Control of Electron Acceleration Process during Merging Start-up of Spherical Tokamak

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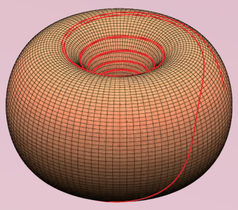
UTST THE UNIVERSITY OF TOKYO SPHERICAL TOKAMAK

Abstract

- **Axial plasma merging method** is one of the start-up schemes to form spherical tokamak plasma **without use of a center-solenoid coil**. It involves magnetic reconnection process in the presence of high toroidal magnetic field parallel to the reconnection electric field and has a **potential to accelerate electrons directly**.
- **Self-generated axial electric field** in the reconnection downstream region was largely suppressed inside the area where the magnetic field lines are contacted to the inboard limiter conductors equipped on the center stack.
- This suppression effect was attributed to the **short circuit connection of the magnetic field lines** to hinder the axial charge separation and then conserve the parallel electric field.
- These experimental results suggest that the merging start-up method has a capability to enhance electron acceleration efficiency by magnetic reconnection and to produce **high electron temperature spherical tokamak plasma** applicable for additional heating and current drive techniques.

Introduction - Spherical Tokamak



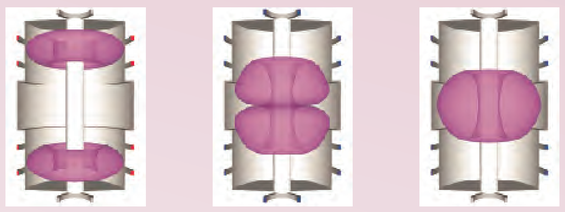
Spherical tokamak (ST) : tokamak with lower aspect ratio <2
[Pros] High beta limit, good confinement.
[Cons] Limited space near the geometrical axis.

Center-solenoid (CS) coil should be removed in the future ST reactor.
Novel start-up schemes, such as RF start-up, helicity injection, etc., without use of CS coil are intensively studied in many ST experiments.

Introduction - Axial Merging Start-Up of ST

Axial merging method is one of the candidates to provide **CS-free start-up** of high-beta ST plasma through highly-controlled magnetic reconnection process.

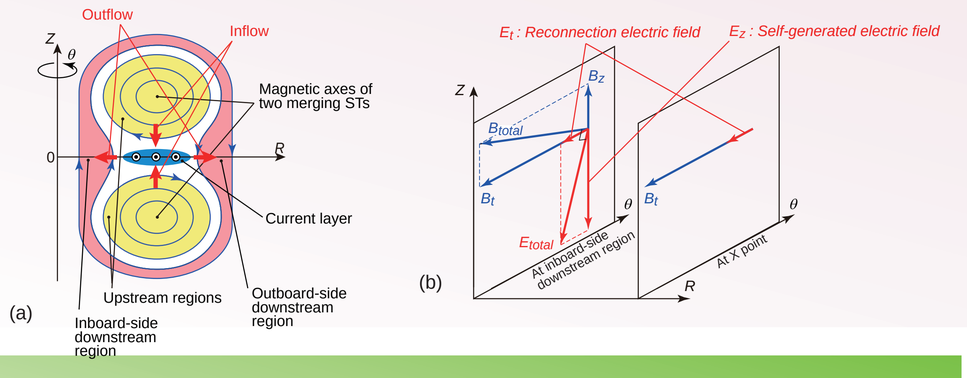
[How?] Two ST plasmas are inductively formed by use of poloidal field coils. They approach each other and merge at the center of the device. Magnetic reconnection between poloidal fields of the two STs changes the field line topology and finally generates a single ST plasma.



[Why?] (1) **No use of CS coil** during the start-up period.
(2) **Significant initial heating** (particularly on ions) is provided by magnetic reconnection because it serves to convert magnetic energy into plasma kinetic/thermal energies as observed in Solar flares.

Introduction - Magnetic Reconnection with Guide Field

In axial merging method, **direct electron acceleration along the magnetic field lines is a potential source for electron heating** because the reconnection process proceeds under a strong toroidal (guide) magnetic field which is parallel to the reconnection electric field. However, the electron acceleration in the reconnection downstream region is considered to be **suppressed by the self-generated electric field** due to the charge separation.

