Use of the method of resonance fluorescence wit a dye laser for plasma diagnostics in the FT-1 tokamak installation

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Resonance fluorescence on the H_a line was used for local measurements of the concentration of neutral hydrogen atoms in the plasma of the FT-1 tokamak installation. The hydrogen-atom concentration on the discharge axis at the maxima of the current was lower than 10^9 cm^{-3}.

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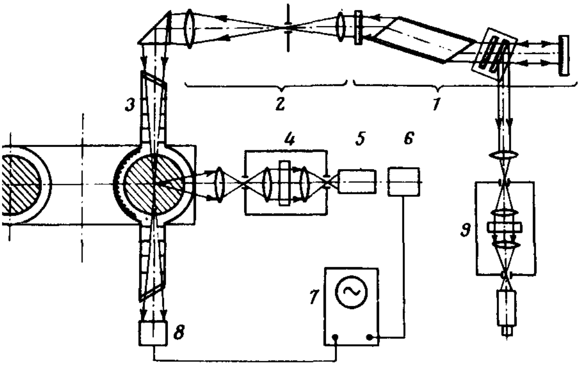
We have used, for the first time ever, the method of resonance fluorescence using a dye l for the diagnostics of a high-temperature plasma. This method has made possible local meas ments of the concentrations of the neutral hydrogen atoms in the tokamak plasma. The lower li of the measured concentrations was less than 10^9 atoms/cm^3. The measurements were perfor with the FT-1 tokamak installation[1] in a discharge with a current up to 27 kA, in a magnetic fi 7.5 kOe. The electron temperature was $T_e = 300$–350 eV, and the electron density $n_e = 1 \times 10^{13}$ cm^{-3}. The hydrogen pressure in the chamber was 7×10^{-5} Torr.

To excite the fluorescence signal of the neutral hydrogen atoms on the H_a line ($\lambda = 6563$ Å) used a laser operating with solutions of organic compounds and pumped with a lamp. The widt



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lasing line was approximately 8 Å, and the energy of the generation pulse reached 0.05 J at a ation 2.5×10^{-6} sec.

The experimental setup is shown in Fig. 1. Its principal elements are: (1) laser with continu-ly tunable frequency, (2) optical-beam shaping system consisting of two lenses with focal ;ths 250 and 750 mm and a 2-mm diaphragm, (3) system of blackened diaphragms for the entry exit of the laser radiation from the discharge chamber, a light trap opposite the observation dow, (4) an MDR-2 monochromator, (5) an FÉU-84 photomultiplier serving as a radiation ·iver, (6) a pulse amplifier, (7) an S8-2 oscilloscope, (8) a laser-energy meter (calibrated FÉK-15 ‹ial photocell), and (9) a DM-1 diffraction monochromator with a microscope, intended to ıitor the laser frequency.

The laser beam in the chamber had an approximate diameter 1 cm. The solid angle in which light was gathered was 4×10^{-3} sr. The fluorescence radiation was observed at an angle 90° to laser-beam axis. The investigated section of the plasma was projected on the monochromator with a reduction of 1:5.

To determine the absolute value of the fluorescence signal we calibrated the apparatus by g the Rayleigh scattering of the laser radiation in argon.

In the experiments with the plasma the spectral density of the laser radiation was approxi-ely 10^3 W/cm^2 Å. When the laser radiation is applied under these conditions the populations of ıpper and lower levels, corresponding to the transition on the H_α line, are practically saturated, the fluorescence signal, as shown by measurements, ceases to depend on the laser power.

Figure 2 shows oscillograms of the observed signals. On the lower trace one can see the rescence signal against the background of the noise component of the emission (instant of time The signal amplitude corresponds to a neutral-hydrogen atom concentration 2.5×10^9 cm^{-3}. The nd signal (instant t_2) corresponds to the light pulse from a light-emitting diode located near the omultiplier cathode. The control pulse of the light-emitting diode made it possible to trace the ation of the sensitivity of the recording apparatus in observations of the signals due to rescence and to Rayleigh scattering by the gas. The upper trace is the output signal of a rated photoreceiver and is proportional to the laser energy.

