged particles must be accelerated before hitting the fluorescent screen. Also, the number of the charged particles must be measured after they hit the phosphor screen. This can be performed with a conductor overlapped to the fluorescent screen through which the charged particles flow outside the instrument.

To meet the above requirement, the fluorescent screen contained in the proposed instrument is made with a phosphor which is precipitated on the surface of a quartz board (the thickness is 1.1 mm.). Also, on the quartz board, an ITO (Indium Tin Oxide) screen is pre-coated. Regarding the phosphor, we have used ZnO: Zn, which emits visible green light having its emission peak at 505 nm. This wavelength is completely different from that of the LaB_6 emitter so that the transmitted light from the fluorescent screen can be easily distinguished with a band pass filter. And finally, to measure the transmitted light, an ICCD camera (DH520-18F01-I) will be installed at the end of the linear device, BX-U.

2.2 Energy analyzer

One of the conventional techniques to analyze the energy of charged particles is to measure the number of them after passing through the potential barrier to which the retarding voltage is externally applied. In the proposed instrument, we adopt this method. Figure 1 illustrates the potential profile along the trajectory of the charged particles in the proposed instrument for two cases. Charged particles are allowed to approach the fluorescent screen only after passing through all of the three grids. For analyzing the energy of electrons, the potential distributes as shown in Fig. 1 (a). In fact, for this case, the first grid is grounded so as to short-circuit the perpendicular electric field to the magnetic field lines, which thus prevents **E**×**B** drift of charged particles. Next, the voltage of the second grid is varied in order to analyze the particle energy. Meanwhile, the third grid is biased strongly positive so as to repel essentially all ions. Another role of this grid is to accelerate the electrons (passing through the second grid) up to several kilovolts. Finally, with the accelerated electrons, the fluorescent screen emits visible light. Because of the symmetry with respect to the particle trajectory, the potential distribution shown in Fig. 1 (b) is in principle adopted for analyzing the energy of ions, on the other hand.

In order to externally apply potential on all of three grids, we use metallic mesh. Because of the Debye shielding, the number of mesh is selected to be narrower than the Debye length λ_D. To satisfy this condition even for the case of high density plasmas, Γ is reduced by the additional metallic mesh having lower transparency. As a result, the corresponding λ_D becomes long enough for applying effective retarding voltages inside the energy analyzer.

Figure 2 shows the schematic drawing of the proposed instrument for the case of analyzing the electron energy (see also Fig. 1 (a)). The distance between the first and the second grids is 5 mm, while 10 mm between all other grids. Also, all grids are insulated each other by being spaced with Teflon rings. Figure 3 shows two different sets of grids; the type of (a) has two metallic meshes (drawn with meshed lines in Fig. 3 (a)) at the both ends of three fine meshes (painted with black color in Fig. 3 (a)). The spacing distance of the metallic mesh is 2.0 mm and the diameter of the wires for the metallic mesh is 0.5 mm. The other role of these metallic meshes is to hold the three fine meshes. Regarding the fine mesh, the spacing distance of it is 0.039 mm and the diameter of the wires used is 0.025 mm. Meanwhile, for the type of (b), only a fine mesh (painted with black color in Fig. 3 (b)) is placed between

