World-wide Progress on Real Time 2-D ECE Imaging Programs

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Abstract

Based on well established fundamentals of the electron cyclotron emission (ECE) process [1] in fusion plasmas, a unique and ambitious real time 2-D ECE Imaging (ECEI) system on TEXTOR [2] was developed which demonstrated the advantage of high temporal and spatial resolution 2-D images over the conventional 1-D data in studies of the physics of the sawtooth crash. Here, the measured real-time 2-D images of the internal *m/n*=1/1 kink mode (sawtooth oscillation) common in tokamak plasmas were directly compared with those from various theoretical models from which the validity of each model was assessed [3]. The collection of a vast array of data provided the basis for the *random* 3-D local reconnection model for the sawtooth crash phenomenon [4]. An upgraded ECEI imaging system [5] utilizing newly developed microwave device technology including a "mini-lens" based collection system and optimized lens based optical system was tested. During commission of this new system, the study on sawtooth phenomena was focused on reconfirmation of the previous measurements, the identification of post crash patterns, and multiple reconnection processes which are closely tied with those from space plasma.

In the AUG imaging system [6] which is based on the improved detection system from TEXTOR and newly designed optics, measurements have been conducted on a wide variety of plasma instabilities, which include the edge localized mode (ELM) [7], neoclassical tearing modes (NTM), the sawtooth instability, and Alfvén waves [6]. To overcome the thermal noise inherent in ECE data, the data have been filtered by both singular value decomposition (SVD) and Fourier frequency filtering (see [6] for details). These ECE-Imaging data are the first local 2-D temperature measurements of RSAEs, and represent a valuable extension to previous 1-D temperature measurements [8].

On the DIII-D ECEI system [9], a capability of simultaneous measurement of two images is implemented with the zooming capability based on a two lens system as shown in Fig.1. Further studies on the sawtooth instability and Alfvén waves at DIII-D [10] have made use of improved image clarity to identify features which distinguish ideal MHD and non-perturbative predictions [10].

Subsequently, an advanced ECEI system was designed and implemented on KSTAR [11]. The generous access to the plasma and relatively modest constraints imposed by KSTAR on the optical elements, facilitated a new optical system based on triplet was designed for more versatility. Major improvements in the optical coupling schemes of ECEI diagnostics have allowed for the implementation of a wide range of vertical zoom capability with a maximum magnification of 3:1, and image focusing from the plasma edge to regions well to the inboard side of the core. Each of these features is implemented while meeting an appropriate wavelength dependent compromise between small viewing beam widths for adequate channel resolution and long confocal lengths for

uniformity over the radial extent of the imaged plasma. The DIII-D system makes use of a doublet zoom lens configuration while the KSTAR system implements a unique adaptation of the Cooke triplet lens [8, 19], which has only a single moving element and yet minimal optical aberration due to a carefully optimized parabolic correction of the plasma facing lens. For two KSTAR experimental campaigns (2010 and 2011), various studies were made including the detailed process of the ELM growth and burst [12] in the H-mode phase in KSTAR. In the 2011 campaign, the detailed images demonstrating change of the ELM characteristics in response to the n=1 magnetic perturbation as shown in the right hand side of the Fig.1.

In summary, visualization of the dynamics of instabilities such as the sawtooth oscillation (internal m/n=1/1 kink mode), NTMs, ELMs and wave dynamics is demonstrated through high resolution (spatial and temporal) ECEI systems. The ECE imaging system is fast becoming a standard tool for many existing tokamaks and has already produced extremely valuable physics results from TEXTOR, AUG, DIII-D and KSTAR. A new, wider coverage ECEI system has been developed for on EAST and is currently being installed and Tore Supra system is under design for the future.

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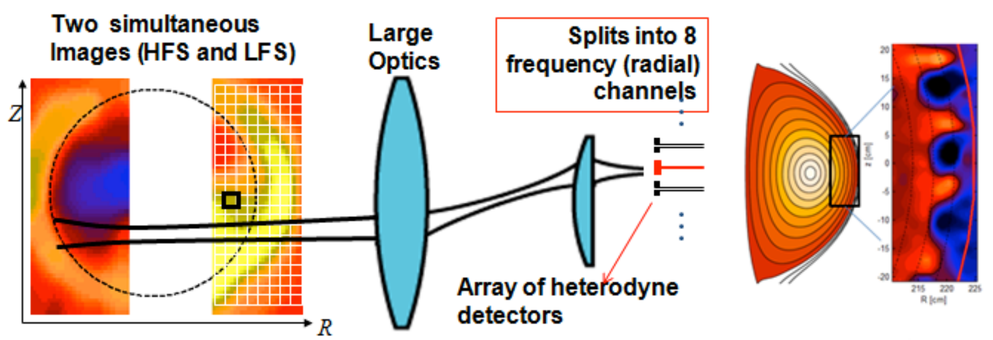

Fig.1. Schematic of the ECEI system (simultaneous measurement of two images at high and low field sides) and the structure of ELMs at the edge of the KSTAR plasma is shown.

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