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Characteristics of water-window soft X-ray emission from bismuth plasmas

Hayato Ohashi[1], Hiroyuki Hara[2], Bowen Li[3], Padraig Dunne[4], Gerry O'Sullivan[4], Akira Sasaki[5], Chihiro Suzuki[6], Naoki Tamura[6], Hiroyuki A. Sakaue[6], Daiji Kato[6, 7], Izumi Murakami[6, 8] and Takeshi Higashiguchi[2, 9]

[1] Institute of Liberal Arts and Sciences, University of Toyama, [2] Department of Electrical and Electronic Engineering, Faculty of Engineering, Utsunomiya University, [3] School of Nuclear Science and Technology, Lanzhou University, [4] School of Physics, University College Dublin, [5] Kansai Photon Science Institute, National Institutes for Quantum and Radiological Science and Technology (QST), [6] National Institute for Fusion Science (NIFS), National Institutes of Natural Sciences (NINS), [7] Department of Advanced Energy Engineering Science, Kyushu University, [8] Department of Fusion Science, The Graduate University of Advanced Studies (SOKENDAI), [9] Center for Optical Research and Education (CORE), Utsunomiya University

e-mail: ohashi@las.u-toyama.ac.jp

Laser-produced plasma sources for use in the soft X-ray 'water window' spectral region (λ = 2.34 – 4.38 nm) are being developed for high resolution biological imaging applications. A laboratory-scale water-window soft X-ray microscope based on laser-produced low-Z plasmas, such as a liquid nitrogen plasma, needs continuous multi-shot operation to record an image because the shot-by-shot output flux is low due to the narrowband nature of the line emission. To overcome the low efficiency of low-Z plasma sources, we proposed and demonstrated a water-window soft X-ray source based on utilizing unresolved transition array (UTA) spectral structure [1]. While the selection of target elements and the target lifetime are important [2], one of candidate high-Z elements is bismuth (Bi) because its UTA consists of many resonant lines that give rise to a feature greater than 0.5 nm in extent with a peak wavelength of 4 nm in the water-window soft X-ray spectral region [3, 4]. Therefore, we expect high output flux with high efficiency from a Bi plasma source compared to low-Z plasmas.

We demonstrate an enhancement of soft X-ray emission in the water-window region from Bi plasmas produced using dual laser pulses using Q-switched Nd:yttrium-aluminum-garnet (Nd:YAG) lasers with a wavelength of 1064 nm. To achieve high photon flux output, it is important to control the spectral behavior by reducing self-absorption and increasing the spectral purity in the spectral region of interest. The pulse separation time dependence between 10-ns and 150-ps pre-pulses and 150-ps main pulse were investigated to realize the optimum spectral structure and most efficient energy coupling for output emission in the water-window and small source size [5]. The effect of optical thickness of Bi plasmas was also investigated using a low density foam target [6]. Magnetically confined optically thin Bi plasmas at high electron temperature were also investigated to understand an optimum condition for efficient water-window soft X-ray emission [7].

The spectral structure of Bi plasmas strongly depends on the separation time. Corresponding photon flux in the water-window changes and has an optimum condition in order to maintain a tiny source size. On the other hand, the photon flux can decrease due to self-absorption in expanding plasmas. As for the target density dependence, the self-absorption effect is relatively small for a Bi plasma as compared to that of another element, tin (Sn), which is used as a 13.5-nm UTA source. For characteristics of soft X-ray emission from magnetically confined optically thin Bi plasmas, quite different spectral structure was observed due to differences in optical thickness and electron temperature compared with the optically thicker laser-produced plasmas.

The number of photons was observed to be 3.8×10^{14} photons/sr in the spectral region of interest at a pulse separation time of 7 – 10 ns under dual laser pulse irradiation. We discuss the differences observed in the spectral structure in the water-window soft X-ray under different optical thickness conditions, together with the issue of the radiation hydrodynamic simulation.

References

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