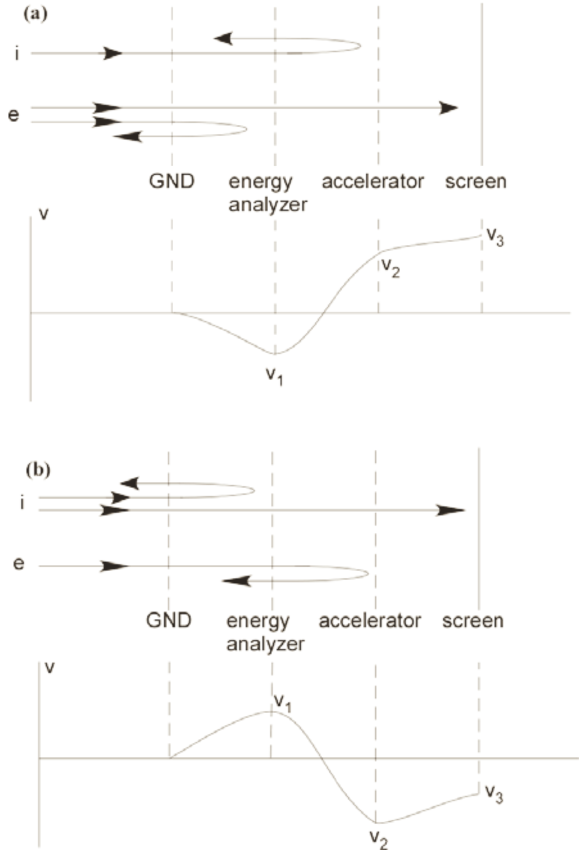

Fig. 1 A schematic drawing of potential distribution along the particle trajectory: (a) for electrons (b) for ions.

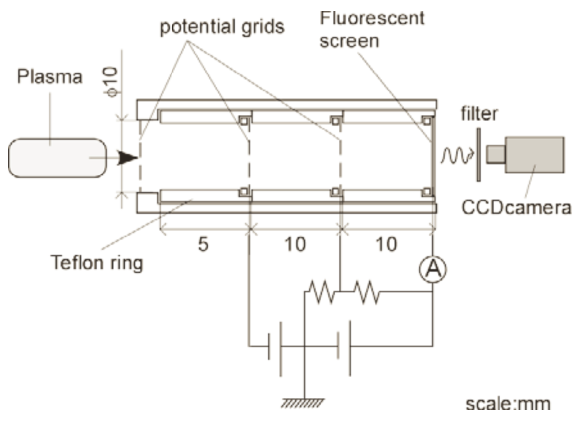

Fig. 2 A schematic drawing of the proposed instrument containing the fluorescent screen and the grided energy analyzer.

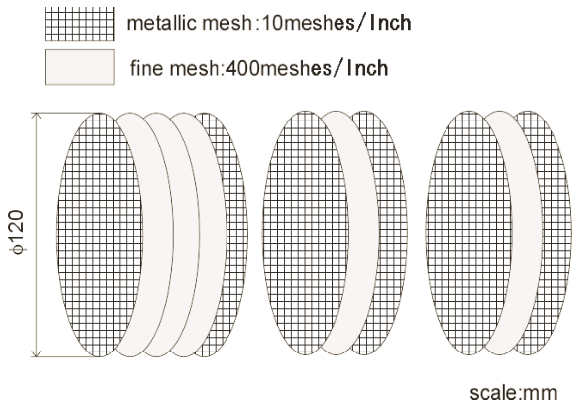

Fig. 3 A schematic drawing of grids; two different sets of grids are used in the grided energy analyzer. All meshs are made of stainless metal (SUS304).

the metallic meshes.

Using the type of (a), the first grid is made. The permeability of the first grid is calculated as

$$\begin{aligned} permeability &= \frac{(spacing)^2}{(spacing + diameter)^2} \times 100 \\ &= \sim 2\,\%. \end{aligned} \tag{1}$$

From the similar calculation, the second- and the third grid have permeability of 15 % and 15 %, respectively. Thus, the total permeability of the three grids results in 0.045 %. On the other hand, the value of λ_D at the second grid (where the particle energy is analyzed) must be larger than 0.039 mm (which is the spacing distance of the mesh). As mentioned above, after passing through the first grid, the particle density n is expected to decrease to 2 % of the initial value of n. Consequently, from the formula of λ_D, the ratio of plasma temperature T to n must satisfy the following relation:

$$\frac{T}{n} \geqslant 5.53 \times 10^{-19}. \tag{2}$$

Therefore, for the case of $T \sim 0.3$ V and $n \sim 10^{13}$ m^{-3}, the value of T/n becomes $\sim 3 \times 10^{-14}$, which certainly satisfies the relation of (2). Thus, this means that the set of the grids using the meshes explained above is expected to work well for analyzing the electron energy.

2.3 Procedure of obtaining absolute $n(x, y)$ from imaging data

Charged particles passing through all grids hit the fluorescent screen. Then, the visible light emitted from the screen transmits toward the end of BX-U. To record the light, an ICCD camera is used. And, from the imaging data taken from the ICCD camera, we will obtain the two-dimensional distribution of n by assuming that the intensity of the visible light is proportional to the number of charged particles. It should be noted here that the obtained $n(x, y)$ is a relative distribution, unless the relation between the visible light and n is examined. In the case of the proposed instrument, this is attained experimentally by measuring the current which flows out through the ITO, as explained before.

