

Use of a High Resolution Overview Spectrometer for the Visible Range in the Boundary Plasma of TEXTOR

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1. Introduction

Present-day fusion devices use graphite as plasma-facing material at the locations of highest flux. Owing to erosion and deposition, a complex hydrocarbon chemistry takes place at the surface, including the formation of a-C:H layers. The ratio of hydrocarbon to deuterium flux defines the chemical erosion yield – a measure for the chemistry. Passive spectroscopy in the visible range is an *in situ* diagnostic to monitor in the plasma edge the fluxes of carbon-containing species (C , C_2 , CH etc.), which are released from the surface or build during the molecular break-up, as well as the fluxes of recycled fuel particles (H , H_2 etc.) [1]. To observe and analyse the emission of these atoms and molecules simultaneously from a given observation volume, a spectrometer system has to fulfil high demands with respect to the spectral, spatial and time resolution, to the observable wavelength range, to the sensitivity and dynamic range of the detector. An optimised system should be able a) to measure at once the strong atomic lines (e.g. $CIII$ at 465 nm) and the weak molecular bands (e.g. C_2 Swan-band) which are spread across the whole visible range, b) to resolve the narrow lines of the molecular bands (e.g. CH Gerö-band) and allow their ro-vibrational analysis, and c) to provide information about the spatial distribution and time evolution of the different species. We present a spectrometer in cross-dispersion arrangement which can be applied as a good compromise and which fulfils most of the needs apart from the spatial distribution from a single measurement.

2. The cross-dispersion spectrometer – principles, set-up and technical data

Conventional spectrometers, e.g. in Czerny-Turner arrangement, use only *one* dispersive element to build a spectrum. These single dispersion spectrometers can provide spatial information if operated in imaging mode, but they are limited in the wavelength range which can be

recorded at once. Their range is restricted to a few nanometres for a resolving power $R = \lambda/\Delta\lambda$ of 20,000 which is necessary for a ro-vibrational analysis of the Gerö-band.

In contrast, the spectrometer presented here (Multichannel Instruments, model: Mechelle 7500 special; schematic set-up in fig. 1) consists of *two* dispersive elements: a prism and a grating. The system covers a spectral range of more than 300 nm without gap in high resolution. This wide coverage is achieved though the combined use of (i) a highly dispersive échelle grating (ruling: 31.6 grooves/mm, size 10.0 cm \times 3.0 cm, blaze angle 63.5°) for wavelength dispersion of the light in horizontal direction and (ii) an order

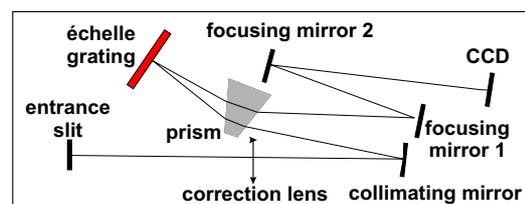


Figure 1: *Spectrometer set-up*

sorter, a highly dispersive prism (BAF50 glass, reference angle 36°), which separates the orders in vertical direction. Note that the prism is used twice (fig. 1) to ensure complete order separation. Fig. 2a shows the observable spectral orders m projected on the CCD array, starting from $m=153$ (blue spectral range) at the bottom to $m=79$ on the top (red spectral range), as well as the spectral range in each order which is used for the reconstruction of the complete spectrum.

The centre wavelength in each order, positioned at the blaze angle of the grating, is determined by the order constant $m \times \lambda[\mu\text{m}]$ which amounts to 56.783 for this system. The overlap of different orders is determined by the condition $\frac{m=x+0.5}{56.783} = \lambda_{min}^{m=x} = \lambda_{max}^{m=x+1}$ while five additional pixels on each side are used for averaging. Fig. 2b shows the contribution of each order to the *standard range* between 372 nm ($m=152$) and 680 nm ($m=84$). The spectrum in each order is spread across several pixels in vertical direction. Thus, a summation over 3 to 7 pixels is made to increase the sensitivity of the system and provides a so-called spectral channel. Additionally, the spectrum reconstruction procedure [2] takes into account the non-equidistant separation of the channels, which are more compressed in the lower orders, as well as their curvature in the higher orders.

Fig. 2c depicts the linear dispersion as a function of the wavelength in the standard range. Although the dispersion varies over the full range, the resulting resolving power is almost constant at 21,000 when the apparatus function of the system is taken into account. The latter was determined to 3.1 channel by the FWHM of the Hg lines indicated in fig. 2a.

Further technical data of the Mechelle are: aperture value $f/7$, focal length $f_L = 190$ mm, entrance slit $25 \mu\text{m} \times 75 \mu\text{m}$ with SMA905 connector for fibre coupling. A 16 bit camera (Andor, model: DV434) with back-illuminated CCD and a coating optimised for the visible range with a quantum efficiency of more than 90% at 500 nm and -60° C is used as detector. The CCD array has 1024×1024 pixels, $13 \mu\text{m} \times 13 \mu\text{m}$ each. The read-out time for the full array is about a second at the maximum frequency of 1 MHz.

