VUV spectroscopic diagnostics of the vibrational temperature to the ground state of the hydrogen molecules in recombination plasma

Takaaki Iijima, Tomohiko Ono, Takashi Torada, Akira Tonegawa, and Kazutaka Kawamura

Department of Physics, School of Science, Tokai University, 411 Kitakaname, Hiratsuka, Kanagawa, 259-1292, Japan,

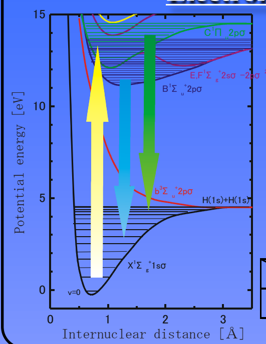
Introduction

The vibrationally excited molecules of hydrogen (H_2) to the electronic ground state play a significant role for the ionization and dissociation processes in processing, space and fusion plasma. In order to understand these plasma, measurements of vibrational temperatures of H_2 to the electronic ground state, Tvib, have been given by many authors using the spectroscopic diagnostic method.

Vacuum ultraviolet (VUV) emission spectroscopy in the spectral range 80-180 nm are investigated for basic research in laboratory experiments. VUV emission intense line spectrum is observed at the Lyman ($B^1\Sigma_u^+ \to X^1\Sigma_g^+$) and Werner ($C^1\Pi_u \to X^1\Sigma_g^+$) bands of H_2. Also, several active laser methods in VUV lights have been applied successfully for the detection of vibrationally excited H_2 with excellent sensivity. Thus, the VUV spectroscopic method is an effective approach to measure the vibrational temperatures of H_2 to the electronic ground state, Tvib, in the recombination plasma.

In this paper, VUV spectroscopic method for determination of the ground-state vibrational temperature of H_2, Tvib, is presented which make use of naturally emitted radiation in recombination plasma. Tvib was deduced by applying the corona equilibrium by using the electron impact excitation rate and the spontaneous emission coefficient between the upper electronic states, with vibrational level and the ground state, taking into account the radiation trapping.

Electronic Transitions of H_2



$$H_2(X^1\Sigma_g^+, v) + e \to H_2(B^1\Sigma_u^+(v'), C^1\Pi_u(v'), D^1\Sigma_u(v')\cdots) + e$$

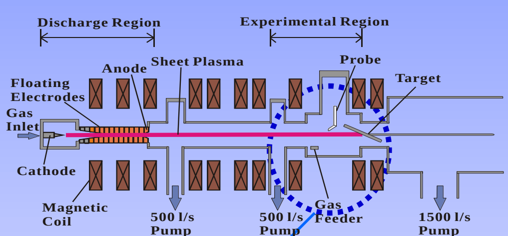
$$H_2(X^1\Sigma_g^+, v'') + h\nu(VUV)$$

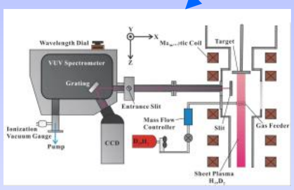
Radiation trapping

Number of vibrational excitation level

	$X^1\Sigma_g^+$	$B^1\Sigma_u^+$	$C^1\Pi_u$	$D^1\Sigma_u$
H_2	15	37	14	18

Plasma Source (TPD-SheetIV) and measuring system





Langumuir probe

・・・Electron Temperature T_e, and density n_e

VUV spectrometer

・・・Relational emission intensity of Molecule

Calculation of vibrational temperature T_{vib} for H_2

Corona equilibrium model

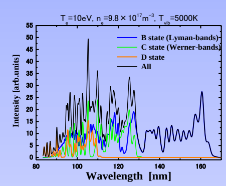
Electron impact excitation rate

$$c_{Xv}^{Bv',Cv',Dv'} = \langle \sigma_{Xv}^{Bv',Cv',Dv'} \upsilon_e \rangle = \frac{q_{Xv}^{Bv',Cv',Dv'} \exp(\frac{\Delta G_{B,C,D}(v)}{T_e})}{\sum_{v'} q_{Xv}^{Bv',Cv',Dv'} \exp(\frac{\Delta G_{B,C,D}(v)}{T_e})} \langle total\,\sigma_{Xv}^{Bv',Cv'',Dv'} \upsilon_e \rangle,$$

