EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT

JET

Initial Pellet Spectrometer Results from JET

G. L. Schmidt [1], P.T. Lang [2], H. W. Mueller [2], M. Stamp [3], and contributors to the EFDA-JET workprogramme*

1 Princeton Plasma Physics Laboratory, Princeton University, New Jersey, U.S.A.
2 Max Planck Institut für Plasmaphysik, EURATOM Association, 85748 Garching, Germany
3 EURATOM / UKAEA Fusion Association, Culham, Abingdon, Oxon. OX14 3DB, United Kingdom

*: See annex of J. Pamela et al, "Overview of Recent JET Results and Future Perspectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).

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This Paper

This paper decribes preliminary spectroscopic measurements of both Balmer a (656nm) and Balmer b (486nm) lines produced in the luminous cloud and plasmoid surrounding deuterium pellets injected into JET H-mode plasmas heated by NBI in combination with RF [Lang]. The measurements were made during pellet experiments on JET carried out as part of the 2001 Campaign.

The purpose of this preliminary study was to determine both the spectral width and the effective line intensity of the Balmer a and b lines for nominal JET plasma conditions. The measurements provide initial values for the pellet cloud parameters in the JET. In particular, the spectral width produced by Stark broadening of the line provides a measurement of the electron density in the pellet shield cloud and plasmoid surrounding and extending away from the pellet during the ablation process. [Seidel, Griem]

The measurement of pellet cloud/plasmoid parameters is important in assessing the potential driving terms for the redistribution of pellet mass during the ablation process [Mueller, Parks].

In addition the spectral data provide indications of other spectral features of general interest present in the deuterium lines under conditions of strong Stark broadening [Wiese].

[Lang]
[Seidel]
[Griem]
[Mueller]
[Parks]
[Wiese]

Motivation

Mass introduced directly within the confinement volume of a plasma via solid deuterium pellets injected at high speed (pellet refuelling) is an efficient mechanism by which to sustain the plasma mass density. However, the final radial distribution of the pellet mass is not determined by the local deposition rate alone. A mass redistribution process has been observed which transports some deposited mass radially within the plasma volume on a time scale comparable to the time of flight of the pellet within the plasma. This radial mass motion tends to move directly deposited mass to larger major radius, improving fuelling effectiveness for pellets entering the plasma from the High Field or small major radius Side (HFS) while diminishing fuelling effectiveness for pellets entering from the Low Field Side (LFS). Typical radial profiles of local deposition indicated by Da and final pellet source indicated by dn are illustrated in Figure 1 for HFS and LFS.

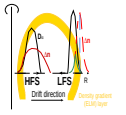


FIGURE 1 -Illustration of ablation light and final pellet source profile; High and Low field side launch. Figure taken from [Lang]

The mass redistribution mechanism appears to be related to the density and temperature present in the plasma cloud and plasmoid surrounding the pellet during the ablation process.[Parks]. The spectral width and the relative intensity of the Balmer a and b lines produced in that luminous cloud and plasmoid reflect the density and temperature of this region. In particular, the Stark Broadening reflects the electron density within the cloud and plasmoid. Detailed measurements of the Balmer a and b lines can therefore contribute to an understanding of the mass redistribution process. A detailed understanding of the redistribution mechanism is critical for the prediction of pellet fuelling effectiveness in future devices.

INSTRUMENT

A compact crossed Czerny-Turner spectrometer with input focal length of 42 mm and output focal length of 68 mm was used for these preliminary measurements. The full spectral range of the spectrometer from 400 to 700 nm was recorded simultaneously with a resolution of ~1nm.

The spectrometer made use of the existing JET pellet viewing geometry shown in figure 2. The view affords a relatively close and direct view of the HFS pellet entry; however, particularly for low temperature target plasmas, the HFS launch pellet trajectory may pass out of the spectrometer view before ablation ceases.

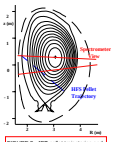


FIGURE 2: JET pellet trajectories and viewing geometry of spectrometer

The spectrometer was configured to integrate in time over the full pellet ablation period. Light is gathered over the entire spectrometer view. Each pellet event therefore produced a single spectrum from 400 to 700 nm integrated in time and space over the entire pellet event. An example of the pellet spectrum is shown in Figure 3.

