22C12

Wideband High-Resolution Spectroscopy of Metallic Pellet Ablation Plasmas in LHD

LHD中金属ペレット溶発プラズマの広波長帯域同時高分解分光計測

Hirotaka Tanaka[1], Keisuke Fujii[1], Taiichi Shikama[1], Motoshi Goto[2], Shigeru Morita[2], and Masahiro Hasuo[1]

田中博隆[1], 藤井恵介[1], 四竈泰一[1], 後藤基志[2], 森田繁[2], 蓮尾昌裕[1]

1, Graduate School of Engineering, Kyoto University
Yoshidahonmachi, Sakyo-ku, Kyoto 606-8501, Japan
2, National Institute for Fusion Science
322-6, Oroshi-cho, Toki 509-5292, Japan

1, 京都大学大学院工学研究科　〒606-8501　京都市左京区吉田本町
2, 核融合科学研究所　〒509-5292　土岐市下石町322-6

We have developed an echelle spectrometer for simultaneous observation of a wide spectral range of 390-770 nm with high resolution (about 0.1 nm at FWHM) and measured emission spectra of ablation clouds of metallic pellets injected into high-temperature plasmas produced in the Large Herical Device (LHD). For an alminum ablation cloud, more than 50 emission lines of Al ions are observed and many of them show Stark broadening. Electron temperature of the cloud is determined from the population distribution of Al^+ against the excitation energy from the ground state, which is estimated from observed line intensities. Electron density is estimated from the Stark broadening of the Al II $3p^2(^1D)$-$3s4p(^1P)$ (466.3 nm) line. From these results, we evaluated Stark broadening coefficients of other Al II lines.

1. Introduction

Pellets of various elements are injected into a magnetically confined fusion plasma for the purposes of investigating impurity transport. A pellet plunged into the plasma is immediately ablated due to heat flux from the plasma and forms a cloud in its vicinity from which luminous radiation is emitted for several milliseconds [1].

Emission spectra of the ablation cloud of a carbon pellet injected into a Large Helical Device (LHD) plasma has been observed and it has been revealed that a high density plasma ($n_e \simeq 10^{20}$-10^{23} m^{-3}, $T_e = 2.5$-3.0 eV) is produced in the cloud [1].

Recently, we developed a wideband high-resolution echelle spectrometer for visible region and observed emissions from ablation clouds of various metal pellets in LHD plasmas. Here, we report the results of an aluminum-pellet ablation plasma.

2. Experiment

Figure 1 shows a schematic illustration of the experimental set-up and the echelle spectrometer. An aluminum pellet used in the present study has a cylindrical shape whose diameter and length are 0.8 mm. The pellet is injected from an outer port of the LHD by a pneumatic pipe-gun system with a helium gas of 18 atm pressure [1].

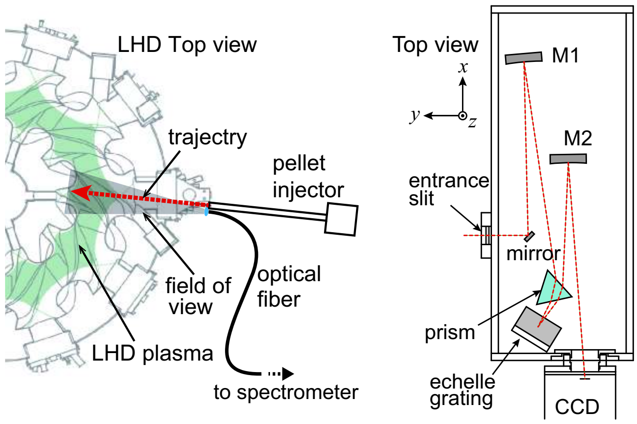

Fig. 1. A schematic illustration of the experimental set-up (left) and the echelle spectrometer (right).

Emission from the pellet ablation cloud is collected by a lens and introduced to the spectrometer through an optical fiber having a core diameter of 300 μm. The observation direction is set along the trajectory of pellet as shown in Fig. 1. The emission introduced from the entrance slit of the spectrometer is collimated by a concave mirror (M1; focal length: $f = 304.8$ mm). The parallel light rays are diffracted in a plane perpendicular to the *x-y* plane by an echelle grating (46.1 grooves/mm, 32° blaze) according to their wavelength. Overlapping 30^{th}-58^{th} diffraction rays are spatially separated in a direction parallel to the *x-y* plane by a 60° quartz prism and focused on a CCD detector (Andor, DV

