CHARGE SEPARATION AND DECELERATION OF HIGH DENSITY PLASMA IN A CUSP TYPE DIRECT ENERGY CONVERTER SIMULATOR

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Concerning an application of a cusp type direct energy converter (CUSPDEC) to high density plasma, subjects on charge separation and deceleration have been experimentally investigated, assuming that previously proposed two-stage deceleration scheme will be employed. As a fundamental measurements on two-stage deceleration scheme, the ions reflected by electric field due to the point cusp ion collector have been successfully detected by a sub-collector as a function of the collector voltage. For efficient charge separation and energy conversion, an introduction of a negatively biased grid has been examined, resulting that the assistance of charge separation to cusp field is effective. By employing the negatively biased grid, direct energy conversion by the point cusp collector also achieved with excluding electrons flowing into the collector.

I. INTRODUCTION

For a fusion plant of open magnetic confinement system, applying direct energy conversion (DEC) is attractive. In the DEC system, particle discrimination process is very essential and a cusp type direct energy converter (CUSPDEC) was proposed as an efficient discriminator in D-^{3}He fusion reactor[1]. Electrons flowing into a CUSPDEC are deflected along magnetic field lines and go to the line cusp, while ions go straight to the point cusp, thus the charge separation can be achieved.

The authors proposed an introduction of a slanted cusp field, in which a potential barrier for electrons based on the Störmer potential was formed in front of the point cusp resulted in more efficient charge separation than a normal cusp field. A small scale experimental simulator, in which gradient of the field lines could be controlled, was constructed. The experiments showed a demonstration of electricity generation on GAMMA 10 as well as an effectiveness of the slant field. The simulator also has an advantageous structure that two-stage deceleration system can be composed[2]. When the bias voltage of ion collector becomes high for high energy ions, low energy ions cannot reach the collector and are reflected. By setting a lateral electrode for reflected low energy ions as an additional collector, increase of the conversion efficiency can be achieved.

The present subject of CUSPDEC is an application to high density plasma. When the plasma density increases, the charge separation efficiency degrades[3]. Even in this situation, the slanted cusp field works efficiently, but an additional scheme is necessary for sufficient separation. On high density condition, the two-stage deceleration will also be affected that the space field by stagnated ions will play the role of the reflection field. This paper presents fundamental experiments on separation and deceleration for high density plasma application.

In Sec. II, the experimental device and a scenario of the two-stage deceleration for high density plasma are explained. The experimental results are shown in Sec. III, and the contents are summarized in Sec. IV.

II. EXPERIMENTAL SETUP

Figure 1 shows a schematic illustration of the CUSPDEC simulator. It has three magnetic coils: coil C for guiding incident plasma and coils A and B for slanted cusp field formation. For high density experiments, a helicon wave excitation plasma source has been employed substituting for an electron cyclotron resonance plasma source[3]. The plasma source can be biased by positive voltage of V_{acc}, by which incident plasma can be accelerated. In this paper, the used gas is argon. The RF power source is operated by a continuous pulse with a duty less than 0.5.

The density of the incident plasma can be measured by a probe located at the guiding section. The separated particles are detected by four collectors. P1, P2, and P3 are plate electrodes and P4 is a grid electrode which cover the front surface of P3. P1 and P2 are located in the line cusp region, and P3 and P4 are in the point cusp. When P3 and P4 are connected electrically, it is denoted by P3+4. All measurements are examination of voltage-current (V-I) characteristics for each electrode. The pulsed signal, which is synchronized with the pulse operating the RF power source, is averaged by a boxcar integrator.

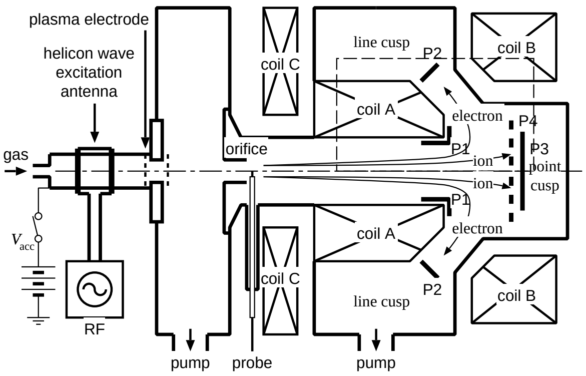

Figure 1: CUSPDEC simulation device.

