Helium operation of IShTAR in preparation of E-field measurements

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Introduction

The main goal of the IShTAR (Ion Sheath Test ARrangement) device is to study antenna near-fields in the presence of a magnetised plasma. The experiments will serve to assess theoretical predictions on RF sheaths. For antenna studies it is favourable to operate at tokamak edge-like conditions for density and temperature. While IShTAR has already been operated extensively in Ar and indeed shown that plasma densities up to 10^{17} m^{-3} and electron temperatures of about 5 - 10 eV are achievable [1, 2, 3], electric (E) field measurements will need to be done in He or H to allow modelling of the Stark and Zeeman effects on the spectral lines. The work presented in this paper concentrates on the characterisation of He plasmas parameters by spectroscopy in the upgraded magnetic configuration [1]. This provides complementary information to the data from the Langmuir and B-dot probes [2]. In addition preliminary results related to electric field measurements are shown.

Helium plasmas

The plasmas in IShTAR are created by an RF powered helical antenna in a separate glass tube, which is connected to the main vessel [1]. The RF power was scanned between 300 W and 2000 W. The ratios of He I spectral line intensities, at 667.8 nm, 706.5 nm and 728.1 nm (triplet), were recorded in the main vessel and at the plasma source. The two installed spectrometers consist of an Avantes Starline (AvaSpec - 3648) wide band (low resolution) overview instrument, and an Andor Shamrock750 high resolution spectrometer (focal length 750 mm), which is also suitable to resolve Stark effects by passive optical emission [4]. Figures 1A and 1B show ratios of He I line intensities at 706.5 nm and 728.1 nm resp. 667.8 nm and 728.1 nm, which are representative for the temperature resp. density evolution, as a function of the power absorbed in the plasma (P_{RF}). An increase can be observed with P_{RF}. Figures 1C and 1D show the evolution in time during a discharge. Further modelling in order to get quantitative numbers for the plasma parameters and also a detailed comparison with the data from the Langmuir probes is ongoing.

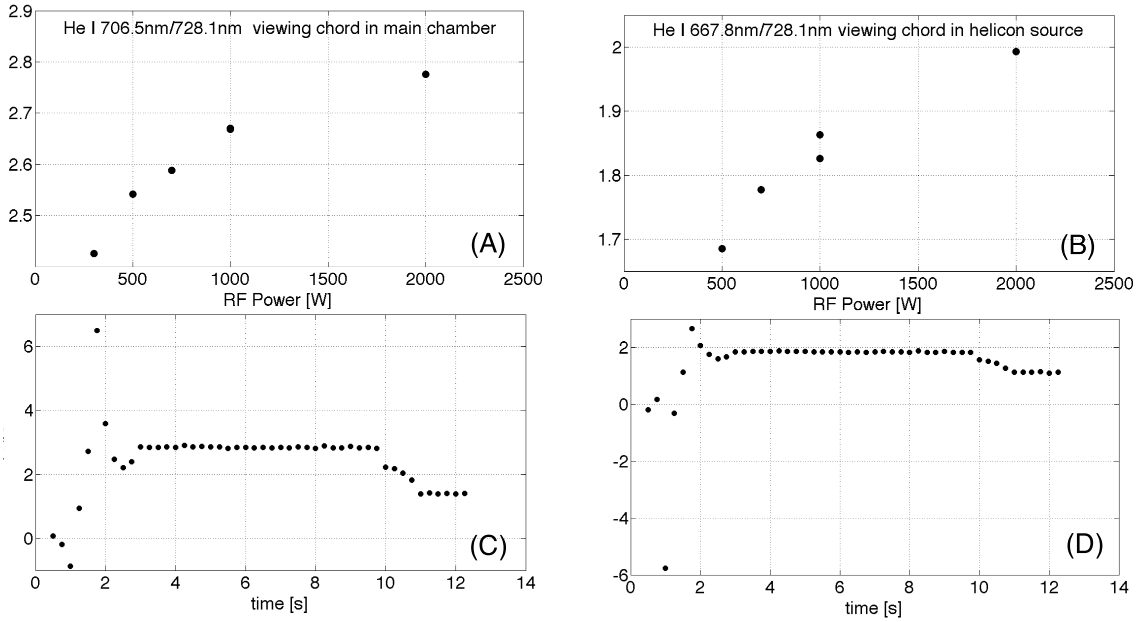

Figure 1: *Time averaged ratios of He I line intensities (A) 706.5 nm / 728.1 nm and (B) 667.8 nm / 728.1 nm vs. absorbed RF power. (C) and (D) corresponding time evolution for a plasma with* P_{RF} *= 1000 W.*

