Light Ion Absorption, Probed with High Spatial, Temporal, and Spectral Resolution: *The Spectrum of C II*

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Abstract

We present a facility for the spectroscopic measurement of the photoabsorption of light ions in the region 30-100 nm. The optical design of the experiment and the characteristics of the backlight continuum source allow a spatial resolution of the absorbing medium of about 0.3-0.5 mm and a duration of its irradiation of about 20 ns. Therefore the absorption of a selected ionization stage of an element can be measured and, in addition, by the use of a high resolution spectrometer, its photoabsorption and photoionization spectra can be recorded with spectral resolution of 5000-8000. The facility is composed of a laser produced plasma acting as backlight continuous source, a stigmatic optical system with toroidal mirror and grating, and a UV CCD in the focal plane. The spectrum of C II is reported as example. The ground state has been effectively populated and both discrete series and continuous spectra with several Fano profiles were measured. From the calculated f-values, it will be possible to estimate the absolute photoionization cross section.

1 Introduction

Despite the vast amount of data available for neutrals, little photon absorption spectroscopy has been done for the elements in ionic stages, especially for the multiply charged ones [1, 2, 3]. The difficulty is that of generating a suitable column of ions for the energy level to be probed. In this context, the twin laser produced plasmas are a well established technique for almost two decades.

The laser produced plasma (LPP) characteristics as absorbing medium are the following:

- the generation of the ion is obtained by focusing a pulsed laser onto a plane target of the element under study,
- by varying the laser power density on the target, almost all the ionic stages can be produced for a large number of elements,
- in the LPP, the various ion species show different temporal and spatial evolution.

As continuum source, the LPP also shows relevant characteristics:

- the duration of the emission is comparable with that of the laser pulse: consequently, measurements with time resolution of order of 20 ns are possible,
- the emission in the spectral regions from VUV to the XUV may be either discrete or continuous, according to the choice of the target element and the laser power density focused onto the target,
- as a continuous backlighter, it has a well defined and small physical size, corresponding to the laser focal spot in transverse direction and a longitudinal expansion of a few tenths of a mm,

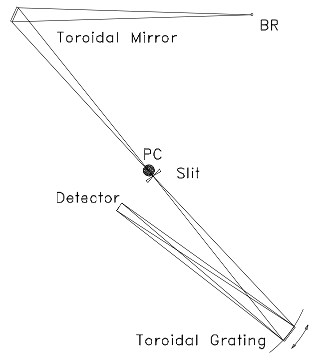

Figure 1: Optical setup, BR: background radiation, PC: plasma column

- it has very high brightness, due to the high plasma temperature and density,
- the emission is usually characterized by high reproducibility and stability,
- there is no requirement for ultra-high vacuum and there is no thermal load on the optics.

To exploit conveniently the LPP as backlighter in the EUV spectral range, an optical design with high optical aperture and a spectral resolution in the range 5000-10000 is needed.

2 Aims of the present experiment

In this contribution we present the measurement of the discrete and continuous spectra originating from the ground state $2s^2(^1S)$ 2p $^2P^0$ of the first ion of carbon. The experimental technique is based on the two laser produced plasmas, applied in the normal incidence spectral region. The spectral range spans from 38 nm to 80 nm, where the complete 2p $^2P^0$-ns ^2S and $2p^2P^0$-nd ^2D series, as well as the series $2s^22p$ $^2P^0$-2s2p np ^2P appears. The first ionization limit is the $2s^2$ ^1S state at 50.8 nm . The following photoionization spectrum has several resonances, giving rise to Fano profiles. The photoionization cross section has been calculated by the London group [4].

As already mentioned, the "knobs" that can be used to optimize the parameters of the experiment are the laser power density on the backlighter target and on the absorbing medium, the graphite target: for these, we have used the values of $2x10^{12}$ and $1x10^{10}$ W/cm^2 respectively. The focal spot on the absorbing medium target was chosen in order to increase the ion column density, and is obtained by a spherocylindrical lens, to produce a line focus of 0.1x7 mm^2 area. The delay between absorbing medium generation and backlight plasma generation has been varied between 50 and 120 ns, by retarding the laser pulse in an optical delay line up to about 40 m long. The distance from the graphite target to the spot where the backlight beam was probing the plasma has been varied between 0.3 and 2 mm, corresponding to noticeably different absorbing plasma densities and temperatures. In particular, with a delay of 58 ns between the formation of the two plasmas and at 1.7 mm from the C target, the ground state of C II was selectively populated and correspondingly the spectrum showed negligible contributions from neutral carbon absorption and only some isolated contributions from excited states of CII and from CIII.