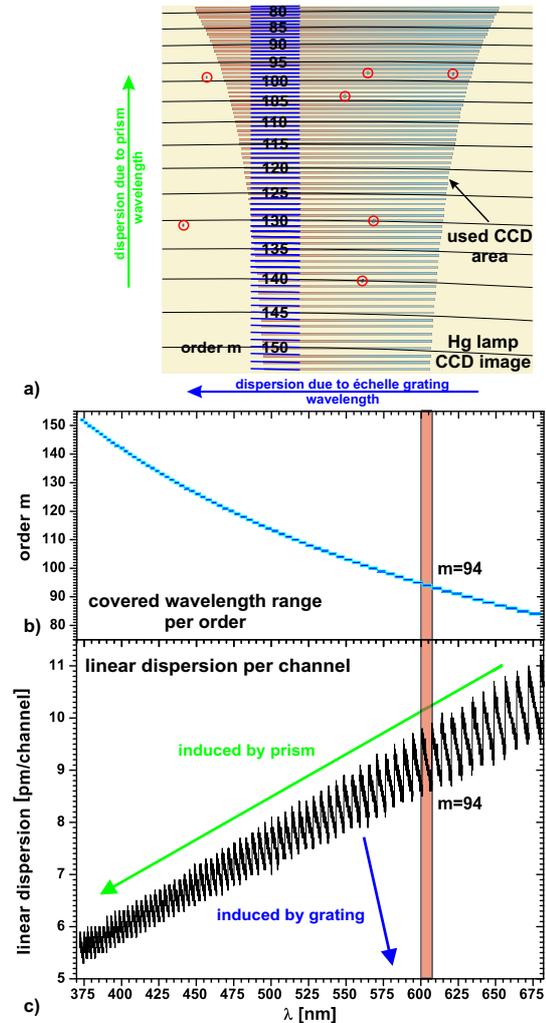


Figure 2: *Spectrum reconstruction*

3. Spectral and radiometric calibration

The spectral calibration of the system is performed with the aid of the line spectrum of Hg. The measured position of seven lines, marked with red dots in fig. 2a, is compared with the theoretically calculated positions. The deviation between calculated and measured position is minimised in a least-square fit procedure. The overall position precision over the standard range lies within two spectral channels and shows almost no drift under constant surrounding temperature conditions. A light source (Labsphere, model: USS 600) is used to calibrate the spectrometer system radiometrically. Fig. 3a shows a false-colour 2D image taken from the continuum source, and fig. 3b shows the resulting reconstructed spectrum. The spectrum represents a convolution of the continuum of the light source and the sensitivity response of the detection system. Both image and spectrum show clearly a non-uniformity of the measured radiation within each order. The strong reduction of the sensitivity of about 40% between the centre and the edges is caused by the blaze angle dependence. A correction function is introduced to compensate for the strong drops of the sensitivity in the spectrum. The influence of cross-talk on the calibration can be neglected for the standard wavelength range. The cross-talk between adjacent spectral orders is below 10^{-3} . The bare inverse sensitivity curve for the standard range is depicted in fig. 3c. The spectrometer system, which is optimised for the visible emission range according to the choice of prism, grating and CCD coating, shows an almost constant spectral response above 450 nm. However, the sensitivity starts to drop significantly below 450 nm. The decrease of more than two orders between 450 nm and 380 nm is caused by the 50% reduction of the CCD quantum efficiency and of the transmission of the prism.