Electric field measurements

The distribution of the E-fields in the plasma and around the antenna components is a crucial input to all RF sheath models, but they are poorly diagnosed in the big fusion experiments, because of constraints in accessibility to install proper diagnostics and the challenging methods that are needed to measure the E-fields. The IShTAR project is developing several approaches, a theoretical benchmark can be found in [3]. Isolating the Stark effect caused by the E-field on the spectral line requires a very high resolution spectrometer as the one that has been installed, but even then Doppler broadening may hide the effect. In order to produce strong local fields an electrode was immersed in the plasma and several He I lines were recorded [4]. The best results so far have been obtained for the transition at 447.1 nm ($4^3D - 2^3P$). The shape of the line with and without an applied positive voltage of 1kV (ion repelling) on the electrode is shown in figure 2A. The sheath thickness is of the order of a couple of Debye lengths and thus depends on the local plasma density. In the main chamber a density in helium of 10^{15} - 10^{16} m^{-3} was measured. Therefore the E-field is estimated to be in the range of 1 - 10 kV/cm. The observed line shift corresponds to the modelling based on the fully quantum mechanical code, Explicit Zeeman Stark Spectral Simulator (EZSSS), for an electric field value of about 3 kV/cm (figure 2B) [5]. An alternative, but more complicated approach, is to use Doppler-free saturation spectroscopy (DFSS) to eliminate disturbing effects such as the Doppler broadening

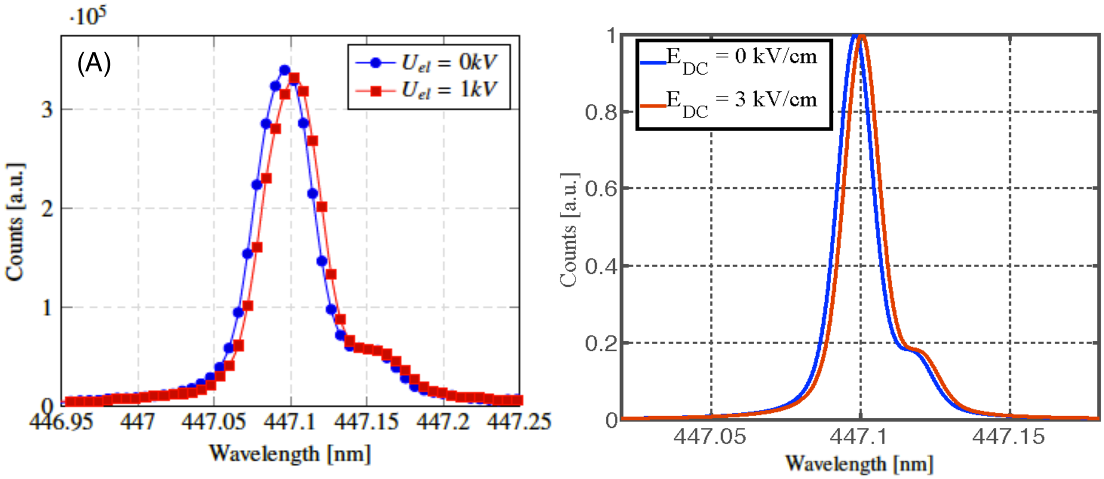

Figure 2: *(A) Time averaged spectra of* 4^3D-2^3P *He I line profile recorded with and without voltage applied to the electrode [4]. (B) Simulated spectra for* E_{DC} *= 0 kV/cm and* E_{DC} *= 3 kV/cm.*

and to highlight the E-field influence [6, 7, 8]. The system for IShTAR is still in its commissioning phase. The basic principle is to create a cross section in the plasma of overlapping pump and probe beams from the same laser source. The pump beam depletes the ground state, the probe beam passes the plasma with reduced absorption. By depleting the ground state, the fine structure of the spectral line should become more clearly visible, in the form of local dips in the Doppler broadened absorption line. As a first step the laser absorption in helium was indeed measured in a glow discharge plasma. The experimental set-up that was used is depicted in figure 3. The plasma pressure was 1.5 mbar, the voltage 2.5 kV and the current 100 mA. The laser was scanned over a range of 10 V at a scanning frequency of 1000 Hz. The mode hop range of the laser is 20 GHz . A clear absorption signal is seen at the central wavelength of 447 nm in the helium plasma (figure 4), which corresponds to the 0 GHz frequency on the graphs. It happens for both cases: without and with the presence of the pump beam. The Doppler broadening corresponds to a gas temperature of 400 K, in agreement with the theory of glow discharges.The spectral line shape in figure 4B however (with the pump beam activated) does not reveal a more clear fine structure, likely due to the relatively low density of the excited He states, which strongly affects the Doppler free signal intensity. Further alignment optimisations of the two beams are planned, as well as modelling with the EZSSS and DFSS codes [5, 8] to find the best possible working conditions for the set-up, before moving the system to IShTAR.

