9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Magnetic Reconnection for Fusion Plasma Ignition and Current Drive

Yasushi Ono[1], Hiroshi Tanabe[1], Michiaki Inomoto[1], Chio-Zong Cheng[2], and TS&UTST Groupe[1]
[1] Department of Advanced Energy, University of Tokyo, [2] Princeton Plasma Physics Laboratory,
e-mail: ono@k.u-tokyo.ac.jp

We have been investigating high-power reconnection heating of two merging spherical tokamak (ST) plasmas in TS-3, TS-4, TS-6 and UTST at the University of Tokyo [1-3] and also in MAST at UKAEA and in ST-40 at Tokamak Energy Inc. based on UK-Japan collaboration [4]. As shown in Fig. 1(a), we merge two tokamak plasmas in the axial direction and the magnetic reconnection at their contact point accelerates ions to two downstreams as indicated by the two red arrows. The magnetic reconnection converts about 40% of the poloidal magnetic energy into ion kinetic / thermal energy within the short reconnection time. The X-point area is surrounded by the thick reconnected flux, indicating most of the heated ions are confined after the merging is over.

The high-power ion heating is achieved only when the current sheet thickness is compressed to ion gyroradius ρ_i. The magnetic reconnection converts 40-50% of the reconnecting (poloidal) magnetic field energy ($B_{rec}^2/2\mu_0 \sim B_p^2/2\mu_0$) into the ion heating energy (W_i) with the scaling law of W_i proportional to B_{rec}^2, as shown as the red line in Fig. 2. If the compressed current sheet thickness is larger than ρ_i, the magnetic reconnection converts only 5-10% of $B_{rec}^2/2\,\mu_0$ into W_i as the green line in Fig. 2.

This B_{rec}^2-scaling of ion heating energy by reconnection can be understood by the fact that in the reconnection downstream the ion energy is mainly in the form of outflow kinetic energy before ions are thermalized in further downstream. The ion outflow velocity is produced mainly by the large E×B drift velocity associated with large poloidal electric field E_z, resulting from the formation of quadrupolar electrostatic potential structure in the downstream region and E_z depends linearly on B_tB_p. Hence, the outflow velocity scales with B_{rec}, and thus the ion heating energy scales with B_{rec}^2 [3].

The B_{rec}^2-scaling of high power ion heating provides an efficient way to produce burning plasmas with $T_i > 10$keV by increasing B_{rec} to 0.6T (for $n_e \sim 1.5\times10^{19}$m^{-3}) without using any additional heating methods like neutral beam injection (NBI) or center solenoid (CS) coil [2-4]. The whole CS coil flux can be used for tokamak profile control after the reconnection startup. The reconnection time is much shorter than the plasma confinement time. Once we start DT burning using the high power ion heating, we can maintain the ST plasma current using the bootstrap current produced by the alpha heating.

Because of its high heating power, the reconnection heating scheme is used not only in our university and Tokamak Energy (UK) Inc. but also in the following institutes: C2-W FRC experiment at TriAlpha Energy (US), the space propulsion system at Helicity Space Corp. (US), SUNIST-2 ST experiment at Tsinghua University and Startorus Fusion (China), possibly VEST ST experiment at Seoul National University (Korea). Our merging / reconnection heating DT burning tokamak reactor related with the FAST project is considered as one of Japanese Moonshot project candidates.

References
[1] Y. Ono et. al., Phys. Rev. Lett. **107**, 185001, (2011).
[2] Y. Ono et. al., Nuclear Fusion **64**, 086020, (2024).
[3] Y. Ono et. al., Plasma Phys. Control. Fusion **67**, 055018, (2025).
[4] Y. Ono et al., Fusion Energy 2020, IAC/P4-3, (2021).

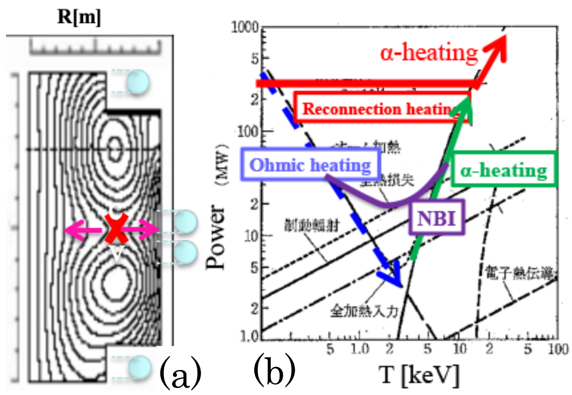

Figure 1(a) 2D poloidal flux contour of two merging tokamak plasmas in TS-3 merging device and (b) the power of reconnection heating and that of the conventional tokamak heating composed of ohmic, NBI and alpha-heating, as a function of temperature.

]

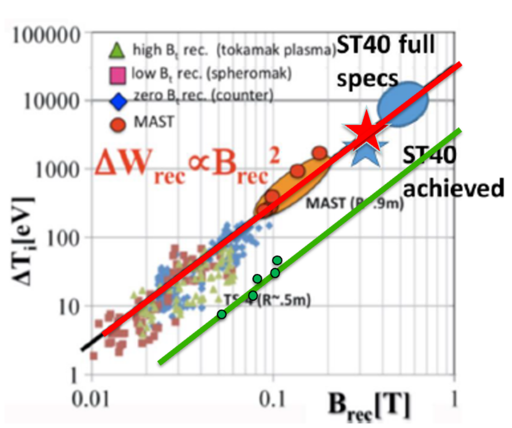

Figure 2 Dependence of ion temperature increment ΔT_i on reconnection magnetic field B_{rec} (~poloidal magnetic field B_p) for high power heating operation (red line) with $\delta \sim \rho_i$ and for low power one with $\delta > \rho_i$.