Figure 2 illustrates a concept of two-stage deceleration in a CUSPDEC, which corresponds to the region encircled by a dashed rectangular in Fig. 1. In the original scenario of CUSPDEC operation, electrons are deflected to the line cusp and ions go straight to the point cusp. On power generation, however, the ion collector is in the optimum potential, so lower energy ions are reflected in front of the collector. In the concept of the two-stage deceleration, these low energy ions are collected by a sub-collector. In the simulator, P1 is assigned as the sub-collector as well as P2 and P3/P4 are for electron and ion main-collectors, respectively.

In the conventional concept, low energy ions are reflected by the electric field due to the main-collector. When the plasma density increases, large amount of decelerated ions stagnate in front of the main-collector, so space potential due to these stagnated ions plays the same role as the collector potential. In the commercial scale device, incident plasma is expected to be high density so the device will work according to the above scenario.

III. EXPERIMENTAL RESULTS

Along the scenario of the two-stage deceleration, reflection of low energy ions due to point cusp collector potential has been examined. Figure 3 shows V-I characteristics of P1 electrode (V_1-I_1) for some V_{acc} and voltages of P3+4 electrode (V_{3+4}), where the positive value of I_1 means ion current. As V_{3+4} increases, the range of V_1 detecting ion current becomes wide except the case of $V_{3+4} = 110 - 140\,\mathrm{V}$ on $V_{acc} = 80\,\mathrm{V}$. This is

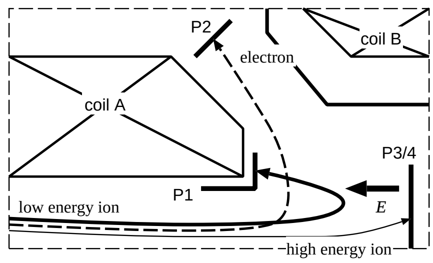

Figure 2: Scenario of two-stage deceleration.

consistent with the expectation that the detected ion current is due to the ions reflected by the potential of P3+4. Examining quantitatively, however, the range of V_1 detecting ion current is lower compared with the original ion energy determined by V_{acc}. This is because the reflected ions do not necessarily arrive at P1, and velocity of ions is not necessarily perpendicular to the surface of P1. These conditions are so complex and further study is required.

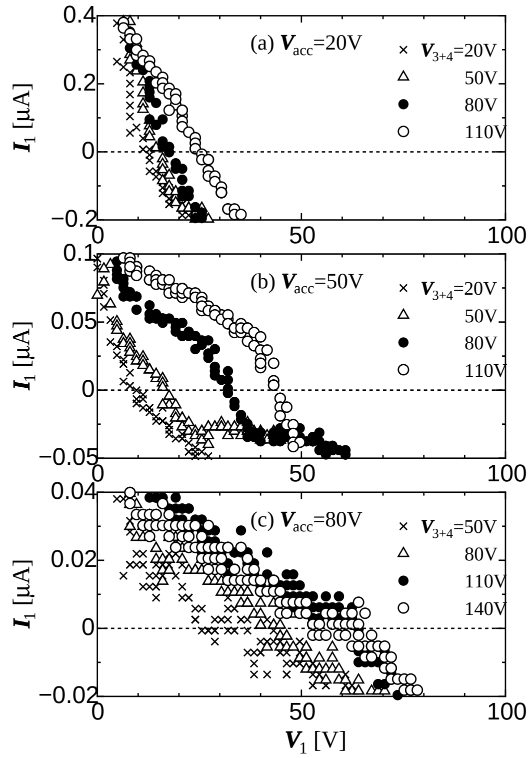

Figure 3: V-I characteristics of P1 for some V_{acc} and V_{3+4}.

When the incident plasma density increases, the charge separation efficiency, and thus the energy conversion efficiency degrades. For recovery, the effect of a negatively biased grid has been examined. Using P4 as the grid, V-I characteristics of P3 has been measured.