SPECTRUM and TARGET PLASMA

A composite sample spectrum is shown in figure 3. The spectra shown have been corrected for variation of grating and detector efficiencies over the wavelength range. Efficiency was determined using a calibrated Tungstun lamp. The spectrum has NOT been corrected for any wavelength dependent attenuation in the ~100m of fiber transmitting the light from the plasma to the spectrometer. The nominal attenuation within the fiber is: ~10dB/km at 650nm, ~20dB/km at 500nm, ~30dB/km at 460nm, and ~50dB/km at 390nm. Although the width of each line can be roughly determined without including the attenuation of the fiber, comparison of Da and Db intensity requires detailed attenuation measurements. These measurements will be made prior to the next JET campaign.

The instrument function for the spectrometer is also shown in the figure. The instrument function influences the measured spectrum and the known instrument function was removed from the spectra before the Lorentz fits to the Da line shown in Figure 5 were done.

FIGURE 3: Sample Da, Db, Dg spectrum. Light integrated over single pellet event. Two spectra are overlaid, one from JPN53196 (black trace) the second from JPN53197 (red points). The spectra are normalized so that the maximum of the Db signal for each spectrum is of equal amplitude and the maximum Da emission for JPN53197 is 1. The Blue trace indicates the shape of the normalized instrument function for Da and Db wavelengths. Normalized Intensity has been corrected for grating and detector efficiency but not for fiber attenuation.

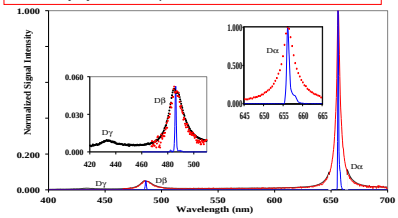
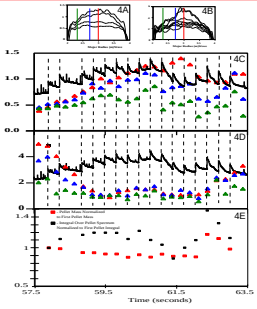


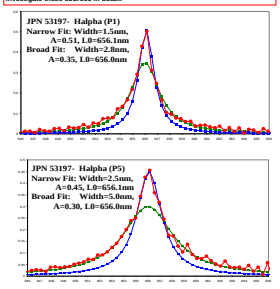
FIGURE 4: Nominal Pellet Target Plasma JPN53197 and Normalized Pellet Mass and Integrated Da Light. Red (3m), Blue(2.7m) and Green(2.3m) triangles indicate electron temperature change during the pellet sequence at the plasma center (3m) and across the region of the plasma penetrated by the pellet (2.3 and 2.7m). Abrupt changes in Vb signal and dashed lines mark individual pellets. Normalized pellet data illustrates variation in pellet mass and Da signal during pellet sequence.



The series of 16 pellets injected at ~5Hz into JET H-mode plasmas shown in figure 4 is typical of the pellet sequences used and the plasma response observed during these Da/Db studies. Pellets are lauched from the High Field Side along the trajectory shown in figure 2. Pellets move through flux surfaces which map in major radius roughly to the region between the inner plasma boundary at 2m and the blue line at 2.7m (Fig 4A and 4B). Plasma density, shown at three radial positions by the colored triangles in Fig 4C, rises at first across the pellet target region, then stabilizes at a higher level and finally falls back with the onset of MHD activity [Lang]. Electron temperature across the pellet region shown in Fig 4D falls during the first few pellets and then remains generally between 1 and 2 keV. Pellet mass, except for several pellets at the end of the series, varies only weakly during the pellet series (Fig 4E). Inspite of a relatively large decrease in target temperature during the first few pellets, the total light emitted in the dalpha line changes by only 40% as shown in Fig 4E; with the light increasing as the target temperature drops. The limited variation with nominal target temperature of the total light emitted suggests some self-limiting mechanism may be present. This variation will be studied in detail during future work when a high time resolution spectrometer is available.

