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Pellet Cloud Investigation via Imaging Spectroscopy in LHD

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Introduction. Understanding the plasma-pellet interaction requires experimental information about the spatial distribution of radiation and plasma parameters in the pellet vicinity. This paper is devoted to simultaneous measurements of local of electron density and temperature 2-D distributions in the cloud surrounding polystyrene pellet during ablation. Experimental observations of the pellet's luminous cloud in LHD plasma are performed using multi-filter device NIOS (Nine Image Optical System) [1, 2].

Experimental setup. In addition to previous results [4] new data were obtained by simultaneous imaging of the pellet cloud through interference filters in 9 spectral intervals with theexposure time of 10-30 s. The filter parameters are given in Table 1.

Table 1. Parameters of the NIOS interference filters:

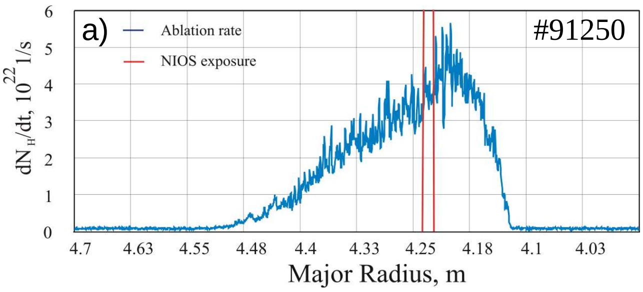
Filter	Stark №1	Stark №2	Stark №3	Stark №4	Stark №5	Stark №6	Stark №7	Cont.	H full
Central WL, nm	484.97	485.39	485.60	485.78	485.97	486.12	486.94	630.45	486.5
FWHM, nm	0.32	0.34	0.29	0.27	0.31	0.31	0.31	4.95	10.
Aperture Ø, mm	4.7	3.9	3.6	3.5	3.4	3.4	3.9	3.5	1.4

WL –wavelength, FWHM - Full Width on Half Magnitude

The pictures, which have been made through the first 7 filters with narrow spectral characteristics, were used for measurements of H spectral shape at every point of the cloud. The 2D local distributions of electron density were restored from the Stark broadened H spectral width. The last two filters in Table 1 were used to determine total H_β-line to continuum (in line free region) intensities ratio.

Experimental results and discussion. The ablation rate evolution measured using H_α emission of TESPEL cloud is shown in Fig. 1a by blue line, the NIOS exposure interval (30 s) is marked by vertical red lines. Plasma parameters were T_e = 1.0. keV, $n_e \approx 3\times10^{19}$ m^{-3}

at the region where the image shown in Fig.1b was obtained. Parameters of #91250 LHD shot were: W_{Pmax} = 1.18 MJ, $n_e(0) \approx 3\times10^{19}$ m^{-3} electron density, $T_e(0)$ = 1.46 keV electron temperature, R_{ax} = 3.80 m magnetic axis radius.



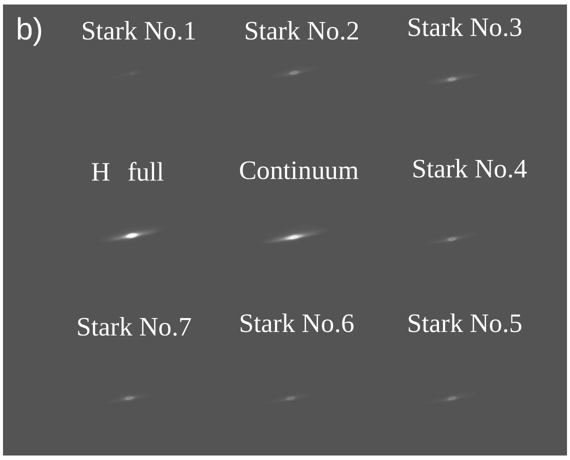


Fig. 1. a) The ablation rate temporal evolution of TESPEL pellet in LHD shot #91250;
b) Example of NIOS measurements in the #91250 LHD shot. Exposure time is 30 s.

It is seen that the cloud tilt angle is the same in all images and its value is close to the vacuum magnetic field tilt angle value of about 10 degree calculated for the TESPEL position. 2-D images of the pellet cloud presenting radiation distributions I_λ(x,y), were first made symmetric relative to the cloud axis and then were processed using the Abel inversion for determining radiation distributions I_λ(r,z), in cylindrical co-ordinates *r* and *z* with the latter being oriented along the pellet cloud axis and parallel to the magnetic field in plasma.

