Resonant-fluorescence plasma diagnostics near the chamber wall in the TUMAN-3 tokamak

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Experiments have been carried out on plasma diagnostics near the chamber wall in a tokamak. The spatial and temporal distributions of impurity metal atoms have been found during ohmic heating and during adiabatic compression.

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A resonant fluorescence method has been used for plasma diagnostics near the wall of the discharge chamber in the TUMAN-3 tokamak. The TUMAN-3 was designed for studying combined adiabatic compression along the minor and major radii by means of an increasing magnetic field.[1] The major radius of the chamber is 55 cm, its minor radius is 25 cm, and the limiter height is 1–1.2 cm. The all-metal discharge chamber has a wall 1.2 mm thick made of a nickel-chromium alloy. The longitudinal magnetic field in these experiments was 0.3–0.4 T during ohmic heating and reached 0.9 T during adiabatic compression. The ohmic-heating current was about 70 kA, and the electron density was about 10^{13} cm^{-3}.

The particular version of the diagnostic apparatus which was developed was intended for exciting and detecting the fluorescence of Fe and Ni atoms near the TUMAN-3 chamber wall. The possible excitation of atoms from the various fine-structure levels of the FeI a^5D and NiI a^3F states is taken into account. This apparatus can also be used to study several other atoms and ions, in particular,[2] TiI, TiII, CrI, and AlI. The fluorescence is excited by the second harmonic of the beam from a rhodamine 4C laser ($\lambda = 285$–310 nm). The dye is pumped by the second harmonic of a neodymium-glass laser. The power in the ultraviolet pulse is 20–50 kW, and the pulse length is about 20 ns. The optogalvanic effect in LSP-1 hollow-cathode tubes is used to tune and monitor the wavelength of the UV probe beam within 0.01 nm.

In the experiments we studied the spatial and temporal distributions of the density of iron atoms. The resonant line FeI $a^5D_4 - y^5D_4^0$ was excited ($\lambda = 302.06$ nm). The linewidth of the probe beam (0.03 nm) was greater than the Doppler width of the absorption lines of the impurity atoms near the tokamak wall.[3] The fluorescence of the iron atoms was observed at a shifted line corresponding to the transition $y^5D_4^0 - a^5F_5$($\lambda = 382.04$ nm), so that it was possible to substantially lower the level of parasitic scattering. The laser beam entered the chamber through a vertical branch pipe, perpendicular to the equatorial plane of the torus. The inner wall of the laser branch pipe (made of the nickel-chromium alloy) was covered with stainless steel foil to increase the number of impurity iron atoms entering the discharge. The edge of this foil protruded about 10 mm beyond the branch pipe into the chamber but remained within the shadow of the limiter. The fluorescence was observed in succession from various parts of the plasma along the axis of the branch pipe inside and outside the shadow of the limiter. The laser beam had a rectangular cross section, 2×0.5 cm, with the long direction along the observation axis. Light was collected from a solid angle of about 5×10^{-3} sr. The region of the plasma along the laser beam was projected by a system of two lenses onto the slit of an MDR-2 monochromator with a threefold reduction. The entrance and exit slits, 1 mm wide (the spectral width was 2 nm), limited the spectral interval of the intrinsic emission of the plasma.

The measurements were taken under conditions corresponding to saturation of the excited optical transition (the saturation parameter was $S\approx10$). Under these experimental conditions the lowest detectable density of iron atoms was about 3×10^6 atoms/cm^3. The sensitivity was limited primarily by fluctuations in the photocurrent from the cathode of the photomultiplier caused by the fluorescence. The noise of the intrinsic emission of the plasma during the measurement of the fluorescence from a region in the shadow of the limiter was several times smaller than the amplitude of the signal of interest.

Figure 1 shows the time evolution of the density of impurity iron atoms near the chamber wall for two discharge regimes. In the ohmic-heating regime the maximum

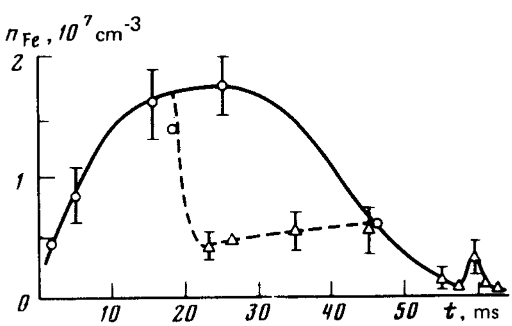

FIG. 1. ○—Ohmic heating; △—adiabatic compression (the compression beings at $t = 20$ ms).

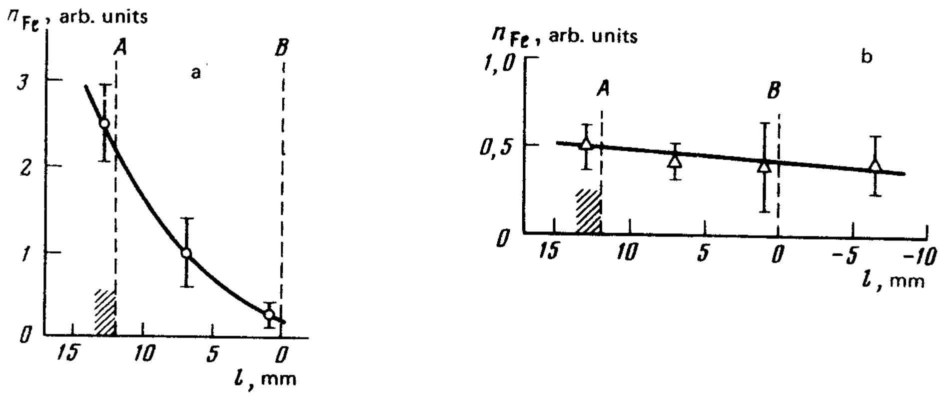

FIG. 2. a—Ohmic heating; b—adiabatic compression. Here B is the edge of the limiter, and the interval AB is the shadow of the limiter.

density of iron atoms was detected during the central stage of the discharge and had a value of about 2×10^7 cm^{-3}. We see that the plasma compression causes a significant decrease in the influx of impurity atoms from the wall.

Figures 2a and 2b show the spatial distributions of the iron atoms near the chamber wall. In the ohmic-heating regime the neutral iron atoms are observed only within the shadow of the limiter. The density of these atoms falls off rapidly from the wall to the edge of the limiter. The apparent reason for the low iron density at the edge of the limiter is the high rate at which the iron atoms are ionized by electron impact at the boundary of the plasma column, defined by the limiter. A very different spatial distribution of iron atoms is observed during adiabatic compression. The densities at the edge of the limiter and about 10 mm closer to the center of the plasma differ only slightly from the density near the wall. The probable reason for this result is the decrease in the ionization rate which results from the decrease in the electron density near the limiter.

In addition to studying the impurity iron atoms in the TUMAN-3 we measured the density of nickel atoms. The transition $a^3F_4 - y^3F_3^0(\lambda = 301.91$ nm) was excited. We observed the fluorescence signal corresponding to the transition $y^3F_3^0 - a^3D_2$ ($\lambda = 310.15$ nm). The maximum density of Ni atoms measured near the wall was (2–3)$\times10^7$ cm^{-3}.

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