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Measurement of spectral response of the CCD camera for spectroscopy of highly charged ion plasma emission in soft x-ray spectral region from 1 to 10 nm

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1 Introduction

Laser-produced plasmas (LPPs) have become important as bright sources of soft x-ray (SXR) radiation, due to their unique characteristics of small source size and high conversion efficiency. In addition, LPPs have attracted much interest in many fields of application such as extreme ultraviolet lithography (EUV) [1], x-ray spectroscopy [2], x-ray laser studies [3], production of clusters [4] and SXR microscopy [5]. For these applications it is important to characterize the SXR emission as a function of laser parameters and irradiation conditions.

The SXR spectral region is currently of major interest for the imaging of molecular structure and high resolution tomography. Suitable wavelength ranges for biological applications are the water window (WW) spectral region from 2.34 to 4.38 nm and the carbon window region, which lies between 4.4 and 5 nm. To date, the most intense, high brightness x-ray sources are synchrotrons and free electron lasers [6]. At present, table-top lab based sources using H-like carbon and nitrogen line emission from LPPs formed on liquid nitrogen droplets that can be focused using zone plates have been developed for transmission microscopy [7]. However the available energy is quite low when using line emission due to the low reflectivity of available collector mirrors and thus it is not possible to record single shot images. To overcome the low efficiency imposed by the wavelengths of line sources, recently that use of emission from unresolved transition arrays (UTAs), which originate from highly charged ions in high-*Z* plasmas, has been proposed [5,8].

The measurement of the spectral response of the CCD camera for use in the wavelength range from 1 to 10 nm is described. A flat-field grazing incidence spectrometer (GIS) was built for to investigate the SXR emission from laser-produced HCI plasmas. The absolute calibration of the GIS was also performed in order to evaluate the spectral structure and the photon flux of LPP sources. It should be noted that the CCD camera does not record the photon number directly. It records analog to digital unit counts. Therefore, the sensitivity of the CCD camera given in terms of the number of counts per 1 incident photon should be evaluated.

2 Experiment

Measurement of the sensitivity of a CCD camera (ANDOR, DO936N-M0W-#BN) was performed at the reflectometry beamline BL-11D of the PF. The camera was mounted at the end port of the reflectometer. The incident beam focused at the center of the reflectometer and then diverged making a 26-mm (2048 pixel) image size on the CCD surface. To avoid overflow, the entrance slit width of the monochromator was turned. To minimize the influence of the high order light included in the incident beam, an Al filter with a thickness of 200 nm was used. A calibrated AXUV100G x-ray diode was used to determine the number of photons incident onto the x-ray CCD camera.

3 Results and Discussion

The experimental and calculated results are plotted as the blue circles and the red line, respectively, in Fig . 1.

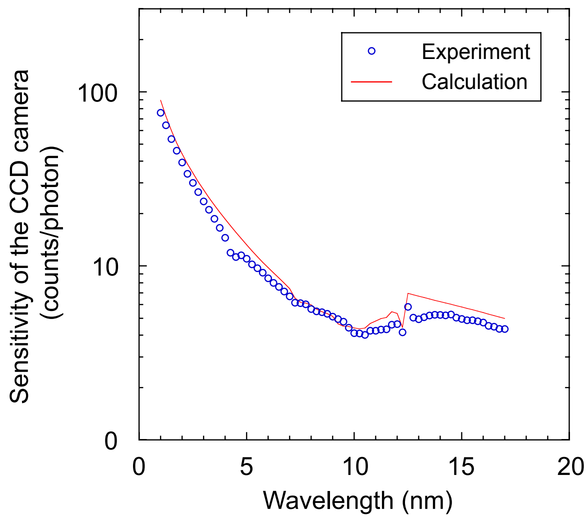

Fig. 1: The sensitivity of the x-ray CCD camera as a function of wavelength. The experimental and calculated results are indicated by blue circles and a red line, respectively.

The L-edge absorption of silicon at around λ = 12.3 nm could be observed in both experimental and calculated results. The slightly difference between the two may be caused by the influence of this hydrocarbon contamination on the surface of the CCD chip. In particular, a dip apparent in the wavelength region around λ = 4.3 nm was observed in the experimental result. This is caused by K-edge absorption of carbon originating from this contamination.

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References

[1] Y. Ueno, G. Soumagne, A. Sumitani, A. Endo, and T. Higashiguchi, *Appl. Phys. Lett.* **91**, 151503 (2007).

[2] P. Dunne, G. O'Sullivan, and V. Ivanov, *Phys. Rev. A* **48**, 4358 (1993).

[3] J. J. Rocca, *Rev. Sci. Instrum.* **70**, 3799 (1999).

[4] T. Ditmire, J. G. Tisch, E. Springate, M. Mason, N. Hay, R. Smith, J. Marangos, and M. Hutchinson, *Nature* **386**, 54 (1997).

[5] T. Higashiguchi, T. Otsuka, N. Yugami, W. Jiang, A. Endo, B. Li, P. Dunne and G. O'Sullivan, *Appl. Phys. Lett.* **100**, 014103 (2012).

[6] T. Gorniak, R. Heine, A. Mancuso, F. Staier, C. Christophis, M. Pettitt, A. Sakdinawat, R. Treusch, N. Guerassimova, and J. Feldhaus, *Opt. Express* **19**, 11059 (2011).

[7] M. Berglund, L. Rymell, M. Peuker, T. Wilhein and H. M. Hertz, *J. Microsc.* **197**, 268 (2000).

[8] T. Wu, T. Higashiguchi, B. Li, G. Arai, H. Hara, Y. Kondo, T. Miyazaki, T.-H. Dinh, P. Dunne, F. O'Reilly, E. Sokell, and G. O'Sullivan, *J. Phys. B* **49**, 035001 (2016).

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