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Onset of Fast Magnetic Reconnection in Plasma Merging Experiments
プラズマ合体実験における高速磁気リコネクションの発現

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Anomalous dissipation in magnetic reconnection is usually recognized as a result of current sheet instabilities such as lower hybrid drift instability followed by a long-wavelength electro-magnetic mode called drift kink instability. In plasma merging experiments, excitation of low frequency wave was observed in the vicinity of the X-point associated with the increase of the magnetic reconnection rate under a guide field. Plasmoid development was also observed to enhance the reconnection rate in the guide field reconnection.

1. Introduction

Magnetic reconnection plays important roles in rapid eruption and structure formation events in magnetized plasmas. Fast magnetic reconnection is provided by large magnetic dissipation, or the anomalous resistivity in the diffusion region, which is induced by microscopic instabilities in the current sheet. One of the primary candidates of the micro instabilities is the lower hybrid drift instability (LHDI), which is often observed in space and laboratory experiments [1,2]. Recent three-dimensional particle-in-cell simulation studies have pointed out that the drift kink instability (DKI) is triggered after the nonlinear saturation of the LHDI mode when the half-width of the current sheet decreases below the ion gyroradius [3], resulting in the reconnection enhancement and anomalous ion heating [4]. Local current sheet behaviors have been experimentally investigated by using toroidal plasma merging devices, in which self-organized magnetic reconnection events develops with small constraint from boundary conditions.

2. Experimental setup

Measurement of low frequency magnetic fluctuation in the vicinity of a current sheet was carried out in the TS-3 plasma merging device, shown in Fig. 1. Two plasma toroids are produced and merge through magnetic reconnection. Current sheet behaviors were observed by a 2D magnetic probe array and four arrays of fast pickup coils. Typical plasma parameters of magnetic reconnection with a guide field are shown in table I.

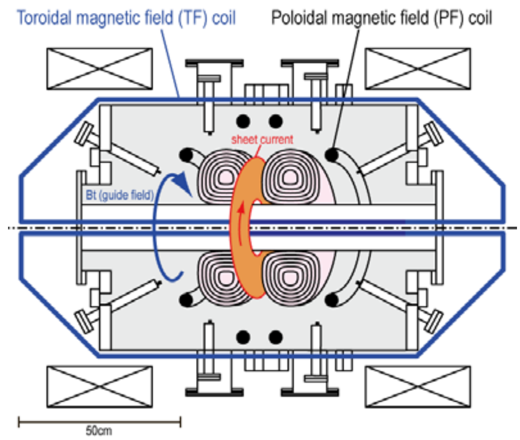

Fig. 1. Schematic view of TS-3 device

Table I. Typical plasma parameters

Reconnecting field	$B_r \sim 50$ mT
Guide field	$B_t \sim 40$ mT
Elec. density	$n_e \sim 1\text{x}10^{20}$ m^{-3}
Elec. / ion temperature	$T_e \sim T_i \sim 10$ eV
Current sheet width	$2\delta \sim 4$ cm
Current sheet length	$2L \sim 10$ cm
Ion gyroradius	$\rho_i \sim 1$ cm
Ion skin depth	$c/\omega_{pi} \sim 2$ cm
Ion cyclotron freq.	$f_{ci} \sim 1$ MHz
Lower hybrid freq.	$f_{LH} \sim 40$ MHz

3. Experimental results

The existence of the guide field brings drastic changes in the appearance of the magnetic fluctuation. Large magnitude of fluctuation with ion cyclotron range frequency ($\sim 2\omega_{ci}$) and parallel wavelength in the order of ion gyroradius was observed during the reconnection with a guide field.

Fig. 2 (a) shows the magnetic fluctuation signals observed inside the current sheet. Large-amplitude magnetic fluctuation with frequency of about 2MHz (see fig. 2(b)) was detected during the magnetic reconnection. Enhancement of the effective resistivity in the current sheet was also observed around the same time when the maximal wave amplitude up to 10 % of the reconnecting field was detected. These experimental results suggest that the drift-instability like current sheet modulation develops and enhances the reconnection rate.

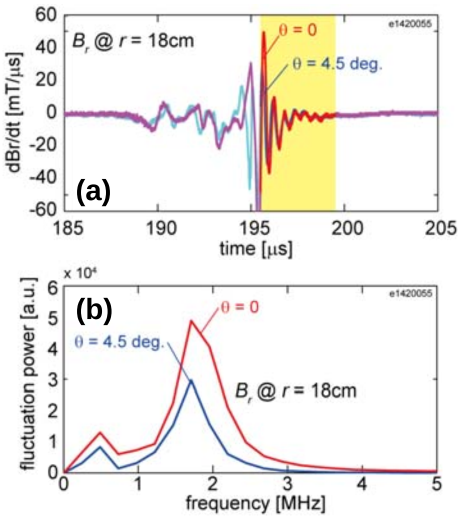

Fig.2. Magnetic fluctuation signals (a) and their Fourier spectrums (b) observed during magnetic reconnection with guide field.

The existence of the guide field provides propagation condition for kinetic Alfvén waves with wave number and frequency observed in the experiment. Thus, the long-wavelength current sheet instability in the guide field reconnection might couple with the kinetic Alfvén mode to develop to a large-amplitude and coherent waves inside the current sheet.

On the other hand, magnetic reconnection without guide field is accompanied by magnetic fluctuation near the end of and after the reconnection. The observed fluctuation frequency of 200-400kHz is close to that estimated from the motion of the reconnected field lines with m=1 and 2 deformation. This low frequency fluctuation may account for the significant ion heating in the reconnection without guide field observed in detail by a two-dimensional Doppler spectroscopy.

Plasmoid development was also observed in the guide field reconnection, resulting in a non-steady fast magnetic reconnection. Externally driven large inflow provokes tentative imbalance of the inflow and outflow fluxes, resulting in a density pile-up near the X point. The accumulated plasma in the current sheet is then suddenly released to develop transient fast magnetic reconnection, which is sometimes accompanied by current sheet / plasmoid ejection events.

4. Discussion

Current sheet behaviors have been investigated in the plasma merging experiment with various conditions of magnetic reconnection. The guide field primarily slows down the reconnection rate since it prevents the current sheet compression to increase the stability for microscopic mode which develops in ion or electron scales. However, once the inflow flux exceeds the outflow rate, the stored flux / energy around the current sheet brings some kinds of instabilities to enhance the reconnection rate.

Acknowledgments

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References

[1] R. S. Pandey and K. D. Misra: Earth Planets Space, **54**, (2002) 159.

[2] H. Ji, S. Terry, M. Yamada, R. Kulsrud, A. Kuritsyn, and Y. Ren.: Phys. Rev. Lett. **92**, (2004) 115001.

[3] R. Horiuchi and T. Sato: Phys. Plasmas **6**, (1999) 4565.

[4] Y. Ono, M. Inomoto, T. Okazaki and Y. Ueda: Phys. Plasmas **4**, (1997) 1953.