OBSERVATIONS OF INTRINSIC TOROIDAL ROTATION USING X-RAY CRYSTAL SPECTROMETER IN ADITYA-U TOKAMAK

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Abstract

A tangential soft x-ray crystal spectrometer has been designed to observe He-like argon, Ar\textsuperscript{16+}, line emission at 3.9494 Å from Aditya-U tokamak plasma using curved crystal and two dimensional CCD detector. In order to simulate possible signal strength of line emission of interest, experiments were conducted to observe externally injected argon impurity in a typical Aditya-U plasma with ~100 kA plasma current and discharge duration of ~ 150 ms. Argon was puffed using Piezo electric valve and its line emissions in the lower ionization stages lying in the visible wavelength range were monitored using high resolution spectrometer CCD system. Simulation using 1-D impurity transport code STRAHL was carried out for Aditya-U plasma parameters and tokamak geometry to obtain emissivity profiles of Ar\textsuperscript{16+} line emission. From the experimental and simulation result, it has been deduced that for typical electron temperature of 500 – 1 keV and electron density in the range of 3 – 5 x 10\textsuperscript{19} m\textsuperscript{-3} in Aditya-U plasma, it is expected that Ar\textsuperscript{16+} line emission will be confined the region of plasma core. Also, with higher temperature the Ar\textsuperscript{16+} line emission will increase.

1. INTRODUCTION

X-ray crystal spectrometers have become important diagnostic for several tokamaks and stellarators [1-7] for their ability to provide profiles of ion temperature and plasma rotation velocities using Doppler broadening and Doppler shift of spectral line emissions respectively. The diagnostic can also provide electron temperature profile using intensity ratio of resonance line to satellite line emissions [8]. The diagnostic is also planned for future reactor like ITER as a crucial diagnostic to provide core ion temperature and plasma rotation [9] together with impurity concentration in the plasma edge region. The diagnostic is designed using focusing properties of a bent crystal to obtain x-ray spectra from ionized ions of medium to high Z impurities. These impurities can be both intrinsic and extrinsic in nature. In case of Aditya-U tokamak, soft x-ray crystal spectrometer has been designed [10] to observe He-like argon ions and measure electron temperature and intrinsic toroidal plasma rotation from the plasma core. Prior to the installation of the x-ray crystal spectrometer onto the tokamak for measurements, argon lines from lower ionization stages lying in the visible wavelength range were monitored using high resolution spectrometer-CCD system. The paper describes observations of these lines. Moreover, typical electron temperature and electron density profiles of Aditya-U plasma were used in 1-D impurity transport code STRAHL [11,12] to estimate signal intensity of He-like argon, Ar\textsuperscript{16+} line emission. The paper describes experimental observations, simulation results and conclusion.

2. EXPERIMENTAL SETUP

Aditya-U [13, 14] is a medium-sized air-core tokamak recently upgraded from Aditya tokamak [15] to the Aditya-U tokamak with divertor configuration. Aditya-U tokamak has maximum toroidal magnetic field, B\textsubscript{t} = 1.5 T, major (R) and minor (a) radii of 0.75 m and 0.25 m, respectively. The main scientific objectives of Aditya-U tokamak involve experiments relevant to large size fusion machines including ITER. These experiments include runway generation and dynamics, disruption prediction and mitigation studies together with plasma position control and confinement improvement studies with shaped plasma. The Aditya-U tokamak produces circular plasma in the limiter configuration with plasma current of 150 – 250 kA and plasma duration of 250 – 300 ms with electron density and temperature in the range of 3 – 5 x 10\textsuperscript{19}m\textsuperscript{-3} and 500 eV – 1 keV respectively. Moreover, it is designed to obtain D shaped plasmas with plasma current of 100 – 150 kA, elongation (k) ~ 1.1 -1.2 and triangularity ~ 0.45.
For the present measurements, a high resolution 1m f/8.7 Czerny-Turner configuration spectrometer equipped with a 1800g/mm grating was used together with a fast CCD with 1024 x 256 pixels having 26 µm pixel size. Light from the plasma was coupled to spectrometer using set of five fibers. These fibers were arranged on a tangential port covering plasma minor radius from ~ -2 cm to 17 cm. The spectrometer-CCD system has dispersion of 0.0144nm/pixel. Argon was puffed using Piezo electric value from the bottom mid-plane port of the vacuum vessel. Fig. 1 shows shot 32172 wherein argon was puffed for a small duration from 37 ms to 40 ms of the plasma duration. The discharge duration was small ~ 50 ms as shown in the fig 1.

![Shot 32172](image)

**FIG. 1. Shot #32172 showing argon puff on Aditya-U discharge.**

3. PRELIMINARY RESULTS

3.1. Observation of Argon lines

Fig 2 and fig 3 show preliminary observations of argon line emissions for shot 32172. Ar II line emission at 458.989 nm was observed together with other lines. Space resolved spectra shows presence of argon impurities up to the plasma core where core intrinsic toroidal rotation measurements will be performed using x-ray crystal spectrometer.

![Spectra](image)

**FIG. 2. Spectra showing Ar II line emission at 458.98 nm observed for the shot 32172 of Aditya-U tokamak.**
3.2. Simulation result using STRAHL code

As the Aditya-U tokamak has density in the range of $3 \times 10^{19}$ m$^{-3}$ and central electron temperature of 500 to 1 keV, emission from He-like argon will be confined to the region of plasma core. The spectral line emission for resonance line at 3.9494 Å is estimated for typical Aditya-U plasma using one dimensional impurity transport code, STRAHL. This code has been utilized on Aditya tokamak to study the oxygen impurity transport [16]. To simulate the He-like argon emissivity, the central electron temperature and electron density were considered to be $T_e \approx 500$ eV and $n_e \approx 3 \times 10^{19}$ m$^{-3}$ respectively. Fig. 4 shows the profiles of electron density and temperature used for the simulation. The calculation is done considering the Aditya-U tokamak plasma produced at its lower operating parameter range. The profile of diffusion coefficient is taken to be exponentially decaying having maximum value of $10$m$^{2}$/s at the plasma edge. Argon concentration was considered to be 0.2 % of $n_e$. Simulated emissivity profile, shown in Fig 5, suggests Ar$^{16+}$ emission up to minor radius of about 6 cm.

4. CONCLUSION

Argon line emissions in the visible wavelength range were monitored for a typical discharge on Aditya-U plasma. Argon line emission up to the plasma core was experimentally observed using the spectrometer-CCD system. Moreover simulation results using STRAHL code suggest Ar$^{16+}$ line emission up to 6 cm of plasma minor radius. With higher temperature and density in the Aditya-U plasma, the emission is likely to increase.
Based on the present measurements, it is possible to measure intrinsic toroidal rotation using x-ray crystal spectrometer on Aditya-U tokamak.

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