§16. Experimental Verification of Constant Deceleration of TWDEC for its Miniaturization

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Traveling wave direct energy converter (TWDEC) was proposed as an energy recovery device for fast protons created in D-^{3}He reaction[1]. Recently, its application to a spacecraft was proposed as an electric generator in a fusion propulsion system[2]. Miniaturization of the device is significant for loading on the spacecraft as well as using in a terrestrial power plant.

The TWDEC has a trade-off between device size and efficiency. The important factor of the device size is the distance between a modulator and a decelerator. It is determined by bunching length, which varies according to the depth of the modulation. A short bunching length can be obtained in a deep modulation whereas velocity deviation of protons becomes large and an efficient energy conversion becomes difficult.

As a decelerator, the optimum deceleration scheme was often used[3]. A traveling wave in the decelerator in this scheme is designed by matching its velocity with that of a proton having standard initial velocity, so large velocity deviation results in low efficiency. On one hand, the constant deceleration scheme was proposed in which protons are trapped in a potential valley of the traveling wave[4]. Thus, the potential well with an enough depth can trap protons even having some deviated velocity, and decelerate them. The constant deceleration scheme may be suitable for miniaturization of TWDEC keeping high efficiency. Its experimental examination, however, is not enough. An experimental verification is shown in the following.

The same kind of experimental simulator as Ref. 3) was used. A decelerator of the constant deceleration scheme was designed for helium ion beam of 3.2 keV and deceleration of 8×10^{11} m/s^2. The length of the decelerator was two wavelength of the traveling wave. The energy distribution of ions can be measured by a Faraday cup. By using an active decelerator[3], the effect of the deceleration was measured for eight different relative phase difference between voltages of the modulator and the decelerator, and the case of the best deceleration effect was taken as the result. Voltages of the decelerator electrodes with appropriate phase differences were provided by using terminal voltages in a tranmission line.

The sample results are in Fig. 1 which shows variation in energy distribution functions due to TWDEC operation. Three cases (a, b, and c) are shown, and note that positions of zero of ordinate are as indicated by 0_a, 0_b, and 0_c, respectively. The thin dashed curve of case a is for the incident beam and the most part of the ions are around incident energy of 3.2 keV. The solid curves are for the cases applying the modulation and the deceleration. The thin curve of b and the thick curve of c correspond to V_{dec4}=100 and 230 V_{0p}, respectively, where V_{dec4} is the amplitude of the voltage on the fourth electrode of the decelerator (voltage amplitudes have ±20 % difference because of a reflection wave in the transmission line). In the case of V_{dec4}=100 V_{0p}, the peak around 3.2 keV decreases and ions are distributed in a wide energy range. In the case of V_{dec4}=230 V_{0p}, the distributed energy range is extended, and a lot of ions are in the lower energy region than 3.2 keV, and the new peak around 0.5 keV appears.

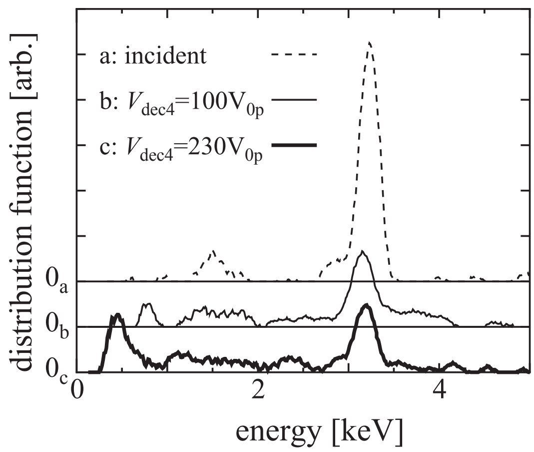

Fig. 1: Variation in energy distribution functions.

According to the theory of the constant deceleration, trapping of ions is explained by a phase space diagram. The ions are distributed widely in the vertical (velocity) direction of the phase space as the velocity-modulation deepens. One of the factors to determine the trapping region in the phase space is the deceleration voltage. As the deceleration voltage increases, the trapping region is extended, so the decelerated ions increase. Thus, the experimental observation of Fig. 1 is consistent with the theory of the constant deceleration. For miniaturization of TWDEC, degradation of efficiency due to deep modulation to shorten the bunching length could be improved by adjustment of the deceleration voltage.

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2) J. H. Scott, et al., Proc. Nucl. Emerging Tech. for Space 2013 (2013) Paper 6756.

3) H. Takeno, et al., Jap. J. Appl. Phys., Vol. 39 (2000) pp. 5287-5291.

4) H. Katayama and K. Sato, J. Plasma Fusion Res., Vol. 77 (2001) pp. 698-711 (in Japanese).