

Spectroscopic study of bismuth ions with an electron beam ion trap

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Synopsis We present the electron beam energy dependence of the emission spectra of multiply charged Bi ions measured with an electron beam ion trap in the wavelength range of the water window. Experimental results are compared to the theoretical ones calculated with the flexible atomic code.

Plasma has a possibility to be a powerful light source for several applications. Tin and xenon plasmas have been studied for the next generation semiconductor lithography in the extreme ultra-violet (EUV) region [1]. Recently, gadolinium and terbium plasmas have been receiving attention for the beyond EUV lithography [2]. Unresolved transition arrays (UTAs) corresponding to the $n = 4 - n = 4$ transitions of multiply charged ions in these plasmas contribute to favorable emissions near 13.5 or 6.7 nm, at which the reflectivity of multi-layer mirrors for each lithography has a maximum [1–3]. Averaged transition wavelengths of these UTAs become shorter with increasing atomic number.

The wavelength range between the K-absorption edge of oxygen (2.34 nm) and that of carbon (4.4 nm) is called “water window” because water has much lower photoabsorption cross section than biological molecules in this window. A soft x-ray source in the water window is thus required for the realization of a living cell microscopy. Laser Produced Plasmas (LPPs) using several elements have been investigated as a candidate for the light source of not only the lithography but also the x-ray microscopy. Higashiguchi *et al.* [4] have demonstrated high-efficiency emission in the water window based on Bi-LPP for the laboratory-scale single-shot live cell imaging. Spectroscopic data of contributed charge states of Bi ions are necessary to analyze and

understand the plasmas for the development of the light source. In this study, we have measured the soft x-ray emission spectra of multiply charged Bi ions in the water window region with an electron beam ion trap (EBIT).

Bismuth ions were produced in the Tokyo-EBIT [5] with Bi injection using an effusion cell. In the EBIT, a quasi-monoenergetic electron beam with electron energies of 1.4 – 3.4 keV interacted with trapped ions, forming a simple plasma in ionization equilibrium. Emissions from the trapped ions in the soft x-ray region were observed with a flat-field grazing incident spectrometer equipped with a Peltier-cooled charge-coupled device [6]. Experimental results are compared with theoretical ones which are calculated with the flexible atomic code [7].

References

- [1] H. Ohashi *et al.* 2010 *J. Phys. B: At. Mol. Opt. Phys.* **43** 065204
- [2] H. Ohashi *et al.* 2013 *Phys. Scr.* (in press)
- [3] D. Kilbane *et al.* 2012 *Phys. Rev. A* **86** 042503
- [4] T. Higashiguchi *et al.*, 2012 *Appl. Phys. Lett.* **100** 014103
- [5] H. Watanabe *et al.* 1997 *J. Phys. Soc. Jpn.* **66** 3795
- [6] H. Ohashi *et al.* 2011 *Rev. Sci. Instrum.* **82** 083103
- [7] M. F. Gu 2004 *AIP Conf. Proc.* **730** 127

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