The electron density distribution $N_e(r,z)$ was determined from H spectral width measurements using the following relationship [2]:

$$N_e = \sqrt[1.03905]{2.3795\times10^{21}(\Delta\ )^{3/2}} \quad \text{m}^{-3} \tag{1}$$

where $\Delta\lambda$ – is a H FWHM in Å.

The cloud temperatures $T_{cl}(r,z)$ were determined using $I_H(r,z)/I_{Cont}(r,z)$ ratio by means of the relationship from Ref. [3] under assumptions of the partial LTE and cloud transparency both for continuum and H radiation:

$$\frac{I_{line}}{I_{cont}} = \frac{3^{3/2}\ \ ^3(137a_0)^2\cdot f_{line}\cdot g_{line}\cdot\ \ ^2_{cont}\cdot\exp\left(\frac{E_\infty - E_{line}}{T_{cl}}\right)\cdot\exp\left[\frac{\frac{h\cdot c}{_{cont}}-\frac{h\cdot c}{_{line}}}{T_{cl}}\right]}{2\cdot CCC\cdot\ \ ^3_{line}\cdot\Delta\ \ \cdot g_i\left(\left(\frac{g_{ff}}{2}\right)\cdot\left(\frac{T_{cl}}{E_H}\right)\cdot\exp\left(\frac{E_H}{n'^2\cdot T_{cl}}\right)+\sum_n\frac{g_{fb}}{n^3}\cdot\exp\left(\frac{E_H}{n^2\cdot T_{cl}}\right)\right)} \tag{2}$$

where f_{line} is the oscillator strength, g_{line} и E_{line} are the statistic weight and energy of bottom level of line, g_i is the ion statistic weight, E_∞ is the ionization energy ($E_\infty = E_H$ for hydrogen),

a_0 is the Bohr radius, $_{line}$ is the line wavelength, $_{cont}$, Δ_{cont} are the continuum's wavelength and interval width, *CCC* is a factor of carbon ions contribution in continuum radiation.

The smoothed distributions of electron temperature $T_{cl}(r,z)$ and density $N_e(r,z)$ along and across magnetic field are shown in Fig. 2a, b and Fig. 2c, d correspondingly. One can see that both distributions of $T_{cl}(r,z)$ and $N_e(r,z)$ demonstrate a wide plateau region. Cloud temperature profiles have a colder region in the pellet vicinity. The measured values are in reasonable agreement with simulations of cloud parameters of carbon pellets injected into W-7AS plasmas [5].

