Argon Ion Temperatures in a 10 kW Helicon Source

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**SUMMARY**

A new Laser induced fluorescence (LIF) experimental setup is presented. An overview of the new LIF scheme is shown. Measurements of ion temperature and bulk flow perpendicular to the magnetic field are derived from ion velocity distributions (IVDFs) measured by LIF. Ion temperatures up to ~2 eV are observed at 10 kW, assuming Maxwellian fits to the ion velocity distributions. These measured temperatures exceed those predicted in previous work by colleagues.

**IMPLEMENTATION OF RESOURCE OPTIMIZED LIF APPARATUS**

The experiment was conducted in the Controlled Shear De-correlation Experiment (CSDX) [Thakur et al. Plasma Sources Sci. Technol. 2014]. Several improvements were made in the LIF experimental setup. A small fraction of laser light from the oscillator that passes through a turning mirror is collected into a single-mode fiber and coupled into a Burleigh 1580 wavemeter. The remaining laser power is modulated by rotating the current in the tapered amplifier stage of the laser. This setup allows simultaneous wavelength measurements and laser modulation without the need for an external chopper and without introducing instability into the oscillator. Because the modulated laser emission is fiber coupled into the experiment and the collected light is fiber coupled into the photomultiplier, there is no need for additional optics in the apparatus. The entire LIF system consists of the laser, the wavemeter, three fibers, and a detector.

Measurements were made at a base pressure of 6.2 mTorr in the source and at a magnetic field strength of 1000G.

**DEIONIZED (DI) WATER-COOLED RF SOURCE ASSEMBLY**

A photograph showing the new DI water cooled RF antenna assembly installed on the CSDX experimental device (before RF shielding is installed over the helicon antenna).

Measurements at higher rf powers are made possible by a new water cooled source design. The antenna is wrapped around two concentric hollow ceramic tubes. Deionized water flows between the walls of the ceramic tube to cool the antenna, allowing longer operating periods over an uncooled antenna at similar powers. Cooling also allows operation at higher forward powers than an uncooled antenna. At such high powers, rf shielding (not shown above) is necessary to avoid interference with diagnostics. Transients that lasted on the order of several minutes were observed in the plasma as the matching network was adjusted. At certain powers, the background ion emission was too strong to pick out the LIF signal. As such, temperatures and flows are not available at these powers.

**ARGON ION TEMPERATURES AND FLOWS AS A FUNCTION OF SOURCE POWER**

Measured ion temperatures as a function of source forward power. The measurements are made perpendicular to the magnetic field in the center of the core. Temperatures range from ~0.5 eV at 1.6 kW to ~2 eV at 10 kW. To date, these are the highest temperature ions measured by LIF in a helicon source.

**COMPARISON WITH PREVIOUS WORK**

Thompson et al. predicted ion temperatures > 1 eV at 10 kW forward power. The red curve is extrapolated from data taken on the Resonant Antenna Ion Device (RAID) at EPFL, Swiss Plasma Center [Thompson et al. Phys. Plasmas 2017]. Measured ion temperatures exceed those predicted.

Results in RAID as presented in [Thompson et al. Phys. Plasmas 2017].

**COMPARISON BETWEEN ION AND ELECTRON TEMPERATURES**

Preliminary measurements of ion and electron temperatures at $r = 0$. Electrons reach a peak temperature of ~9 eV at 10 kW. The ions reach ~2 eV at 10 kW. Electron temperatures are obtained from Langmuir probe measurements, while ion temperatures come from LIF.

Ratio of ion temperature to electron temperature as a function of rf power. The above curve is the ratio of the polynomial fits to the ion and electron temperature profiles, respectively. The ratio is relatively flat over the range shown.

**ELECTRON DENSITIES AND TEMPERATURES FROM LANGMUIR PROBE MEASUREMENTS**

Radial profiles of electron density at rf powers ranging from 2 - 5 kW. The probe is located 1.5 m downstream of the antenna. The density peaks at 4 kW.

Radial profiles of electron temperature at rf powers between 2 and 5 kW. The plasma scarping along the inner ceramic produces hot electrons around $r = 5$ cm.

**KEY RESULTS**

Successful implementation of a novel method for diode laser based LIF was demonstrated. This new LIF system has several advantages: the number of required components is reduced; the use of fiber optic cables eliminates the need for optical alignment beyond initial setup, and the entire apparatus is relatively easy to transport for use at other facilities.

The ion to electron temperature ratio is nearly constant over an RF power range of 1 to 10 kW. Ion temperatures perpendicular to the magnetic field up to ~2 eV at powers between 2 and 10 kW were observed. As the RF power increases, the ratio of ion to electron temperatures remains ~0.2.

Plasma density peaks at $10^{19} \text{ m}^{-3}$. Electron densities and profiles were evaluated using Langmuir probes. Peak electron density is $2 \times 10^{19} \text{ m}^{-3}$ at 4 kW. Electron temperatures up to ~9 eV were observed at 10 KW.

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