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First Detection of High-Energy Electrons at X-point in Spherical Tokamak Merging Experiment

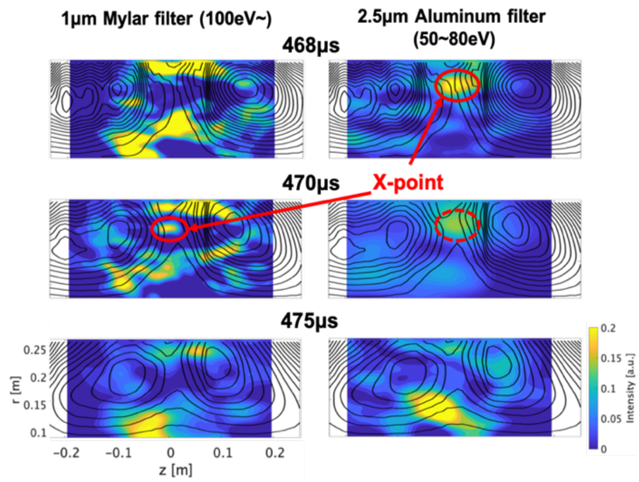
S. Takeda[1], Y. Okunishi[1], Y. Cai[1], H. Tanabe[1], Y. Ono[1]
[1] University of Tokyo
e-mail(speaker): stakeda@ts.t.u-tokyo.ac.jp

We developed a new stereotype soft X-ray camera system for high-energy electron distribution measurement of magnetic reconnection. Using two microchannel plates, a bifurcated optical fiber bundle, and a high-speed framing camera, time evolutions of two soft X-ray emission images with different energy bands were simultaneously obtained. In this system, the Phillips-Tikhonov regularization and GCV were used to reconstruct 2D soft X-ray emission profiles of two merging tokamak plasmas from their line-integrated images by assuming toroidal symmetry. This system successfully detected acceleration and heating at the X-point for the first time together with downstream heating of electrons during magnetic reconnection. It was also found that electron energy at the X-point increases with the guide toroidal magnetic field.

During magnetic reconnection, antiparallel magnetic field lines in the plasma approach together, reconnect with reconnection outflow. Through this phenomenon, the magnetic field structure changes drastically and the energy of the magnetic field is converted into kinetic and thermal energy of the particles in the plasma. Especially for electron acceleration and heating, PIC simulations [1] have confirmed the production of energetic electrons, and experimental studies of high-temperature, energetic electron production have been conducted in laboratory plasmas [2,3]. The measurement of energetic electron distribution is often performed by observing the Bremsstrahlung emitted from the electrons. In this study, we developed the stereo-type soft X-ray camera [4] that can simultaneously acquire two images of the emission distribution of Bremsstrahlung in different energy bands.

A small vacuum vessel (soft X-ray camera) containing a microchannel plate (MCP) was mounted on the TS-6 spherical tokamak merging experimental device. In this study, we used two filters, one made of mylar for high energy and the other made of aluminum for low energy. The field of view of a soft X-ray camera extends three-dimensionally, but by assuming axial symmetry of the plasma distribution, each line of sight constituting the field of view can be projected onto a single poloidal plane. Since the brightness of the image taken is a line-integrated value of the local emission intensity on the line of sight, the Tikhonov-Philips regularization and minimum GCV [5] were used to reconstruct the local distribution from the captured image.

The time evolution of the measured soft X-ray emission distribution is shown in Fig. The image in the left column is the high-energy image observed through the Myra filter, and the image in the left column is the low-energy image observed through the aluminum filter. In the high-energy image, the emission peak is localized at the X-point at t=470μs, and in the low-energy image, at t=468μs. When the magnitude of the toroidal guiding field is varied, the emission intensity near the X-point is found to increase with the guide field. This is probably due to electron acceleration by the reconnection electric field in the localized X-line area.



R-Z contours of 2D soft X-ray emission (color) with poloidal flux surfaces (black lines) for 1-μm-thick Mylar and 2.5-μm-thick Aluminum

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