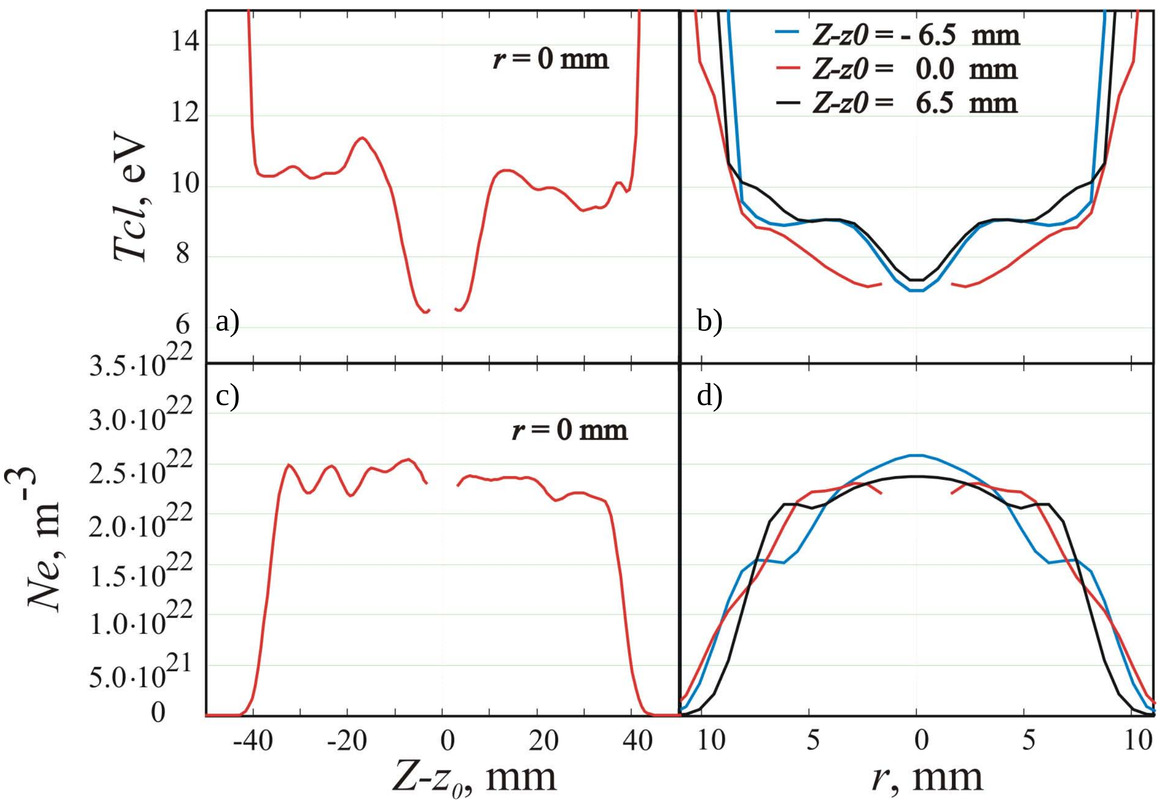


Fig. 2. The smoothed distributions of local electron temperature $T_{cl}(r,z)$ (a, b) and density $N_e(r,z)$ (c, d) in polystyrene pellet cloud in the #91250 LHD shot.

The $T_{cl}(r,z)$ data presented in Fig. 2 a, b correspond to $CCC = 2$ (the continuum emission from carbon and hydrogen ions was assumed equal to each other). It is clear that the obtained temperature values give upper limit of the cloud temperature because of an accurate evaluation of the carbon ions contribution to continuum radiation will reduce the obtained temperature values as shown in Fig. 3.

Summary. For the first time the electron temperature and density 2D distributions were obtained together for the polystyrene pellet cloud. The electron temperature distributions in the cloud were obtained in assumption of partial LTE in the cloud using measurements of the

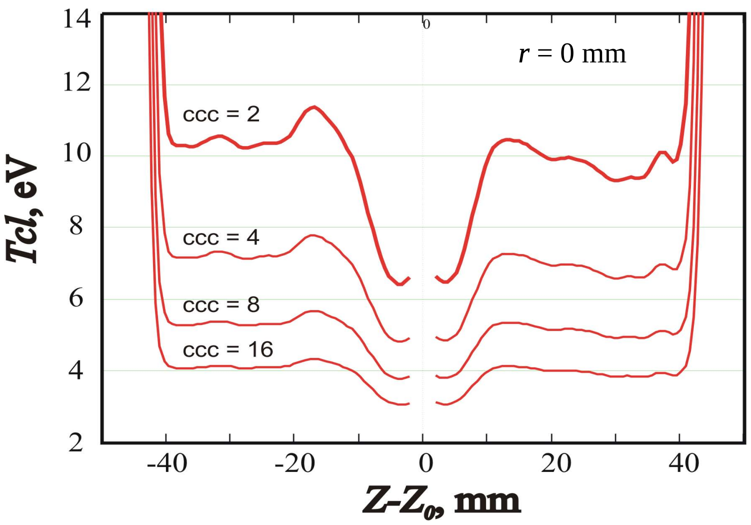


Fig.3 Pellet cloud temperature $T_{cl}(0,z)$ profiles calculated for different assumed enfacement factors CCC = 2-16 for $(I_{cont.C}+ I_{cont.H})/ I_{cont.H}$ ratios, where $I_{cont.C}$ and $I_{cont.H}$ are continuum intensities of carbon and hydrogen correspondingly.

ratio of H_β line to continuum intensities. The temperature values of ablating pellet are about of 3-6 eV in the cloud core and about of 4-10 eV in a plateau region. These values give the upper limit of cloud temperature because of the contribution of carbon ions to continuum radiation should be taken into account accurately. Nevertheless, the values measured are in a reasonable agreement with predictions of the carbon pellet cloud parameters [5]. The 2D distributions of local electron density in clouds were obtained using H line Stark broadening measurements. The density values of ablating polystyrene pellet are about of $3x10^{22}$ m^{-3}, which are close to the average polystyrene cloud density values evaluated earlier [2].

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