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# Variation of Charge Separation due to Radio Frequency Application in a Cusp-type Direct Energy Converter

# カスプ型直接エネルギー変換器における高周波印加による電荷分離の変化


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The effect of radio frequency (RF) to charge separation in a cusp-type direct energy converter was investigated as an assist of its charge separation function. In an experimental simulator with small size, voltage-current (V-I) characteristics of a particle collector were measured with a provisional RF electrode. The V-I characteristics were similar to those of a Langmuir probe in the RF potential fluctuation. The measured characteristic in the RF field and the one calculated with an assumption of RF potential fluctuation were compared, showing a slight difference between the cases of different field curvatures.


## 1. Introduction

Cusp-type direct energy converter (CuspDEC) was proposed as an efficient particle discriminator used in a direct power generation system in a D-$^3$He fusion plant [1]. Although the slanted cusp field was introduced for the efficient charge separation [2], its performance was degraded in the high density plasma [3]. Some additional methods to assist the charge separation may be necessary to achieve enough performance. One of the possible methods is use of radio frequency (RF) field as the important merit of the CuspDEC is a grid-less device. Some non-linear RF effects, such as ponderomotive force, are sensitive for the kind of species, thus an appropriate composition of RF field will assist charge separation in a CuspDEC.

Following to the previous report [4], we present experimental results on the effect of RF field application in a CuspDEC simulator with a provisional RF electrode. By taking the examination of the results into account, we also propose an improvement of the RF electrode with numerical calculation.

## 2. Experimental Setup

Figure 1 schematically shows the experimental device used. The magnetic field of the CuspDEC simulator is created by four coils. The coils A and B are for creation of a slanted cusp field. Relative variation of the current of the coil B ($I_B$) to that of the coil A ($I_A$) controls the field curvature. The coils D and C are for production of Ar plasma and its guidance, respectively. At the point cusp, a particle collector (P3) is settled, and a grid RF electrode (P4) assisting separation is in front of the collector.

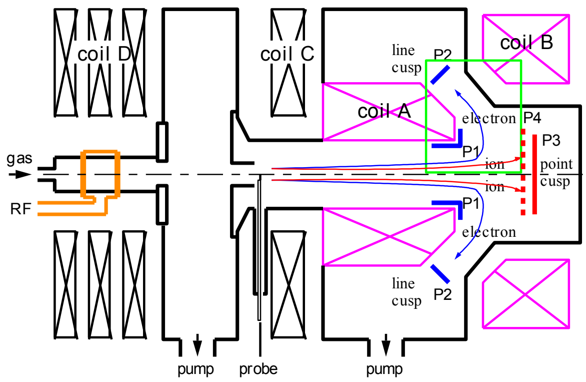


Fig. 1. The CuspDEC experimental simulator

The plasma production is due to continuous RF pulse, and separation assist RF is supplied by a pulse synchronized with the production RF pulse. The voltage($V$)-current($I$) (V-I) characteristics are measured with dc-biasing the collector. The recorded currents are evaluated during the terms with and without the separation assist RF for the corresponding V-I characteristics.

## 3. Experimental Results

In Fig. 2, results are indicated. Here, (a) and (b) are for $I_B$ = 0 A and 20 A on $I_A$ = 30 A, respectively. Open and closed circles are for with and without the separation assist RF, respectively. For (a), the rapid current variation to the voltage polarity becomes gentle by an application of the separation assist RF. On one hand, difference of the characteristics between with and without RF is small for (b).

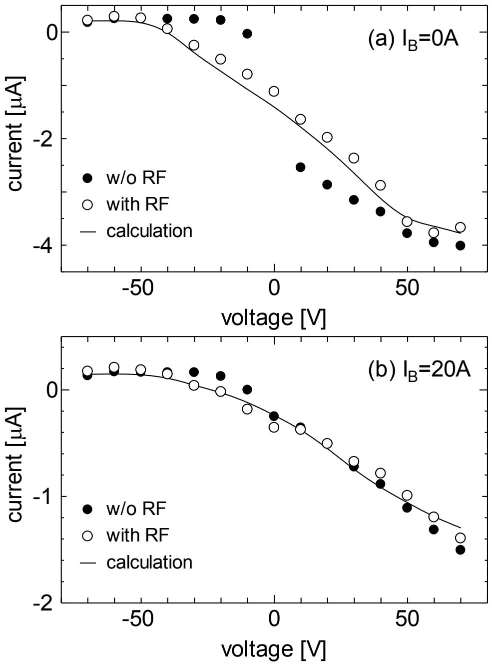


Fig. 2. V-I characteristics of the collector

Here, we consider the assumed characteristic $I_f(V) = \int_0^T I_0(V+V_{RF}\sin\omega t)dt/T$, where $T$ and $\omega$ are period and angular frequency of the RF, $V_{RF}$ is amplitude of fluctuation, and $I_0(V)$ is the measured V-I characteristic without RF. The calculated $I_f(V)$ are shown in Fig. 2 by solid curves. As for $V_{RF}$, the value minimizing its difference with the measured characteristic with RF ($I_{RF}(V)$) is taken.

According to Fig. 2, $I_f(V)$ for (b) agrees with $I_{RF}(V)$ well, but that for (a) has a difference with $I_{RF}(V)$. $I_{RF}(V)$ for (b) can be explained by the fluctuation of potential, and the difference between $I_f(V)$ and $I_{RF}(V)$ for (a) means the existence of other effects. For $I_B$ = 0 A of (a), magnetic field $B$ is almost in the axial direction and RF field $E$ is relatively parallel to $B$, so strong ponderomotive effect can be expected. For $I_B$ = 20 A of (b), however, $B$ forms cusp and $E$ is nearly perpendicular to $B$, so the effect may be weak.

## 4. Improved RF electrode structure

The observed effect was rather small and was not found in the cusp field, so the improved structure of RF electrode is necessary.

Figure 3 corresponds to the area indicated by a green rectangular in Fig. 1. The proposed improved electrode consists of two metal rings placed coaxially, and their cross sections (blue circles in Fig. 3) are aligned in the direction of slanted magnetic field. In Fig. 3, Numerically calculated RF field are indicated by red arrows, the direction and the length of which mean the direction and the strength of RF field, respectively. RF voltage are applied to two rings with the same phase (in-phase) for (a) whereas with the opposite phase (out-of-phase) for (b). The strong RF field parallel to the slanted magnetic field lines (black curves in Fig. 3) is found in Fig. 3(b), and thus the strong ponderomotive effect can be expected in the case of out-of-phase.

(a) in-phase

(b) out-of-phase

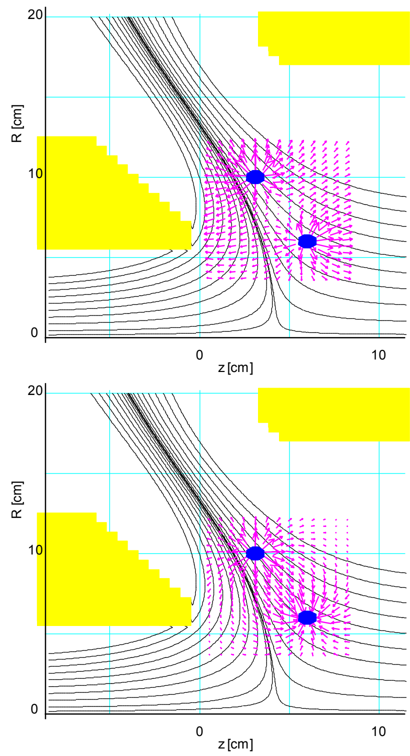


Fig. 3. RF field distribution by an improved electrode


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