Conclusions

The characterisation of the IShTAR helium operation is ongoing. The two installed spectrometers offer possibilities to study the plasma parameters, which complement the probe diagnostics. In particular for the electric field measurements two different approaches are being followed. The first preliminary results at the electrode show that passive optical emission spectroscopy might be a suitable tool if the E-field is strong enough such that the Stark effect shifts

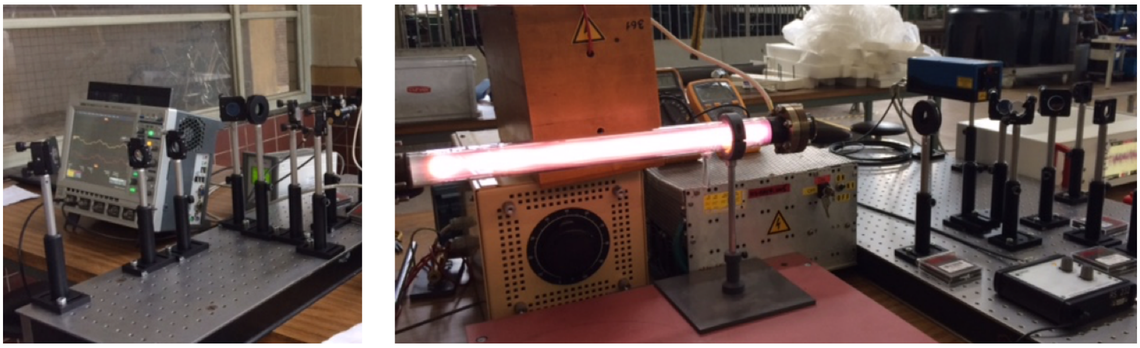

Figure 3: *Experimental set-up for testing the laser absorption in a helium glow discharge plasma.*

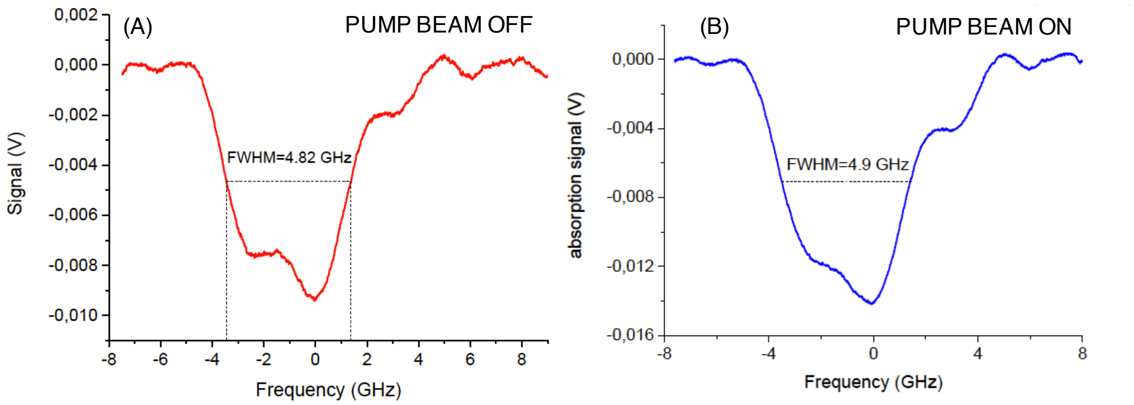

Figure 4: *Absorption of laser light in a He plasma: (A) probe beam only, (B) with pump and probe beam.*

and separates the lines out of the Doppler broadened width of the spectral line. In parallel a DFSS system is being developed, the more complicated method of installation and alignment, is rewarded by a much stronger sensitivity to E-field effects since the ground state is depleted, which makes the fine structure in the spectral line more visible.

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