The absolute value of the fluorescence signal (the number of photons G from a unit volume a unit solid angle) is obtained by measuring the amplitude of the observed fluorescence signal, g the results of the calibration of the sensitivity of the apparatus. The measured number G of fluorescence photons is used to calculate the increment ΔN_3 of the population of the third

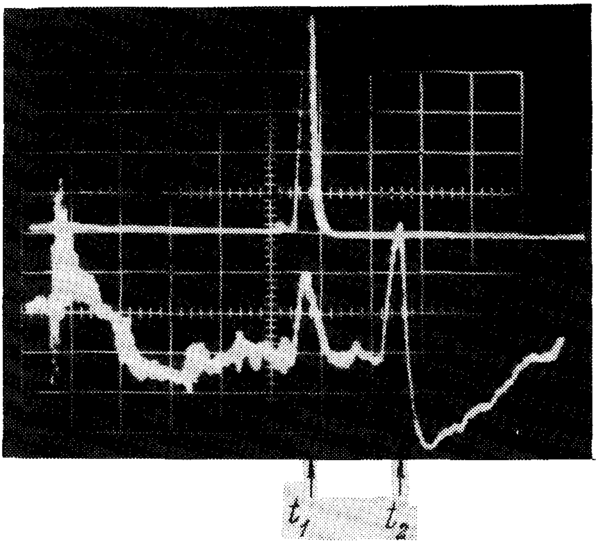

FIG. 2

excited level, due to laser radiation, and hence the initial population N_3 of the third level (in th absence of laser radiation). The values of ΔN_3 and N_3 are obtained from the expressions[1)]

$$\Delta N_3 = \frac{4\pi G}{A_{32}\tau},$$

$$1 + \frac{\Delta N_3}{N_3} = \left(1 + \frac{R_2}{R_3}\right)\frac{A_{32} + A_{31}}{\frac{g_2}{g_3}A_{21} + A_{31}},$$

where A_{ki} are the probablities of the spontaneous transitions between the levels with the princip quantum numbers k and i. R_2 and R_3 are the probabilities of excitation of the hydrogen atoms fro the ground-state level to the levels $n=2$ and $n=3$. g_2 and g_3 are the statistical weights of the seco and third excited levels, and τ is the duration of the laser pulse.

In a high-temperature plasma, the ratio R_2/R_3 depends little on the electron temperature For our plasma, with an electron temperature higher than 100 eV, the values of ΔN_3 and N_3

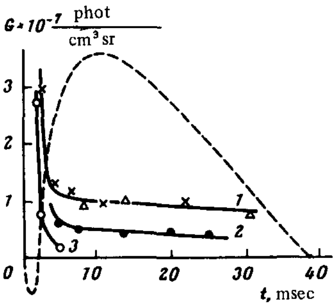

FIG. 3. Variation of the fluorescence signal in the course of the discharge. Crosses—regime with discharge current 17 kA. Remaining points—discharge current 27 kA. Dashed curve—discharge current.

en by formulas (1) and (2) are $0.117G$ and $0.083G$, respectively. The neutral hydrogen atom ncentration in the ground state can be determined from the population N_3 of the excited state m the known values of the relative populations of the excited levels, data on which are given in[4] different values of n_e and T_e. Figure 3 shows the values of the fluorescence signal measured at ferent instants of time elapsed from the start of the discharge (the experimental points are erages over several pulses). The measurements were made at a distance 10 cm from the discharge s (curves 1 and 2) and on the discharge axis (curve 3). The rapid decrease of the fluorescence nal at the start of the current after the preliminary ionization pulse corresponds to a decrease in concentration of the hydrogen atoms as a result of ionization. Curve (1) was obtained in a charge with inadequate vacuum conditions. The concentration of the neutral hydrogen atoms r the maximum of the current was in this case $N_1=2\times10^9$ cm^{-3}. In the standard regime (curve after prolonged heating and conditioning with discharges, the concentration of the neutral drogen at the current maximum decreased to $N_1=1\times10^9$ cm^{-3}. The fluorescence signal on the charge axis, in the standard regime (curve 3), decreases rapidly with time and becomes comparle with the noise at 5 msec after the start of the discharge. The concentration of the neutral drgen atoms at the center plasma pinch and at the instant of the maximum current is lower than cm^{-3}.

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ormula (2) is valid for saturated laser power. It was derived from more general expressions ited in[2] under the assumption that in a tokamak plasma, at an approximate electron density 10^{13} m^{-3}, the levels $n=2$ and $n=3$ are populated in the absence of laser radiation by electron impacts om the ground state, while the excited levels relax via spontaneous emission.

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