1.17 Space-resolved VUV spectrometer system for edge impurity and
temperature profile measurement in HL-2A\textsuperscript{1}

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The 1 m normal incidence spectrometer equipped with two manually interchangeable 1200 grooves / mm gratings (800Å
blaze with Pt coating and 1500Å blaze with Al-MgF\textsubscript{2} coating in
rectangular size of 56 × 96 mm\textsuperscript{2}) is located at a distance of 6.3
m away from the plasma center. The sight line of the spectrometer is tilted by an angle of \(\phi = 10.98^\circ\) with respect to
the horizontal plane.

A space-resolved slit, which is used for the vertical
resolution of the VUV line emission, is placed between the
entrance slit and the grating of the spectrometer. The position
of the space-resolved slit is determined by a ratio of the vertical
size of the detector to the vertical size of the grating. The space-
resolved slit system located at the distance of 106.86 mm
behind the entrance slit consists of five different horizontal slits
with aperture widths of 50 \(\mu\)m, 100 \(\mu\)m, 200 \(\mu\)m, 400 \(\mu\)m and
full opening, which are mounted on a rotatable sample wheel.
The spatial resolution is determined by the space-resolved slit
width and the distance, \(d\), between the entrance slit and the
plasma center. In the present arrangement with \(d = 6.3\) m the
spatial resolution is about 4 mm when the space-resolved slit of
100 m is used.

In the VUV wavelength range the recombination radiation
is weaker than the bremsstrahlung radiation by nearly two orders
of magnitude. The bremsstrahlung radiation is then considered
as the dominant component of the continuum radiation. The
bremsstrahlung radiation power along the line of sight can be
calculated taking into account the plasma parameters. The
continuum radiation is measured with the 1500 Å blaze grating
by setting the space-resolved slit to 'full open' and the entrance
slit width to 100 \(\mu\)m. A set of five deuterium plasma discharges
are used for the calibration with parameters of \(I_\text{s} = 200\) kA, \(n_e =
3 \times 10^{13}\) \(\text{cm}^{-3}\), \(B_T = 2.0\) T, \(T_e = 1\) keV and \(Z_{\text{eff}} = 2.5\). In
order to obtain a reasonable statistics the counts of the
continuum radiation are summed over several tens of channels at
several different wavelengths of \(\lambda = 470\), 900, 1380, 2360
and 3000 Å, where the line emissions are not entirely observed.
When the measured counts are fitted with formula of \(Y = a n_e^{-2} + b\), the second term expresses the thermal noise or scattered
light, if the value of \(Z_{\text{eff}}\) is constant against the density. The
detected counts are thus plotted as a function of \(n_e\) in Fig. 1
(a). The comparison of the measured counts with the
calculated \(P_{\text{brems}}\) is given in Fig. 1(b). The calculated \(P_{\text{brems}}\) are
in good agreement with the measured counts in the \(n_e\)
dependence plot.

![Graph](image)

Fig. 1. Measured counts as a function of electron density for five
different wavelength (a) and comparison of measured counts
with calculated bremsstrahlung intensity as a function of electron density
(b).

The sensitivity calibration of the present VUV system is
then done by plotting the ratio of the calculated values to the

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measured counts as a function of wavelength, as shown in Fig. 2. The sensitivity of the present spectrometer is very similar with the result obtained with the 1 m normal incidence VUV spectrometer in CHS calibrated using a traditional method. The increase in the sensitivity around 1400 Å is reasonable since the grating is blazed at 1500 Å. The sensitivity of the 800 Å blaze grating is also calibrated with the same method.

When ions have a Maxwellian velocity distribution, the ion temperature, $T_i$, in eV is thus given by an equation of

$$T_i = 1.8 \times 10^4 M \frac{\Delta F_{\text{ion}}}{\lambda_0}$$  \hspace{1cm} (1)

Where $M$ is the atomic mass. Measured spectral lines are fitted by a Gaussian profile, the ion temperature is thus obtained.

The electron temperature can be estimated based on the line intensity ratio between two emissions with different transition energies in the same isoelectronic ion. For optically thin plasmas in the corona model regime, the ratio between two populations in different upper levels of $m_1$ and $m_2$ nested to the ground state is given by

$$R = \frac{i_{m_1}}{i_{m_2}} = \frac{\omega_{m_1}}{\omega_{m_2}} \frac{\lambda_{m_1}^2}{\lambda_{m_2}^2} \exp\left(-\frac{E_{m_1} - E_{m_2}}{kT_e}\right)$$  \hspace{1cm} (2)

The electron temperature can be thus obtained from the line ratio. The intensity of the transition with $\Delta n = 0$ is generally very strong in the plasma. Therefore, if the transition with $\Delta n = 1$ has enough intensity, the electron temperature profile measurement is also possible from the two intensity profiles of $\Delta n = 0$ and 1 transitions.

A typical example of the edge electron temperature measurement is shown for the intensity ratio of C III ($2s^2 - 2s2p2s^2 - 2s2p$). Although ECRH and NBI pulses are supplied as additional heating during 620 – 920 ms and 500 – 840 ms, respectively, the edge electron temperature does not seem to be responsible to them. The accuracy of the electron temperature measurement is estimated to be roughly 30% which is mainly caused by the uncertainty of the VUV spectrometer sensitivity calibration.

A 1 m vacuum ultraviolet spectrometer system with the maximum spatial resolution of 1.5 mm has been developed for the study of edge plasma behaviors in HL-2A tokamak. Radial profiles of the impurity intensity and the ion temperature are measured at the plasma edge and the electron temperature is measured from the line intensity ratio. The spectrometer sensitivity has been successfully calibrated using the VUV bremsstrahlung radiation emitted from the HL-2A tokamak plasma. The present calibration method demonstrates a clear advantage that the instrument can be calibrated in situ even in the VUV range. A relative change of the plasma poloidal rotation is also observed before and after the L-H transition. The radial profiles of the poloidal rotation will be observed at the edge boundary using several lines such as CII, CIV, OVI and OVI, and high-time response of the measurement will be also possible in the near future.