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LIF-based model experiments on Ar II temperature and density measurements and the time-dependent collisional-radiative model for ITER divertor

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In order to improve operational conditions in ITER divertor, in the literature the concept was suggested to inject an "extrinsic" impurity to enhance the radiated power to protect the divertor plates. The rare gases (Ne, Ar, Kr) were selected for application of this technique. It makes it worth to apply LIF-technique to diagnose such impurities.

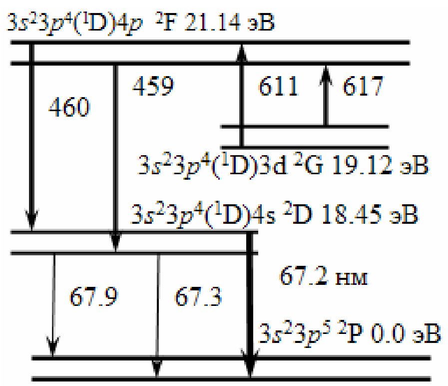

Fig. 1.
Diagram of the Ar+ ion levels involved in the LIF measurements: the 611.5 nm is used for optical pumping, while the 461.0 nm line is used for LIF measurements.

Neutral atoms and ions of rare gases could be used as trace particles for Doppler measurements of velocity distribution function (e.g., ion temperature) by laser spectroscopy method. Using of collisional-radiative model for atomic level populations gives an opportunity to calculate the concentration of Ar II by absolute measurements of Ar II spectral line intensities. Laser induced fluorescence (LIF) is a non-steady-state process therefore CRM should take it into account. As a first step, the static model was developed [1]. Now we develop a fully time-dependent model. Thus, duration of laser pulse and its temporal shape are taken into account.

The measurements were performed by a three-level spectroscopic scheme with a common upper level (see Fig. 1). Optical pumping from the $3d\ ^2G_{9/2}$ metastable level was produced at a wavelength of λ_L = 611.5 nm. The fluorescence signals were monitored at a wavelength of $\lambda_{FLU} \approx 461$ nm. This allowed us to avoid the parasitic effect of radiation scattered by the facility components and the elements of the optical tract.

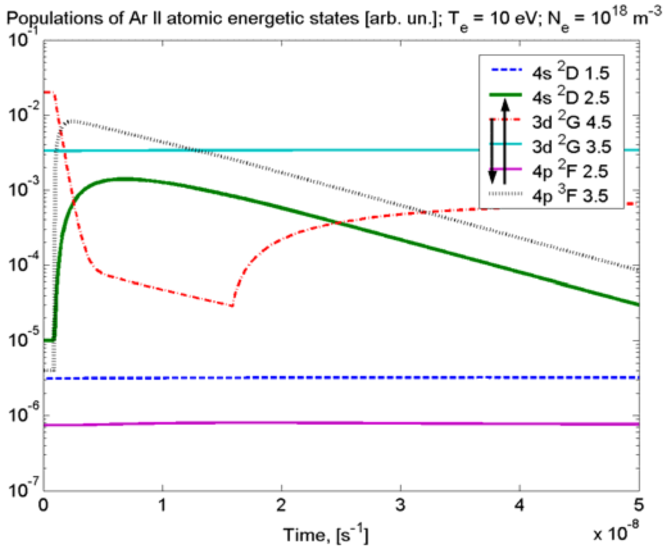

Fig. 2
Populations of Ar II atomic energetic states; T_e=10 eV; N_e=10^{18} m^{-3}

We took into account six excited states corresponding to the sublevels of the fine structure (see Fig. 1) This scheme can be extended substantially to include other excited states; however, a serious obstacle to this extension is a lack of reliable information on the lifetimes of the excited states and the excitation cross sections. For the probabilities of radiative transitions, we use the data from the NIST chemical kinetic database [3] and also the data from [4]. Calculations were performed for 15 ns duration of laser impulse. Temporal character of atomic kinetic is seen from figure 2. Laser pumping is from 3d ^{2}G 9/2 to 4p ^{2}F 7/2 and observable spectral line is 4p ^{2}F 7/2 → 4s ^{2}D 5/2. It is seen that influence of laser impulse on other states is small.