The spectral width of the Da line is produced predominantly by Stark broadening and serves as a measure of the electron density in the pellet cloud. Figure 5 shows the range of line width seen in shot JPN53197. This range generally represents the range seen throughout the study. As indicated in the figure caption, the spectra appear to be combinations of low and high density sources likely as a result of integration over the entire pellet event. In general, the wings of the spectra are determined by the highest densities; the narrow central peak by the lowest density. Uncertainty in fitting the wings is greater than the uncertainty in fitting the central peak. Analysis of the spectra can not be precise, but nominal line widths, identified in Fig 5, indicate that the plasmoid densities are in the range of 10^23...10^24m**-3. This density range is comparable to or slightly higher than that observed on ASDEX Upgrade [Mueller] (I must check TFTR [McNeil] results) which is consistent with differences in JET and ASDEX Upgrade plasma target plasmas. The variations in line width, particularly the broader high density wings and the higher density they suggest will also be the subject of further study when a high time resolution spectrometer is available.

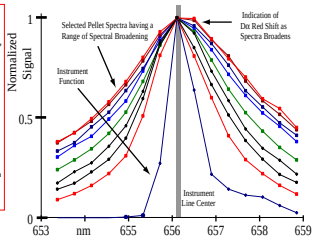
FIGURE 5: Most Narrow and Most Broad Da lines JPN53197. Red traces show the measured Da spectra corrected for the instrument function. Blue and Green traces show the Lorentz function fits to the central peak (blue) and profile wings (green). Because of the time integrated nature of the measurement, the spectra appears to be a combination of a lower density (narrow) source and a higher density (broader) source. Future time resolved measurements will be used to investigate these sources in detail.



ADDITIONAL FEATURES OF THE SPECTRUM

FIGURE 6: Showing
1) a range of normalized Da spectra of increasing width from JPN53201.
2) the instrument function for comparison with the width of the observed spectra, and
3) the instrument line center for Da.

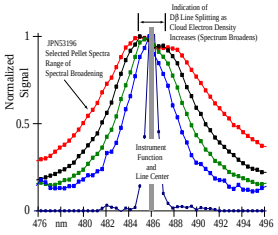
The data suggests that the pellet Da spectra exhibits a red shift which increases as the broadening and therefore the electron density increases. A red shift of the hydrogen alpha line which varies linearly with electron density has been observed in earlier wall stabilized arc experiments. [Wiese et. al.].



ADDITIONAL FEATURES OF THE SPECTRUM

FIGURE 7: Showing
1) a range of normalized Db spectra of increasing width from JPN53196
2) the instrument function for comparison with the width of the observed spectra, and
3) the instrument line center for Db.

The data suggests that the pellet Db spectra exhibits a line splitting which increases as the broadening and therefore the electron density increases. A splitting of the hydrogen beta line has also been observed in earlier wall stabilized arc experiments. [Wiese et. al.].



SUMMARY

- High time resolution studies of the density and temperature in the pellet cloud/plasmoid can be undertaken using existing JET diagnostic access. Preliminary studies of pellet spectra from JET HFS launch pellets show there is sufficient light from existing diagnostic access to permit high time resolution studies of the density and temperature in the shield cloud and plasmoid.
- Analysis of data from the preliminary study of pellet spectrum indicates plasmoid density in JET to be comparable to or slightly greater than plasmoid density on ASDEX Upgrade HFS launch pellet ablation. Analysis of the spectra can not be precise due to the time integrated character of the data, but nominal line widths, identified in Fig 5, indicate that the plasmoid densities are in the range of 10^23...10^24m**-3.
- Measurements o f both the Da and Db spectra show indications of spectral features seen in Starkbrasdening measurments in other plasma experiments;. A read shift of the Da line is seen to appear and increase with Da spectral width. Splitting of the Db line is observed with increasing spectral width.
- Given the results of this study, we anticipate installation of new high time resoultion pellet spectrometer on JET. The new spectrometer will have increased spectral resolution capability and 200microsec time resoultion. High time resolutions studies should be possible during the C5 and C6 campaigns in 2002.