Ion temperature imaging in the divertor of the W7-X stellarator using coherence imaging spectroscopy

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A new coherence imaging spectroscopy (CIS) diagnostic has been developed to measure the ion temperature spatial distribution in the divertor plasma of the W7-X stellarator [1]. The CIS technique provides high-spatial-resolution (~1 cm) images of line-integrated impurity ion parameters, making it well-suited for diagnosing the 3D island divertor scrape-off layer in W7-X. While CIS is well-established for flow velocity measurements [2], measuring the edge ion temperature in magnetic confinement fusion devices has historically been challenging because the high magnetic field ($B > 2$ T) causes Zeeman splitting and Doppler broadening to have comparable effects on the spectral line shape [3]. To overcome this challenge, a new CIS instrument was designed that can distinguish between the contributions of Zeeman splitting and Doppler broadening to the overall spectral line width. The instrument employs the recently developed "pixelated multi-delay" configuration [4] to obtain four times the spectroscopic information as conventional CIS. A novel birefringent crystal design approach is used to minimize the instrument's sensitivity to Zeeman splitting. The instrument was deployed on W7-X and collected data throughout the entirety of the most recent experimental campaign. The CIS measurements of C^{2+} ion temperature, which is well-coupled to the main ion temperature in typical W7-X edge plasma conditions, are validated by cross-comparison with a high-resolution spectrometer whose sightlines overlap the CIS field of view. The CIS and spectrometer T_i profiles have the same shape and agree quantitatively to within ±10% on average across the profile and to within 25% in the worst case. Images of the T_i distribution in limiter-like and attached divertor plasmas show toroidally elongated bands aligned with the magnetic field, with T_i ranging from 10 to 40 eV. The ion temperature distribution is anti-correlated with the intensity of a C III line; i.e., the regions of largest carbon radiation have the lowest T_i. Ion temperature strongly influences erosion of plasma facing components, so this new diagnostic capability will aid the development of the physics basis for and projection of erosion in the W7-X island divertor concept.

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[2] V. Perseo et al., Rev. Sci. Instrum. **91** 013501 (2020).
[3] D. Gradic et al., Nucl. Fusion **61** 106041 (2021).
[4] J.S. Allcock et al., Rev. Sci. Instrum. **92** 073506 (2021).