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Investigation of global ion heating/transport process during merging/reconnection startup of spherical tokamak in TS-3U

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Ion heating/transport is a key physical process for the application of magnetic reconnection on solenoid-less plasma startup of spherical tokamak (ST). In the last decade, the application of high guide field reconnection made major progress such as (a) achievement of ~1keV heating both for ions and electrons, (b) demonstration of B_{rec}^2 scaling of ion heating ranging 0.01keV<T_i<1.2keV with 0.01T<B_{rec}<0.15T in many plasmas merging experiments [1] and (c) successful connection to ramp-up and steady scenario with additional heating by NBI and Ohmic-solenoid [2]. For those high guide field condition, established temperature profile tends to form characteristic distribution: (i) peaked T_e around the X-point [3], (ii) hollow T_i through the dissipation of outflow jet downstream [4], and (iii) electron-ion energy equilibration to form triple peak distribution both for electrons and ions [3]. For further understanding of the promising application scenario of reconnection heating under high guide field condition, we have developed a novel ultra-high resolution ion Doppler tomography [5] diagnostics using multi-slit spectroscopy technique. The key physical process of fine structure formation under the influence of better toroidal confinement has been successfully resolved by the new diagnostics for the first time. Several clear processes of merging/reconnection heating/transport will be presented in the conference.

Figure 1 shows typical features of reconnection heating during merging plasma startup of ST in TS-3U. As shown in the fast camera images and flux plots with current density profile, two plasma rings merge together around the midplane (z~0m). Under the condition of high guide field ratio of B_t/B_{rec}~5 (B_{rec}~0.02T and B_t~0.1T), toroidally ring-like structure is observed in the fast camera image at t=816μs where current sheet exist. Around this phase (t=810μs–820μs), poloidal magnetic energy of two merging tokamaks is converted to plasma thermal energy based on outflow heating mechanism, and then ion temperature rapidly increases globally downstream of outflow jet and also inside the current sheet. After merging, high T_i region is finally surrounded by closed flux surface of spherical tokamak.

Figure 2 shows highlight and interpretation of the new finding from the high resolution ion Doppler tomography: fine structure formation of ion temperature profile both around X-point (r~0.15m) and downstream region of outflow jet. Magnetic reconnection accelerates ions up to the order of poloidal Alfven speed of two merging tokamaks, ion temperature increases on the trajectory of outflow by conversion of flow energy to ion thermal energy based on outflow heating mechanism. After merging, because the high temperature region is surrounded by the thick layer of closed flux surface, high T_i region propagates vertically and finally forms poloidally double-ring-like structure aligned with the closed flux surface of two merging tokamaks under the influence of better plasma confinement with higher toroidal field. The ratio of ion thermal diffusivity $\chi_i^{//}/\chi_i^{\perp}$ ~$2(\omega_{ci}\tau_{ii})^2$>>10 ($\omega_{ci}$~10Mrad/s, τ_{ii}~1μs) is sufficiently high in comparison with spheromak and FRC and the suppressed cross field thermal transport helps to form the characteristic profile.

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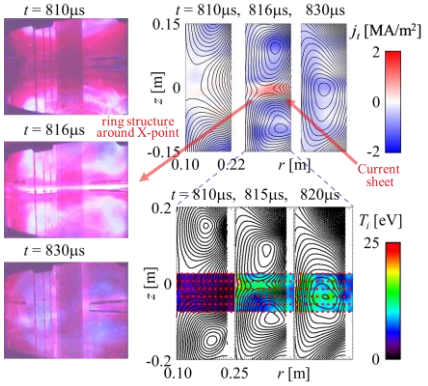

Figure 1 Typical features of guide field reconnection in TS-3U visualized by 2D imaging measurement.

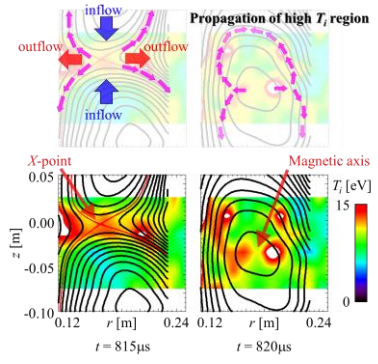

Figure 2 2D ion temperature profiles at t = 815μs and 820μs, and interpretation of the characteristic profile formation during merging/reconnection.