Hα spectroscopy for hot plasma parameters measurement

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Abstract

The new spectroscopic method for measurement of hot plasma parameters is developed. The method based on Hα profile monitoring. The profile was accurately calculated for a wide range of plasma parameters ($n_e \sim 10^{14} \div 10^{17}$ cm$^{-3}$, $T_e \sim 1 \div 500$ eV). Use of the method in the experiment gives the electron density and ion temperature dependence from the time. Measurements was in a good agreement with diamagnetic loop dates.

Key words: Hα spectroscopy, line profile, density and high temperature measurement.

1 Introduction

The use of Hα profile for measurement of plasma density founded on H.R.Griem calculations [1] of Hα line broadening in a low temperature plasma (1÷4 eV). The later works (see, for example [2,3,4]) only refine these calculations. So, application of Hα spectroscopy was limited by temperature of investigated plasma. But Hα line is very strong in the hot plasma too! This can be caused by both background hydrogen penetration in the plasma volume or artificial implantation of the hydrogen. The Hα profile of a hot plasma have a strong dependence of the plasma density and the ion temperature. For the definition of these parameters with Hα line contour we made the accurate calculation of Hα profile in a wide range of main variables ($n_e \sim 10^{14} \div 10^{17}$ cm$^{-3}$, $T_e \sim 1 \div 500$ eV). The range can be widen.

2 Hα contour calculation

The main simplifications that had been used by authors are dipole approximation of the interaction potential between atomic electron and flying over electron

$$V(r) \approx e \frac{r_0 r_e}{r^3}$$

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Figure 1: H\_\alpha profiles at low temperatures. Parameter $\alpha = \Delta \lambda / F_0$ [\AA/CGS]. $\Delta \lambda$ - distance from the line centre (in \AA), $F_0 = 2.6 \cdot e \cdot n_e^{2/3}$ - characteristic electric field strength of micro fields near the atom (in CGS system).

and the connected approximation of far pass

$$\frac{1}{\hbar} \int V(r) dr \ll 1$$

that permits to simplify the calculations (see, for example [1]). With temperature rise the role of close passes is increased. And the dipole approximation have to be changed by multipole (see [3,4]). But such approach is diverged when the temperature is close to ionization potential.

We decline both approximations and use for calculations the exact potential

$$V(r) = \frac{e}{|r_e - r_a|} \exp\left(-\frac{r_e - r_a}{R_D}\right)$$

that takes into account Debye shielding effect.

In the calculation process we avoid any simplification and get the precision profiles for any plasma density and electron temperature with H- ALPHA programme. Estimated accuracy of calculations was less than 3%.
To check our calculations we compare it with H.Griem dates (see Fig.1). Our calculations are in a good agreement with Griem’s ones for low temperature.

Noticeable difference arises on a far wings of the line where the influence of close passing electrons is substantial and Giem’s calculations are not correct.

Our calculations for higher temperature are shown on Fig.2. With temperature increasing the profile becomes more narrow.

3 Use of H\textsubscript{\alpha} profile for hot plasma parameters measurement

Real H\textsubscript{\alpha} profile is the convolution of the Stark broadening contour and the Doppler contour (see Fig.3). The wings of the contour is mainly defined by the Stark broadening, but the centre of the line is defined by Doppler effect. Since the electron density can be determined from the wings of experimental contour and the centre of the line is the region for T\textsubscript{i} measurement.

Figure 3: The convolution of Stark and Doppler contours.
The experiments on measurement of ne and $T_i$ was carried out on GOL3-II device [5] in the regime when the expansion of the dense hydrogen cloud along the plasma column was investigated. Luminosity of $H_\alpha$ line was observed in the transverse direction of the column in the middle of it. The apparatus permits us to get the profile every 5 µs.

Density and temperature of the plasma was measured with fitting of the theoretic contour to the experimental one by changing of $T_i$ and ne parameters (see Fig.4). The dependence of measured plasma parameters from the time is shown on Fig.5. The ion pressure was got by multiplication of measured temperature and density. It compares with the full pressure measured by diamagnetic loop. First 20 µs these two dates are not coincide because the electron temperature is higher then the ion temperature in this time.
But after the temperatures becomes equal the spectroscopic measurement becomes in a good agreement with the diamagnetic loop dates.

Initial growth of the density is caused by hydrogen cloud motion. The density and temperature rise in 120 $\mu$s is connected with foil vapour cloud that reaches the observation point in this time. The foil cloud expands in the hot plasma medium ($T_e \sim 100$ eV) that causes the rise of density and temperature on the edge of the cloud. The jump of density and temperature on the back side of the edge cloud we connect with breaking off of the density rarefaction wave.

4 References

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