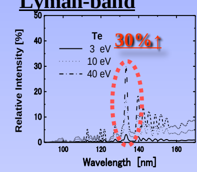
Calculated relative intensities

$$I_{Xv''}^{Bv',Cv',Dv'} = \frac{A_{Xv''}^{Bv',Cv',Dv'}}{\sum_{v''} A_{Xv''}^{Bv',Cv',Dv'}} \frac{hc}{\lambda_{Xv''}^{Bv',Cv',Dv'}} n_e \sum_{v} \left\{ c_{Xv}^{Bv',Cv',Dv'} n_{Xv} \exp\left[-\frac{G_X(v)}{kT_{vib}^X} \right] \right\},$$

Calculated



Cascade contributions to Lyman-band



Radiation trapping effects

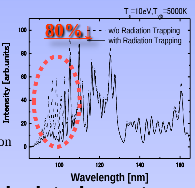
Escape factor g_0

$$A_p^q \to A_p^q g_{0_p}^{\ q} \quad (g_0 \le 1)$$

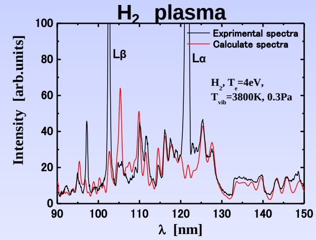
$$g_0 \cong \frac{1.92 - 1.3/[1 + (\kappa_0 R)^{6/5}]}{(\kappa_0 R + 0.62)[\pi \log_e(1.357 + \kappa_0 R)]^{1/2}},$$

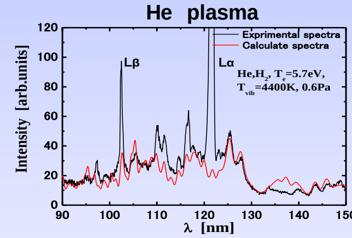
$$\kappa_0 = \frac{e^2}{4mc\varepsilon_0 \nu_p^q} \sqrt{\frac{Mc^2}{2k_B T_n \pi}} n(p) f_{p,q}$$

$n(p)$ is population density of level p,
$f_{p,q}$ is oscillator strength for transition $p \to q$

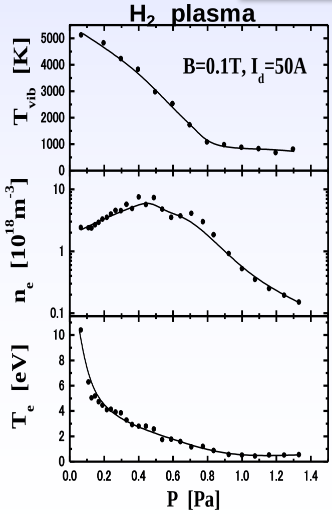


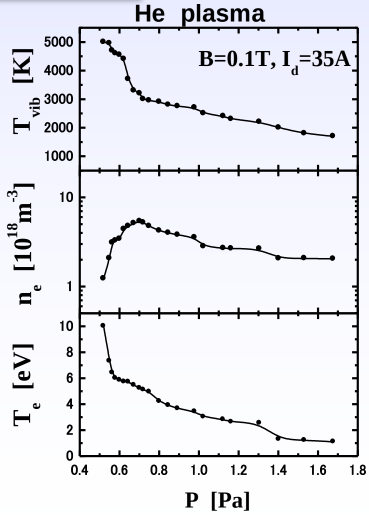
Example of the measured VUV spectrum compared with a calculated spectrum





Experimental results





Conclusions

VUV spectroscopic method for determination of the ground-state vibrational temperature T_{vib} of H_2 or D_2 is presented on a linear plasma device, TPD-SheetIV.

(1) The experimental results and the theoretical values show good agreement when the effects of the radiation trapping. The intensity of the wavelength range 80-110nm decay about 40-80% for the radiation trapping effects.

(2) With increasing the gas pressure P, T_{vib} gradually decreases from 4000-5000K to 1000 K in the detached plasma.

(3) The effect of increasing P is a decrease in T_{vib} due to increasing dissociation which leads to a loss of vibrationally excited molecules.

References

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Tokai University