§6. Direct Power Generation by High Heat Flux Divertor Plasmas

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In fusion devices, a divertor plate receives huge heat load released from a core plasma. If the huge heat load can be converted to electricity by using a thermionic energy converter (TEC), the efficiency of the fusion reactor could be improved. TEC has been developed for a long time for application to nuclear thermionic power generator in spacecrafts and combustion heated thermionic power system. This is because TEC has good properties such as high conversion efficiency and simple configuration.

We have investigated basic property of TEC by 2D PIC simulation (Berkeley code). The emitter and the collector are assumed to be made of tungsten with a work function of 4.5 eV and thoriated tungsten with a work function of 2.6 eV respectively. Figure 1 shows dependence of output current normalized by thermoelectron emission current from the emitter on distance d between the emitter and the collector at an emitter temperature of 2300 K. As decreasing d, the output current increases exponentially to be unity at $d = 0.1$ mm. This means that virtual cathode formed in front of the emitter disappears at d below 0.1 mm, and all electrons emitted from the emitter can reach the collector.

Based on the simulation result, we made a TEC test module having thoriated tungsten electrodes with $d = 0.06$ mm by using thin BN film as an insulator. We performed verification experiments of the TEC under a huge heat flux by using Active cooling Test device (ACT) in NIFS as shown in Fig. 2. The emitter is heated by an electron gun (its power is about 500 W) and the emitter temperature is gradually increased to be up to 2000 K. The emitter temperature was measured with a radiation thermometer. Figure 3 shows the current density J as a function of the emitter temperature. The experimental result agrees well with the PIC simulation result. In high temperature region, the output current does not saturate, probably because the initial velocity of the thermionic electron increases with the emitter temperature . In this experiment, TEC system effectively generated an electric power of 10 kW/m^2 at 2000 K. The conversion efficiency from heat to electricity was estimated to be 0.01.

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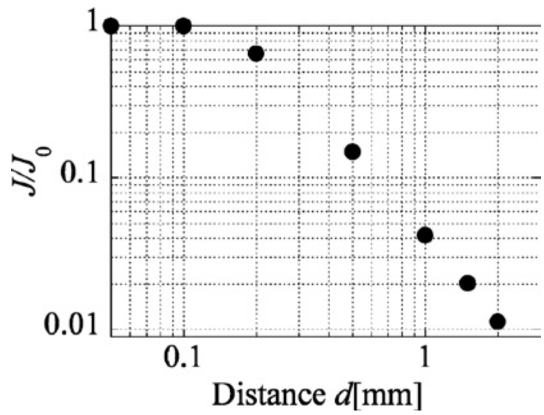

Fig. 1: Simulation result of the output current as a function of distance between electrodes.

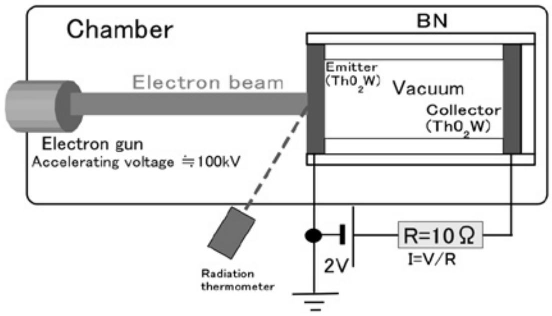

Fig. 2: Schematic of experimental setup.

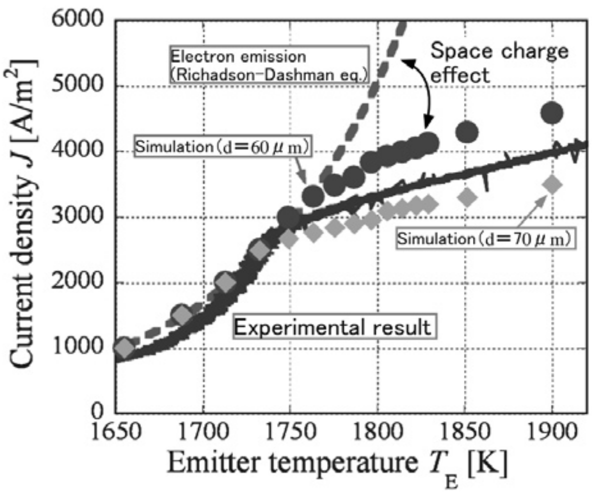

Fig. 3: Current density as a function of emitter temperature. Closed circles and diamonds represent the PIC simulation results. Experimental result is shown as a solid line.