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3D dynamics of thin current layer formed during fast magnetic reconnection

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Magnetic reconnection is a common process in space and laboratory plasmas, facilitating fast release of energy stored in the compressed magnetic field into plasma kinetic and thermal energy. It is well known in theoretical and simulation studies that a thin current layer characterized by the electron inertia length is formed around the magnetic X-line associated with 2D magnetic reconnection. In the thin current layer, the electrons are intensely accelerated by the reconnection electric field and are quickly ejected toward the downstream region. This electron behavior gives rise to the electric resistivity, so-called the inertia resistivity, in the current layer, which results in the dissipation of the magnetic field and plays a significant role in the reconnection processes. However, it is easy to expect that such a thin current layer would be unstable to current driven modes which propagate in the current density direction and are artificially suppressed in the 2D system. In fact, the simulation studies in a 2D plane orthogonal to the magnetic field have revealed that the Harris-type current sheet is unstable to the lower hybrid drift instability (LHDI) and a kink instability. In particular, it has been suggested that in high mass ratio regime (mi/me > 100) the kink mode decouples into two modes: the ion-ion kink mode with kyL ~ 1 and a smaller-scale mode with an intermediate scale of the ion and electron Larmor radii. Because of the high nonlinearity and the limitation of computer resources, it has been very difficult to investigate the role of the current-aligned modes in magnetic reconnection.

In order to challenge large-scale 3D simulations of kinetic reconnection with high mass ratio (mi/me > 100), we have recently developed a massively-parallel code of the electromagnetic particle-in-cell (PIC) model with the adaptive mesh refinement (AMR). The AMR technique enables efficient high-resolution simulations of the current sheet evolution, while the parallelization on the distributed memory system allows us to use much computer resources for a single simulation run. Thus the massively-parallel AMR-PIC code is a strong tool to achieve the large-scale 3D simulations.

The present study investigates 3D effects of the reconnection processes for the cases of high mass ratio with mi/me > 100. The main difference between 2D and 3D reconnections is the fact that in 3D case the thin current layer is unstable to a kink mode even in a quasi-steady phase. The kink mode has a scale with kyLe ~ 1 and propagates in the ion drift direction, where Le is the half width of the thin current layer and is characterized by the electron inertia length. The mode is neither the LHDI nor the ion-ion kink mode. Since the wavelength is comparable with the electron meandering scale, this mode can scatter the electrons and yield the anomalous resistivity.

In this paper, we show the initial results of large-scale 3D simulations of magnetic reconnection and describe the 3D aspects of the processes in the thin current layer. The mechanisms of the magnetic dissipation and particle acceleration will be discussed.

Keywords: 3D magnetic reconnection, AMR-PIC simulation, dissipation mechanism, kink mode