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Tomography-based 2D plasma imaging for low and high temperature large-scale plasmas

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Recent trends in modern plasma diagnostics emphasize the imaging of plasma, which has been possible by powerful imaging and spectroscopic diagnostic tools. A combination of various imaging devices and selection tools for photon energy has offered ways of low-cost recording of selective spectral images. These imaging diagnostics can provide not only the 2D or 3D intensity distributions of emission from the plasma but also the 2D or 3D profiles of the physical parameters such as electron temperature. These are important particularly in harsh environments such as high temperature fusion plasmas where accessibility to the plasma is limited because of narrow space and high level of neutron flux. Measurement of plasma emission with high spatial and temporal resolutions can provide abundant information on plasmas such as precursor of sawtooth, trace-impurity injection for particle transport analysis, total radiated power and so on. The importance of the imaging diagnostics is also valid for low temperature industrial plasmas. As large throughputs and low production costs are key requirements in display panel and semiconductor industries, the size of the processing equipment has increased along with that of the substrate, even the scale of multiple meters. For this reason, a real-time monitoring or inspection of process uniformity has become critical for each process step, especially in plasma processing.

Emission spectroscopy has been commonly employed as a non-invasive diagnostic method for a wide range of plasmas. This technique is incredibly useful because of its non-intrusive nature, but it is difficult to directly obtain the spatially resolved information because the data acquired by the detector are line or volume-integrated emission intensity along the line of sight. The tomography technique, which mathematically reconstructs the local intensity from a set of line-integrated data, is sufficiently powerful for visualizing the inner plasma structure. However, implementing tomographic diagnostics for large scale plasmas is a nontrivial task because of the very limited projection, resulting in sparse information.

In this presentation, several examples of tomographically reconstructed images of tokamak plasmas, such as X-ray emission and plasma radiation power from the Infrared Red imaging Video Bolometer (IRVB), as well as low temperature plasmas are presented [1-12]. In particular, we show optical emission tomography diagnostics developed to measure spatial uniformity of meter-sized plasmas for display manufacturing. The lines of sight and detector location were selected based on tomographic reconstruction tests using synthetic phantom images. The developed pinhole cameras as collection optics are discussed, which consists of slits, plano-convex lenses, optical bandpass filters, and array detectors. Using the collection optics, the line-integrated emission was acquired from meter-sized rectangular radio-frequency plasma, which was developed for display manufacturing. From the measured emission, 2D spatial distributions of argon atomic emissions were obtained through tomographic reconstruction based on the Phillips–Tikhonov algorithm. The 2D argon plasma emission profiles match well with the shape of the electrode and etch profile. In addition, 2D profiles of the excitation temperature were obtained from the measured argon emissions.

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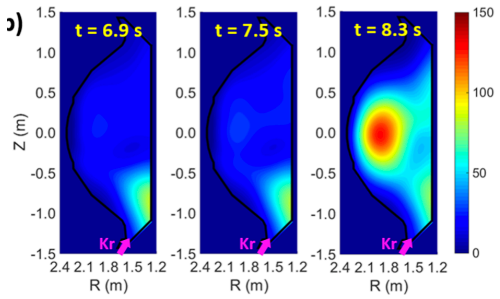

Figure 1. Tomographically-reconstructed cross-sectional radiation profiles at three time slices by Kr injection into the KSTAR plasma.

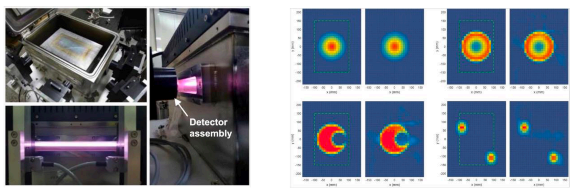

Figure 2. Plasma chamber with a tomographic diagnostic system for lab-scale low temperature plasma experiments, and examples of reconstruction. Phantom images are on the left and reconstructed images are on the right.