In Fig. 4, electron saturation currents of P3 ($I_{\rm es3}$) are shown as a function of current of coil B ($I_{\rm B}$) where current of coil A ($I_{\rm A}$) is 30 A. $I_{\rm es3}$ is normalized by the value of $I_{\rm es30} = I_{\rm es3}(I_{\rm B} = 0, V_4 = 0)$. In this measurement, $V_{\rm acc} = 0$ V. P3 is the ion collector, thus smaller $I_{\rm es3}$ means better separation.

On $V_4 = 0$, $I_{\rm es3}$ reduces as $I_{\rm B}$ increases, and becomes less than 10 % on $|I_{\rm B}/I_{\rm A}| = 1.17 - 1.33$. In the case of $V_4 = -50$ V, $I_{\rm es3}$ becomes less than 10 % for all ranges of $I_{\rm B}$ except $I_{\rm B} = 0$. When V_4 becomes -100 V, it becomes less than 1 % and electron current has not been observed on $|I_{\rm B}/I_{\rm A}| \geq 0.67$.

In the sense of recovery of separation, the negatively biased grid is effective. Although an introduction of a grid on the electron's path brings about thermal problems in the commercial scale device, the problem is reduced compared with a grid-only device as the significant amount of electrons are deflected by the effect of cusp field.

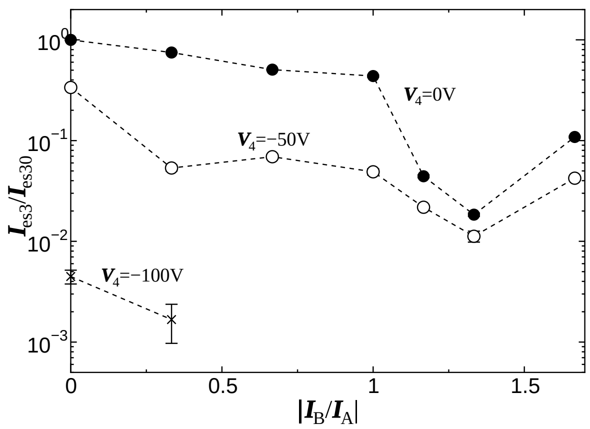

Figure 4: Normalized electron saturation currents of P3 as a function of current of coil B for some V_4.

The effect of the negatively biased grid has been further examined in the view point of energy conversion on P3. Figure 5 indicates V-I characteristics of P3 for some $V_{\rm acc}$ cases under the condition of $V_4 = -100$ V. The range of V_3 detecting ion current varies according to $V_{\rm acc}$. In the region of V_3 over the value of $V_{\rm acc}$, the electron current is small enough and the amount of offset between ion and electron currents is small. By using a negatively biased grid, an efficient energy conversion is expected.

IV. SUMMARY

About the operation of CUSPDEC assuming two-stage deceleration for high density plasma, fundamental measurements were performed in the simulator. The ions reflected due to point cusp ion collector potential were successfully detected as a function of collector voltage. By an introduction of a negatively biased grid, the assistance of the charge separation to cusp field effectively worked, and the elimination of electrons resulted in sufficient reduction of offset on the direct energy conversion by the point cusp collector.

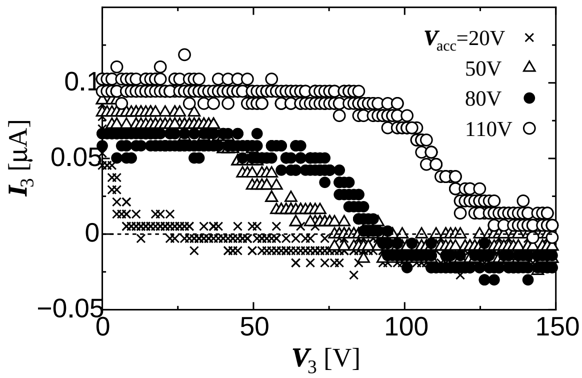

Figure 5: V-I characteristics of P3 for some $V_{\rm acc}$.

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