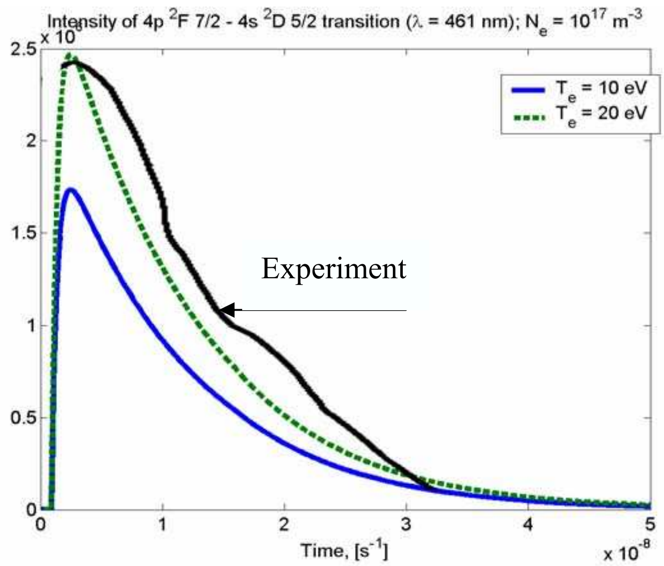

Fig. 3
Intensity of λ = 461 nm line for different electron temperatures and for electron density N_e=10^{17} m^{-3}

Good agreement with the experiment is seen from figure 3.

The measurements of Doppler-broadened profile of Ar^{1+} have been performed on plasma neutralizer PNX-U, which is a multicusp magnetic trap, in the discharges of low-input microwave power ($P_H \approx 12.7$ kW) (see Figure 4). Ionization and plasma heating are provided by the electron cyclotron resonance discharge.

Scheme of the Experiment

The arrangement of the LIF diagnostics is shown in Fig. 5. Figures 4 and 5 show the positions of the magnetic coils with an inner diameter of 0.6 m and the directions along which the laser beam was input in the system and the fluorescence radiation was output from it. The main measurements were performed in the central region of the plasma (at $R<R_0/2$, where R_0= 30 cm), where the magnetic field was relatively low. It is this plasma region that is used for ion beam neutralization.

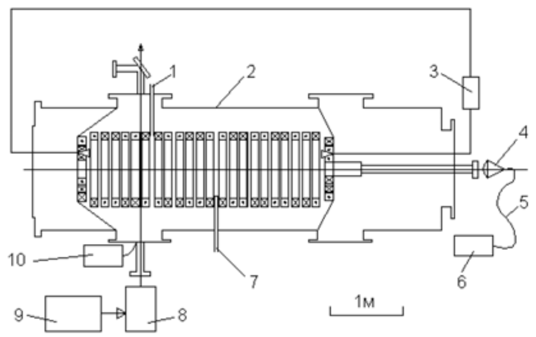

Fig. 4.
Arrangement of the diagnostic apparatus in the PNX-U facility: (*1*,*7*) microwave power inputs, (*2*) vacuum chamber, (*3*) 4-mm interferometer, (*4*) lens, (*5*) optical fiber, (*6*) monitoring spectrometer, (*8*) dye laser, (*9*) excimer laser, and (*10*) LIF spectrometer.

