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Merging of Two Tokamak Plasmas for High-Power Ion Heating, Magnetic Helicity Injection and Plasma Flow-Drive

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The merging operations of spherical tokamak (ST) plasmas have been studied using TS-3[1], START, TS-4, UTST, MAST[2] and ST-40 experiments and MHD/ PIC simulations[3] for (1) high-power reconnection heating and (2) magnetic helicity injection. As shown in Fig. 1, we merge two ST plasmas through the magnetic reconnection. The former realizes the high ion temperature plasma production useful for a direct access to high-beta burning ST plasmas and the latter is often used for startup and helicity injection (current drive) of ST plasmas. Then, an important question arises as to what conditions are required for the merging operations to optimize the ion heating and helicity injection, respectively.

We found that (i) the compression of current sheet thickness to ion gyroradius ρ_i realizes fast reconnection as well as high-power ion heating whose heating power increases with the square of reconnecting magnetic field B_{rec} almost equal to the poloidal magnetic field B_p[1,4], and that (ii) the current sheet thickness larger than ρ_i produces slow reconnection with small magnetic-energy loss for the magnetic helicity/energy injection. Figure 2(a) show time evolutions of current sheet thickness δ, ion gyroradius ρ_i and reconnection electric field E_{rec} in TS-3 ST merging experiment and (b) those in 2D PIC simulation. Initially, δ is much thicker than ρ_i but when we compress the sheet to ρ_i, the reconnection electric field E_{rec} increases significantly, transforming slow reconnection to fast reconnection. A similar phenomenon is observed in 2D pic simulation[3]. The red and green arrows show fast and slow reconnection periods, respectively.

Figure 3 shows the ion temperature increment ΔT_i after the ST merging as a function of the reconnecting magnetic field $B_{rec} \sim B_p$. The electron density is set constant ~$1.5\times10^{19}m^{-3}$ in this scan. The red and green lines indicate the ΔT_i scaling for the fast ($\delta \sim \rho_i$) and slow ($\delta >> \rho_i$) reconnection operations. In both cases, ΔT_i increase almost proportional to B_{rec}^2 but the former ΔT_i is about one order higher than the latter. The former operation converts about 40% of reconnecting magnetic energy into ion thermal energy, while the latter operation does less than 10%. The former operation is useful not only for the high-power heating but also for formation of interesting high-beta ST with reversed-shear and absolute minimum-B profile.

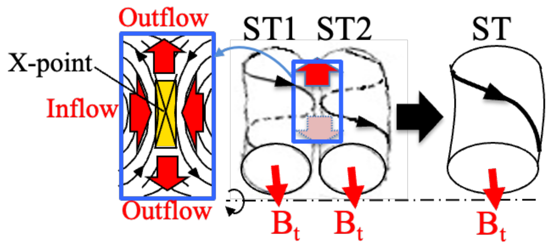

Fig. 1 Merging of two ST plasmas with bi-directional radial outflow and its reconnection region.

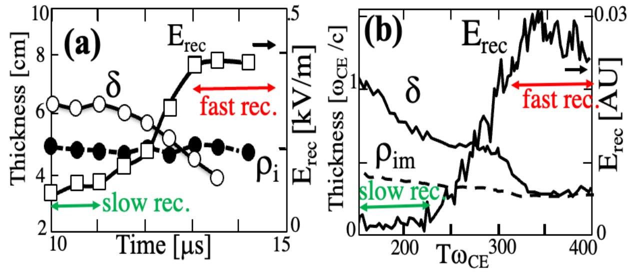

Fig. 2 (a) Time evolutions of current sheet thickness δ, ion gyroradius ρ_i and reconnection electric field E_{rec} in TS-3 ST merging experiment and (b) those in 2D PIC simulation. The red and green arrows show fast and slow reconnection periods, respectively.

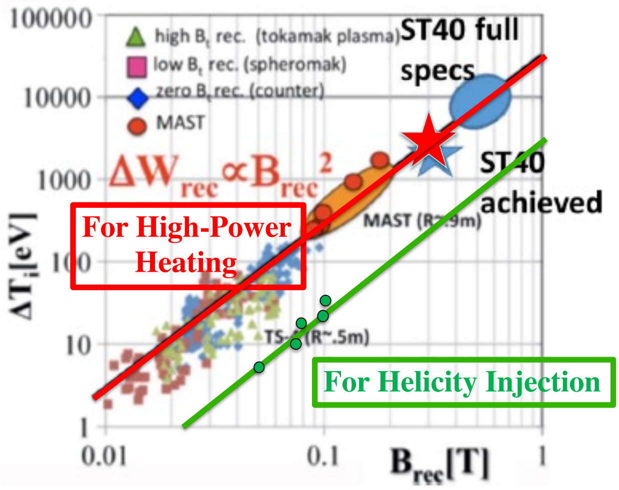

Fig. 3 Ion temperature increments ΔT_i as a function of B_{rec} for fast ($\delta \sim \rho_i$, red line) and slow ($\delta >> \rho_i$, green line) reconnection operations in the ST merging experiments.

References
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