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Generation of anomalously energetic suprathermal electrons by an electron beam interacting with a nonuniform plasma

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Electrons emitted by electrodes surrounding or immersed in the plasma are accelerated by the sheath electric field and become electron beams penetrating the plasma. In plasma applications where controlling the electron velocity distribution function (EVDF) is crucial, these beams are an important factor capable of modifying the EVDF and affecting the discharge properties. Recently, it was reported that an EVDF measured in a dc-rf discharge with 800 V dc voltage has not only a peak of 800 eV electrons emitted from the dc-biased electrode, but also a peak of suprathermal electrons with energy up to several hundred eV. Initial explanation of the suprathermal peak suggested that the fast long plasma waves excited by the beam decay parametrically into ion acoustic waves and short plasma waves with much lower phase velocity which accelerate bulk electrons to suprathermal energies. Particle-in-cell simulation of a dc beam-plasma system, however, reveals that the short waves appear not due to the parametric instability, but due to the plasma nonuniformity. Moreover, the acceleration may occur in two stages. Plasma waves excited by the beam in the middle of the system propagate towards the anode and enter the density gradient area where their wavelength and phase speed rapidly decrease. Acceleration of thermal electrons by these waves is the first stage. Some of the accelerated electrons reflect from the anode sheath, travel through the plasma, reflect near the cathode, and enter the accelerating area again but with the energy higher than before. The acceleration that occurs now is the second stage. The energy of a particle after the second acceleration exceeds the initial thermal energy by an order of magnitude. This two-stage mechanism plays a role in explaining previous observations of energetic suprathermal electrons in similar discharges. The study is performed in collaboration with I. D. Kaganovich (PPPL), P. L. G. Ventzek and L. Chen (Tokyo Electron America).