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Direct Access to the Burning Plasma by High-Power Reconnection Heating of Merging Tokamaks

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We have been investigating toroidal plasma merging and reconnection for high-power heating of spherical tokamak (ST) and field-reversed configuration (FRC), using TS-3 (ST, FRC: R=0.2m, 1985-), TS-4 (ST, FRC: R=0.5m, 2000-), UTST (ST: R=0.45m, 2008-) and MAST (ST: R=0.9m, 2000-) devices. The series of merging experiments made clear the promising scaling of reconnection heating: its ion heating energy scales with square of the reconnecting magnetic field B_{rec}, as shown in Fig. 1(c).

We studied mechanisms for the B_{rec}^2-scaling of reconnection (ion) heating mainly using TS-3 experiment. Figures 2 shows dependences of growth rate $1/\tau_{rec}$ of ST merging/ reconnection on toroidal (guide) field B_t (normalized by B_{rec}~const.) and similar dependences of ion temperature increment ΔT_i before and after ST merging on B_t/B_{rec} for acceleration coils currents: (a) (a') I_{acc}=13kA, (b) (b') I_{acc}=10kA. The sheet compression to the order of ion gyroradius ρ_i was found to be a key to start the fast reconnection as well as the high-power ion heating consistent with the B_{rec}^2-scaling prediction. Under this condition, ΔT_i is determined uniquely by B_{rec}~B_p not by B_t in the conventional tokamak operation region: B_t/B_p>1. In TS-3, the ion heating energy is as high as ~40-50% of poloidal magnetic energy of two merging ST plasmas. However, the insufficient compression of the current sheet, causes the ion heating lower than the scaling prediction. To obtain this large ion heating, two merging ST plasmas should be fully isolated from the PF coils and walls for large ion heating unlike most of laboratory reconnection experiments in low temperature range. In the present TS-3 experiment, its energy loss lower than 5% during the reconnection.

Additional key physics for the reconnection hating are as follows: (i) the weak dependence of ion heating on the guide (toroidal) field B_t, for B_t/B_{rec} > 1. It is probably because the sheet compression to ρ_i, causes large increase in anomalous resistivity due to ion meandering motion and instabilities in the current sheet. (ii) The ion heating energy is obtained in the downstream during the reconnection and is 3-10 time larger than its electron heating energy (at around X-point).

This promising scaling is expected to realize the burning plasma temperature T_i>10keV just by increasing B_{rec} over 0.6T (n_e~$1.5\times10^{19}m^{-3}$), leading us to construction of new high-B_{rec} merging ST devices: ST-40 in Tokamak Energy Inc. and TS-6 in Univ. Tokyo.

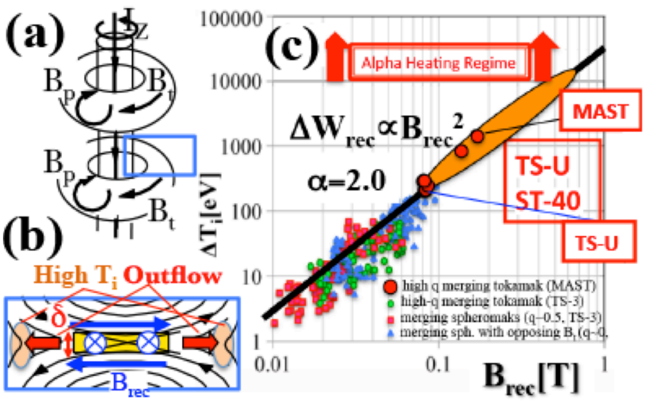

Fig. 1 (a) Two merging ST plasmas (top) and their X-point region (bottom), (b) dependence of ion temperature increment ΔT_i on reconnecting magnetic field B_{rec} of merging STs and spheromaks under constant electron density n_e~$1.5\times10^{19}m^{-3}$.

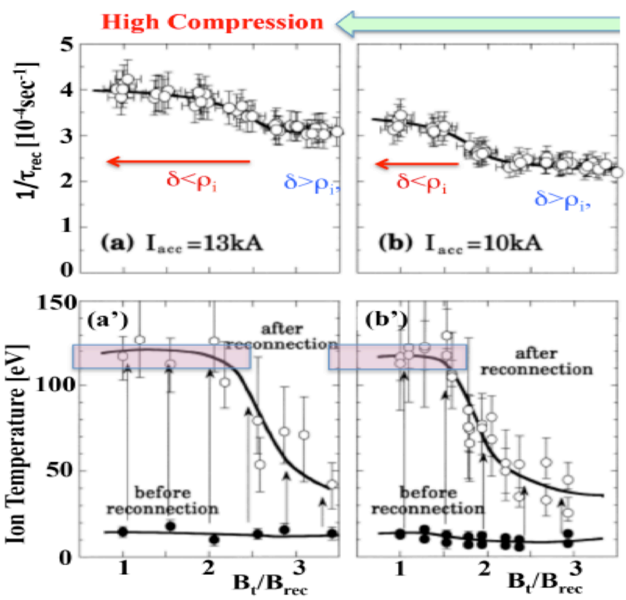

Fig. 2 Dependences of reconnection speed $1/\tau_{rec}$ of ST merging on toroidal (guide) field B_t (normalized by B_{rec}~const.) and similar dependences of ion temperature increment ΔT_i before and after ST merging for acceleration coils currents: (a) (a') I_{acc}=13kA, (b) (b') I_{acc}=10kA.

References:

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