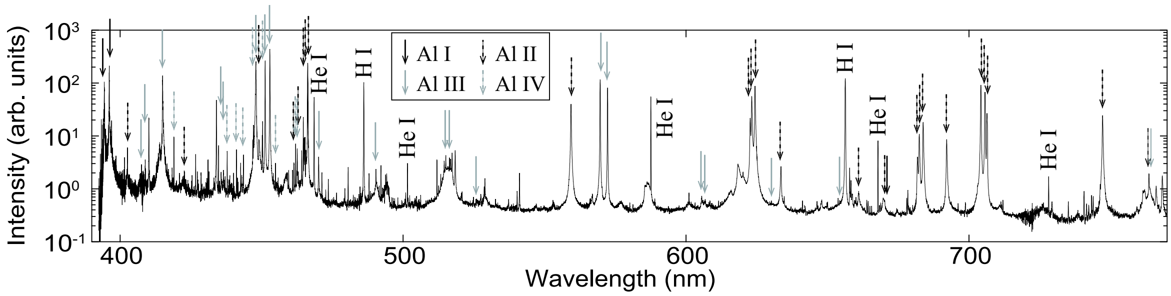

Fig. 2. Emission spectrum of an aluminum pellet ablation cloud in LHD. The relative intensity is calibrated.

435-BV) by another concave mirror (M2; f = 304.8 mm). The wavelength range from 390 to 770 nm is simultaneously recorded with resolution of about 0.1 nm.

We set an exposure time of the CCD to be much longer than the period of luminous radiation from the ablation cloud.

3. Results and Discussion

Figure 2 shows an example of the observed spectra. The relative intensities of all the emission lines are calibrated. More than 50 of Al I, Al II, Al III and Al IV lines are resolved, which are identified with the NIST database [2].

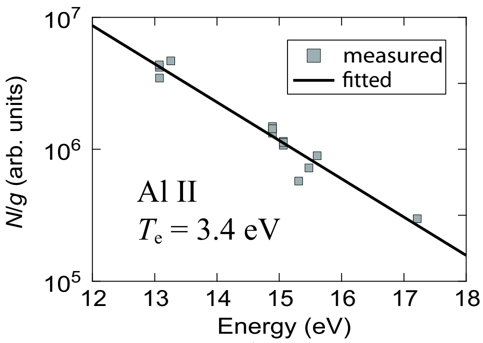

Fig. 3. Populations of Al^+ excited levels per unit statistical weight as a function of the excitation energy.

Figure 3 shows excited level populations of Al^+ per unit statistical weight estimated from the observed line intensities. They are plotted against their excitation energies from the ground level. Here, we assume that the aluminum ablation plasma is in local thermodynamic equilibrium (LTE) state as verified for the carbon pellet ablation plasma in a similar condition [1]. By fitting the data in Fig. 3 with a straight line, we determine the electron temperature (T_e) to be 3.4 eV from the slope.

Figure 4 shows the enlarged profile of the Al II $3p^2(^1D)$-$3s4p(^1P)$ (466.3 nm) line. Remarkable line broadening is seen. The broadening would be mainly due to Stark broadening approximated by a Lorentzian function and due to the instrumental broadening approximated by a Gaussian function. From the fit with a Voigt function to the observed profile with a known instrumental width (W_G=0.062 nm at 466.3 nm), the Stark width (W_L) is determined to be 0.045 nm.

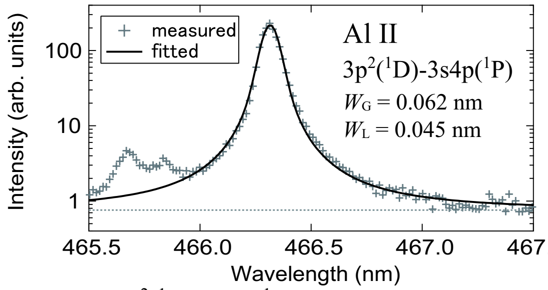

Fig. 4. Al II $3p^2(^1D)$-$3s4p(^1P)$ emission line profile. The solid line is the result of Voigt function fit. The dotted line indicates the background signal level for the fit.

The Stark broadening coefficient of this line has been determined to be 7.88 x 10^{-25} nm m^3 in the case of T_e = 40000 K (corresponding to about 3.4 eV) [3]. From dividing W_L by this value we obtain n_e = 5.7 x 10^{22} m^{-3} for the ablation cloud. Using this electron density, the Stark broadening coefficients of other two Al II lines are estimated from the observed W_L. The results are in agreement with the previous report [4] as shown in Table I.

Table I. Stark broadening coefficients of Al II lines at T_e=3.4 eV.

Wavelength (nm)	Config. (Term)	C_S (10^{-24} nm m^3) This work	[4]
624.3	$3s4p(^3P)$-$3s4d(^3D)$	3.1	3.40
683.7	$3s4p(^3P)$-$3s5s(^3S)$	3.2	3.26

Acknowledgments

The support of LHD experiment group is greatly acknowledged.

References

[1] M. Goto, S. Morita and M. Koubiti: J. Phys. B: At. Mol. Opt. Phys. **43** (2010) 144023

[2] NIST Atomic Spectra Database. ver. 4. http://physics.nist.gov/PhysRefData/ASD/lines_form.html

[3] A. Allen, M. Blaha, W. Jones, A. Sanchez and R. Griem: Phys. Rev. A **11** (1975) 477

[4] H.Griem: *Spectral Line Broadening by Plasmas* (Academic Press, 1974).