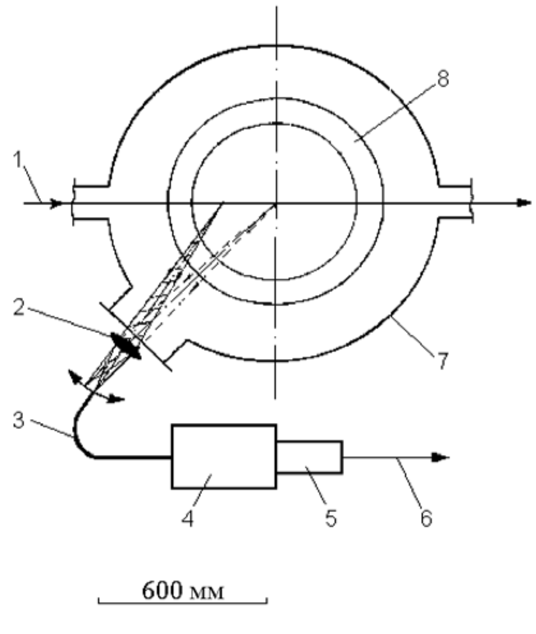

Fig. 5.
Arrangement of the LIF diagnostics in the transverse cross section of the PNX-U facility: (*1*) laser beam, (*2*) lens,(*3*) optical fiber, (*4*) MDR-23 monochromator, (*5*) photomultiplier,(*6*) to the system for recording photomultiplier signals, (*7*) vacuum chamber, and (*8*) magnetic coil.

The probing dye-laser beam passed through the plasma axis in a horizontal direction. The dye laser was optically pumped by a XeCl excimer laser with a pulse repetition rate of 100 Hz. The induced fluorescence radiation was collected by lens *2* (see Fig. 5), which

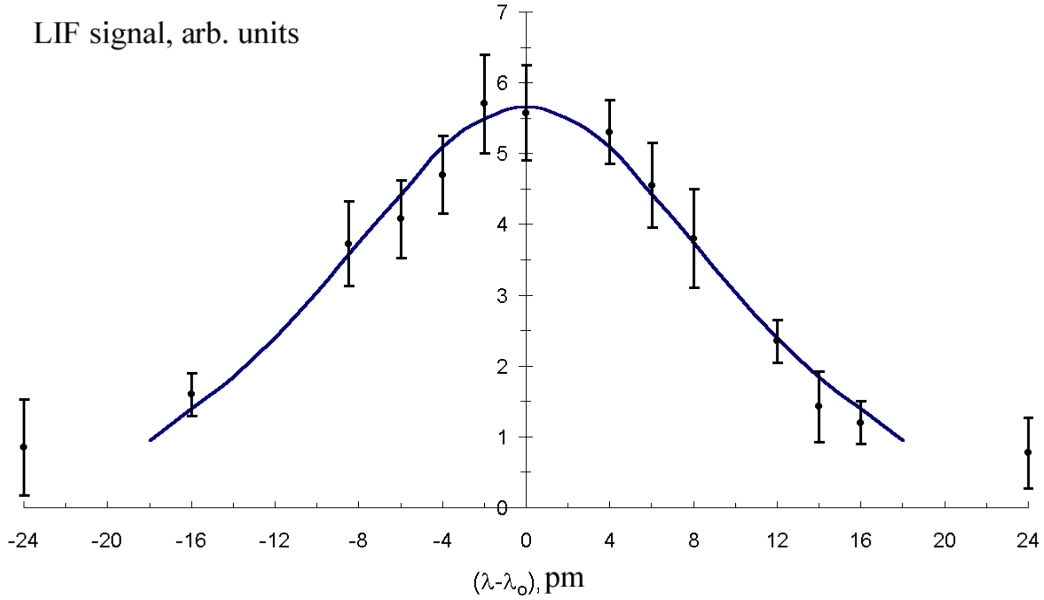

Fig. 6
Measured profile of the Ar^{1+} 611.5 nm absorption line for R = 0 cm and P_{mw} = 12.7 kW.

was a part of an optomechanical unit. The unit allowed one to scan the absorption line and to focus the LIF radiation onto the input end of an optical fiber, whose output was connected to the entrance slit of an MDR-23 monochromator. The spatial resolution along and across the laser beam was 4 and 0.3 cm, respectively.

An example of the line profile measured at the axis of the plasma column is shown in Fig. 6. After introducing corrections for the instrumental function, the line is described a Doppler profile, which points to a Maxwellian distribution of ions in the plasma core.

The study has been performed as a proof-of-principal of capability to apply this method to ITER divertor diagnostics.

References

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