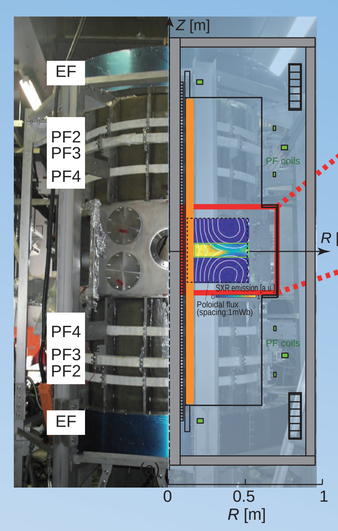


Question

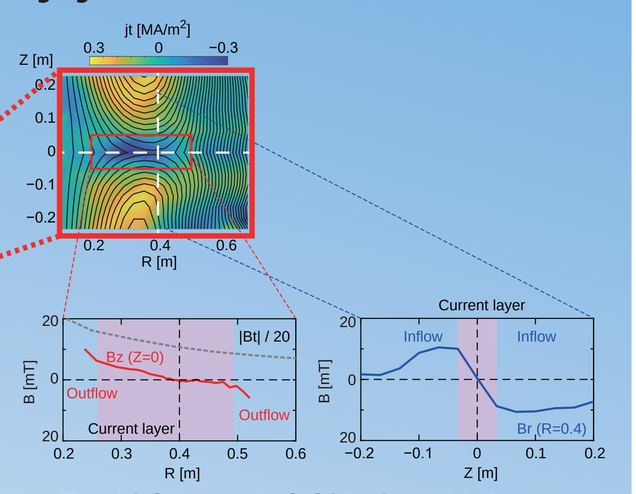
Can we control the self-generated electric field and enhance electron acceleration in the wide area of the downstream region?

Experimental Setup

(A) Magnetic reconnection condition



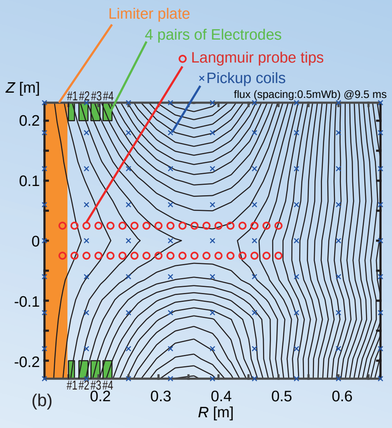
Magnetic flux surfaces with toroidal current density during merging ST formation in UTST



Toroidal magnetic field is about 20 times as large as the inflow magnetic field (Br).

(B) Ez measurement

Langumuir probe array with tangsten tips was installed to measure the axial electric field Ez on the midplane (Z=0) where the reconnection current layer locates.



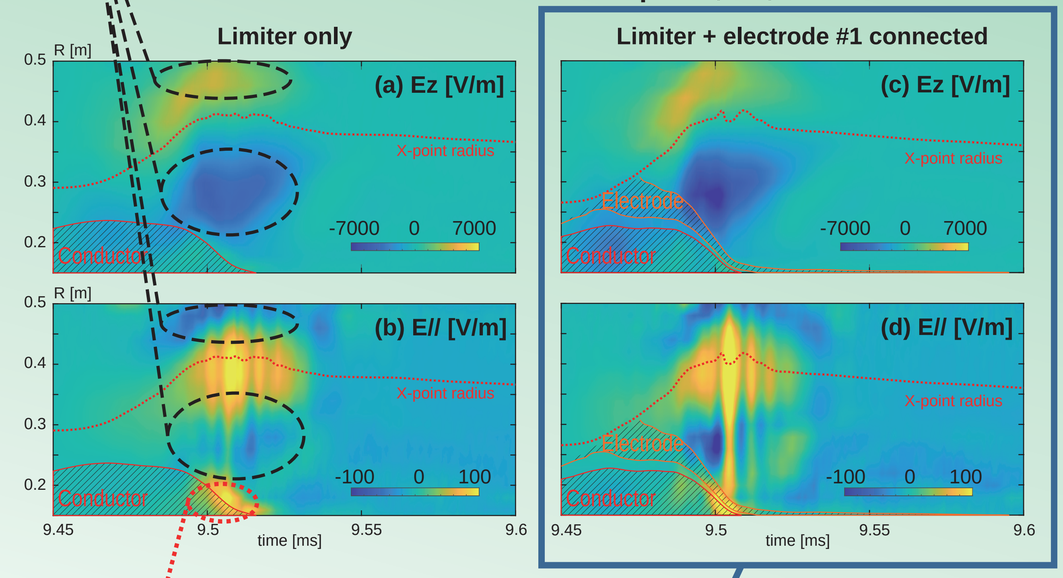
(C) Boundary conditions

Four limiter plates were equipped on the center-stack with 90 degrees apart. The magnetic field lines which contact the limiter plate will be shorted and the charge separation will be cancelled. A pair of additinal electrodes were also inserted near the limiter plate to change the bondary condition.

Experimental Results

Downstream regions : Large axial electric field Ez was generated in the downstream region to cancel the parallel electric field.

Time evolutions of radial profiles of (a,c) axial electric field Ez, and (b,d) parallel electric field E// for two boundary condition cases measured on the midplane (Z=0).



inboard-side downstream region : Parallel electric field survived where the field lines were connected to the limiter plate, which possibly suppresses the charge separation and reduces the axial electric field.

Additinal electrodes are potentially capable of extending the electron acceleration region unless they extert a negative effect on the upstream plasma, e.g. slowing down the inflow velocity.

Summary

We have investigated the role of inner limiter on generation of in-plane electric field and found that the parallel electric field in the downstream region was sustained on the magnetic field lines that contacted the limiter conductors. It is concluded that limiter shape modification will change the charge separation condition in the inboard-side downstream region and be capable of improving the electron acceleration efficiency in the merging start-up of STs. This result suggests that higher electron temperature ST could be formed by the merging start-up scheme with optimized conducting material structure that contacts the plasma.

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