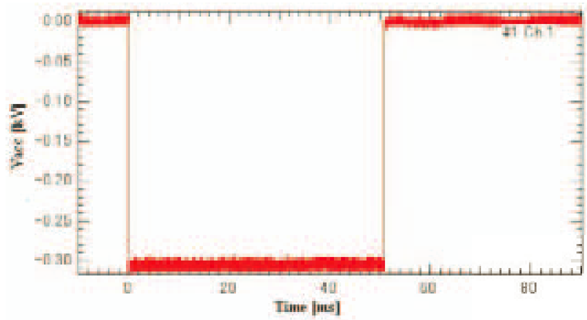

Fig. 4 The time evolution of acceleration voltage applied to the LaB_6 cathode. During the duration time (~50 ms), electrons are emitted from the LaB_6 cathode.

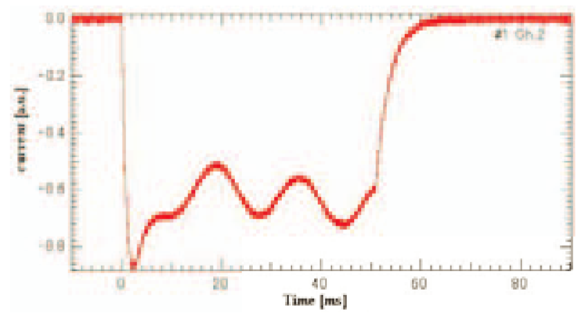

Fig. 5 The time evolution of the current flowing out from the fluorescent screen.

3. Experimental Test of the Energy Analyzer

Since the proposed instrument was completed in November of 2006 except the ICCD camera, we have started the first test of analyzing the electron energy. The thermal electrons are emitted from the LaB6 cathode and accelerated up to −300 V as its maximum. The magnetic field strength of BX-U is variable but being fixed to about 150 G for this experiment. The background pressure is 2.5×10^{-7} Torr. The electron gun is placed off the center axis of BX-U and the emitted electrons are deflected by the externally applied $\boldsymbol{E}$.

Figure 4 shows the time history of V_{acc}; it is energized at $t = 0$ ms and immediately down to −0.3 kV using an FET switch. As also recognized, the duration time of the emitting electrons is about 50 ms for this test experiment. A preliminary data of the current flowing out from the fluorescent screen is described in Fig. 5. Apparent amount of the current can be observed. This means that the electrons can penetrate the fluorescent screen. Using the value of it,

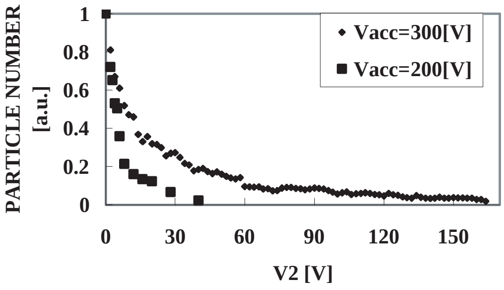

Fig. 6 The total number of electrons hitting the fluorescent screen for $V_{acc} = -300$ V and $V_{acc} = -200$ V.

the particle number of the electrons hitting the fluorescent screen can be calculated. The calculated result is shown in Fig. 6. Since data are measured with changing the retarding voltage V_2 by 4 V in this test experiment, the plotted data are almost continuously connected each other.

As seen from the plotted data in Fig. 6, the number of electrons seems to decrease exponentially with increasing V_2. Regarding the visible light emitted from the fluorescent screen, we have observed it but only by naked eyes. After completing the ICCD setup, the emitted light will be recorded by the ICCD and calibrated with the value of the current flowing out from the fluorescent screen.

4. Summary

A new type of fluorescent screen with the particle energy analyzer is proposed. This new method clearly has an advantage of clarifying both space distribution of number density and particle energy simultaneously. A preliminary data show that the energy analyzer works well. The fluorescent screen emits visible green light with reducing the number of electrons. After completing an ICCD camera, the proposed instrument will be totally tested.

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