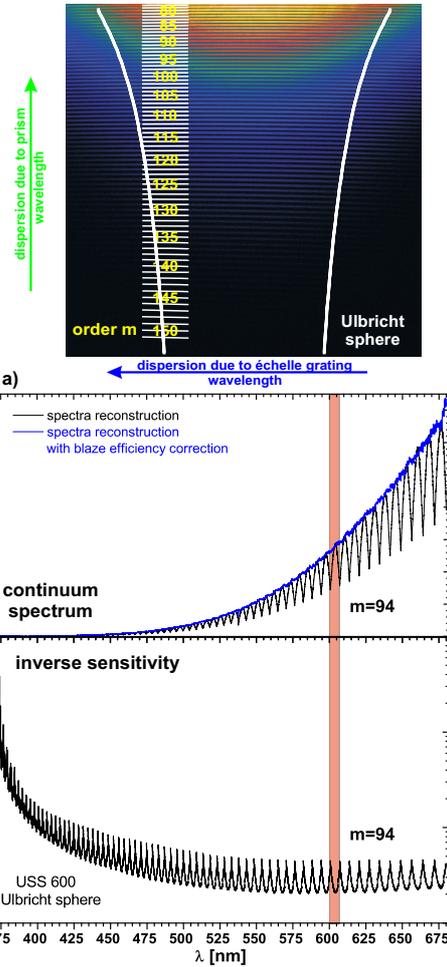


Figure 3: Calibration of the system

4. Spectra of hydrocarbon break-up products

A series of experiments with the injection of different hydrocarbons (CH_4 , C_3H_4 etc.) in similar plasmas has been recently started in TEXTOR. The aim of these experiments is a) to check if the injected stable hydrocarbon leaves a "footprint" e.g. with regard to its appearance, intensity ratio, ro-vibrational population of the molecular break-up products C_2 , CH , CH^+ , C_3 etc., and b) to determine the inverse photon efficiencies and branching ratios which relate the photon flux of the break-up products to the particle flux of in-

jected hydrocarbon species. A first result of such a "footprint" spectrum, recorded with

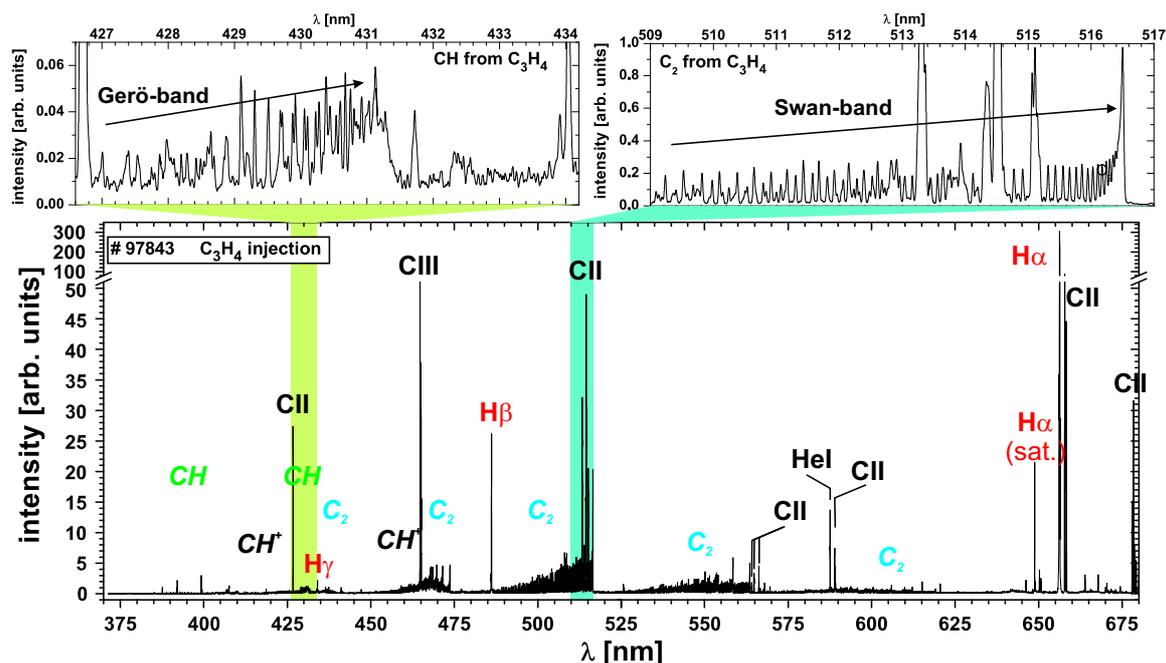


Figure 4: C_3H_4 injection into TEXTOR edge plasma – spectrum of the break-up products the Mechelle spectrometer, is shown as an example in fig. 4. Spectra of the band heads of the two most important transitions, CH Gerö-band and C_2 Swan-band, are enlarged. The ro-vibrational analysis and the comparison with spectra of other injected hydrocarbons is outside the scope of this contribution. Spectra examples of intrinsic hydrocarbon sources recorded with the Mechelle spectrometer in the JET MKII-SRP divertor and their spectral analysis can be found in [3].

5. Conclusion

Although there is currently no spectrometer available to fulfil *all* the mentioned requirements, the Mechelle is a good compromise to study spectroscopically the high temperature plasma edge, i.e. the different hydrocarbon break-up products. Experiments at TEXTOR provide "footprints" of the injected hydrocarbons C_xH_y . Thus the appearance, the amount, the ratio, and the ro-vibrational population of the different species can now be further studied. Other synergetic effects can be achieved when – like in TEXTOR – the Mechelle spectrometer is embedded in a set of spectroscopic systems which complement one another and which observe the same plasma volume. The Mechelle provides the high spectral resolution, the large wavelength coverage, and the high dynamic range, whereas the other systems provide the needed time and spatial resolutions.

Acknowledgement

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