3 Description of the setup

The optical setup, shown in Fig. 1, is composed of two toroidal optics setups: a mirror and a grating. The mirror, with meridional and sagittal radii of 1.26 m and 1.04 m, respectively, operates at 24.6^0. This is used as a condenser optics, gathering the backlight emission with

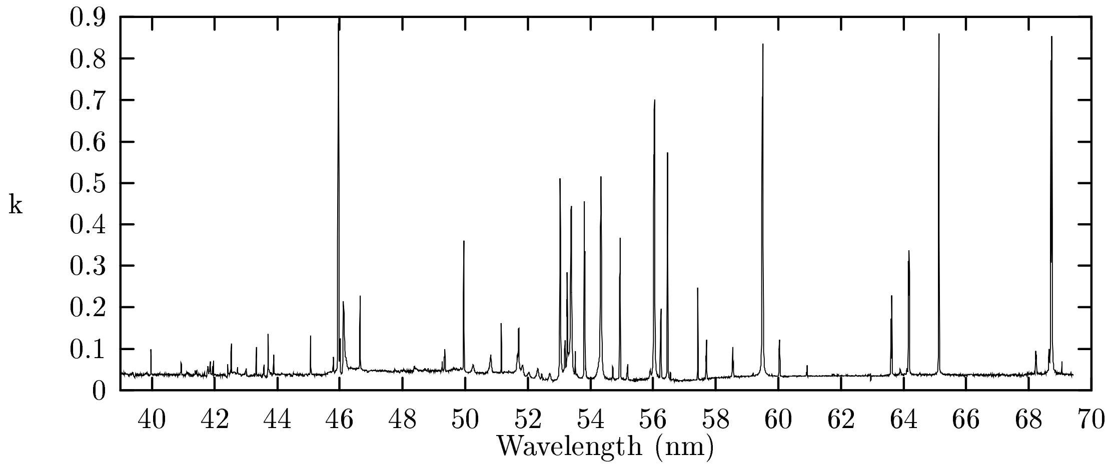

Figure 2: Absorption spectrum of C II: the discrete part begins at 50.8 nm

about f/10 and focusing it onto the spectrograph entrance slit. The grating with 3600 lines/mm of radii 1.011 m and 0.992 m operates between 10^0 and 14^0 . It provides stigmatic imaging of the absorption region with a dispersion of 6.7 pm per detector pixel. The latter is a cooled UV CCD made by Princeton Instruments, with 16 bit of conversion, and 512x512 square pixel of 24 μm of size. The laser is a Q-switched Nd:YAG, and the typical energies used for the plasma generations are 3.8 J on the backlight radiator and 1.2 J on the absorbing medium. The high S/N ratio and the very low residual optical aberrations of the acquired spectra allowed the use of deconvolution techniques to improve the limit of resolution up to 5 pm.

4 Results and discussion

The C II spectrum was taken in contiguous spectral intervals, each of about 3.8 nm and averaged over 20 shots. The complete reconstruction of the spectrum, the evaluation of the relative oscillator strengths of the series and the photoionization cross-section is in progress, and the preliminary results are shown in Fig 2. The spectrum has been taken at 2.3 mm from the target surface and with a delay of 58 ns after the plasma generation. The discrete series are converging to the limit at 50.8 nm. The transitions of the type $2s^22p\ ^2P^0$-$2s^2$ nd ^2D and ns ^2S can be observed for n larger than 10, and show the effect of a strong perturbation about the 7d state.

For these experimental conditions, the ground state absorption of the next ionization stage, C III, is noticeable. For instance, the strong 45.9 nm multiplet appears in the middle of the Fano profile originating from the interaction of $2s^22p\ ^2P^0$-2s2p4p ^2D and 2s2p (^1P) 3p ^2D with the ($2s^2\ ^1S$) kd ^2D open channel.

The strong variation of the plasma density with the distance from the target and how it affects the observed spectra is clearly shown in Fig. 3, where the transition $2s^22p\ ^2P^0$-$2s^2$ 6d ^2D at 54.338 nm for different distances from the target and with the same delay of 58 ns is presented. The profiles show the large variation, that occurred in less than a millimeter of displacement, of the absorption coefficient, whose integral changes by more than one order of magnitude, and of the linewidths.

For the assessment of the data quality, many efforts are made both during the acquisition and the data analysis. Particular attention is paid, during the measurements, to the absorbing plasma and the backlight continuum shot-to-shot reproducibility. Consequently, we have verified the conservation of the ratios between lines in a single spectral segment within a few percent. In addition, we are adopting an acquisition scheme in order to average over the target condition, in its shot-to-shot ageing, for all the quantitative measurements. In the profile integration, particular attention is paid to the extended wings and possible external contributions.

Figure 3: 2p-6d absorption at different distances from the target

5 Conclusions

A new experiment for absorption spectroscopy of ionized species with the dual LPP technique has been realized in the VUV spectral range.

The optical setup is stigmatic in an extended region, in order to achieve a fine spatial probing of the absorbing medium. This characteristic has shown a noticeable improvement of the species selection and then of the data quality.

Preliminary measurements of the CII photoabsorption and photoionization spectra has been performed. The analysis of the experimental data is in progress, in particular an estimate of the absolute photoionization cross-section. This is obtained through the evaluation of the column density. The latter is derived from the photoabsorption coefficients of strong suitable discrete transitions, whose oscillator strengths have been calculated [5, 6]. Moreover, the oscillator strengths for high n terms of the p-s and p-d transitions will be estimated with respect to known terms.

Finally, we are working on the identification of the perturbations in the photoionization cross section, in order to extract information on the level energies and the matrix element of the interaction.

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