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Coaxial Helicity Injection experiment on QUEST

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The QUEST device in Kyushu University is a mid-sized (R = 0.68 m, a = 0.4 m, Bt = 0.25 T) spherical tokamak, in which non-inductive current drive by electron cyclotron heating (ECH) has been developed. The current drive up to about 70 kA has been achieved using a 28 GHz microwave ECH system [1]. Recently, coaxial Helicity Injection (CHI) has been introduced to implement the CHI current drive in QUEST through cooperation with University of Washington and Princeton Plasma Physics Laboratory (PPPL). The CHI plasma is produced by applying high voltage between CHI electrodes. CHI has been previously studied on HIT-II (R = 0.3 m, a = 0.2 m, Bt = 0.5 T) at the University of Washington and on NSTX (R = 0.86 m, a = 0.66 m, Bt = 0.55 T) at PPPL. The CHI electrodes of both devices consist of inner and outer of the vacuum vessel parts in which upper and lower toroidal ceramic breaks are interposed between the two parts. The CHI electrodes installed in QUEST is designed for implementation of CHI on future fusion reactor, in which the design will facilitate to shield the ceramic breaks from the neutron irradiation. CHI operation in the new electrode configuration needs to be demonstrated to introduce CHI into a fusion reactor. The first purpose of the collaborative research is to find out the appropriate condition for reliable initiation of plasma with the new CHI electrodes. (Figure 1 shows the electrodes which is described later.)

The second purpose is to investigate the effect of ECH to heat the CHI plasma on QUEST. If the new CHI electrodes can be used for the reliable initiation of plasma as on HIT-II and NSTX, then the CHI-produced plasma can be heated by ECH system in QUEST. The start-up method referred to as "transient CHI" has been shown to be effective with ohmic heating on HIT-II and NSTX [2], in which the seed plasma produced by CHI is heated more efficiently than the plasma produced and heated solely by ohmic. The transient CHI with ECH is also prospected to be effective and planned to be tested in a full non-inductive current start-up and ramp-up scenario on the upgrade to NSTX (NSTX-U).

In the first CHI experiment on QUEST, we initiated CHI plasmas with the new CHI electrodes. As shown in figure 1, the new CHI electrodes installed in QUEST consist of the bias-electrode isolated by ceramic break on the lower end-plate and the ground electrode electrically attached vacuum vessel. In the beginning of the discharge sequence, the toroidal field (Bt = 0.25 T at R = 0.64 m) and the poloidal field as shown in figure 1 by gray contours are applied. The vacuum field plot shows the CHI electrodes to be connected by helical field lines. In the next step, H2 gas is injected to near the CHI electrodes and then the voltage is applied between the electrodes by a capacitor bank power supply (< 30 mF, < 2 kV) for achieving gas breakdown. In the experiment, the necessary condition of breakdown was examined on various field configurations with the new CHI electrodes. The result shows that breakdown is achieved if the connection length of the field line and H2 gas pressure between the electrodes satisfy the Paschen's condition. As shown in figure 2, some discharge results show that the injector current which is driven by the power supply to flow along the helical field line from electrodes extends the plasma into the vacuum vessel by the interactive force "$J_{\mathrm{POL}} \times B_{tor}$". With the new CHI electrodes under appropriate conditions, gas breakdown was stably achieved and toroidal plasma current up to 29kA was generated. These data demonstrate the usefulness of the new CHI electrodes.

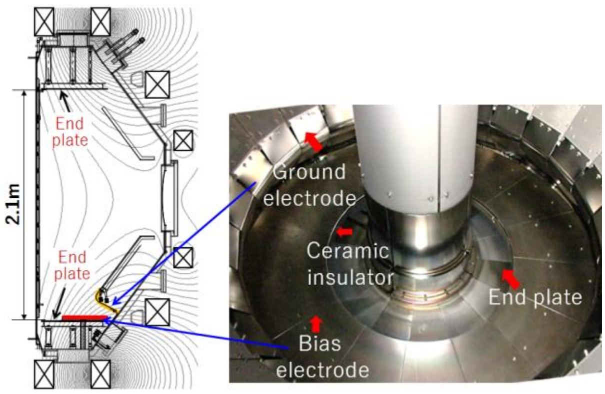

Figure 1 Installed CHI electrodes (Bias and Ground electdodes) in QUEST.

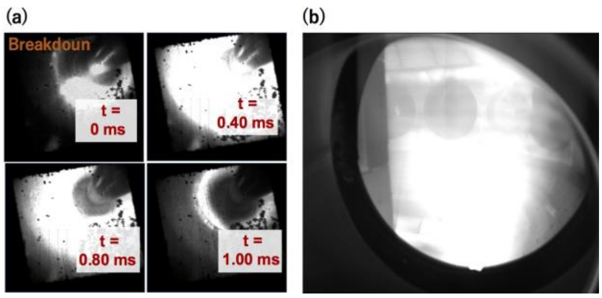

Figure 2 Camera images of CHI plasma viewed from top (a) and side (b).

[1] H. Idei *et al.*, *Proc.* 26th IAEA *Fusion Energy Conference* (2016) EX/P4-50.

[2] R. Raman *et al.*, *phys. plasmas* **18**, 092504 (2011)