Characteristics of soft x-ray emission from optically thin high-*Z* plasmas in Large Helical Device

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Introduction

The bismuth ($_{83}$Bi) laser-produced plasma (LPP) was proposed as a light source in the water window, λ = 2.3–4.4 nm, for soft x-ray imaging of biological structures in living cells [1]. The theoretical calculation has predicted a dominant unresolved transition array (UTA) at 3.2 nm with the electron temperature $T_e \geq 1$ keV that could not be achieved in previous ps-LPP studies [2]. On the other hand, quasi-mono-energetic T_e plasmas produced by an electron beam ion trap (EBIT) have demonstrated the 3.2-nm emission from highly charged Bi ions with $T_e \geq 2.5$ keV [3]. This disagreement between theoretical and experimental results suggests to evaluate and modify the theoretical calculation by using **benchmark experimental data** with optically thin plasmas.

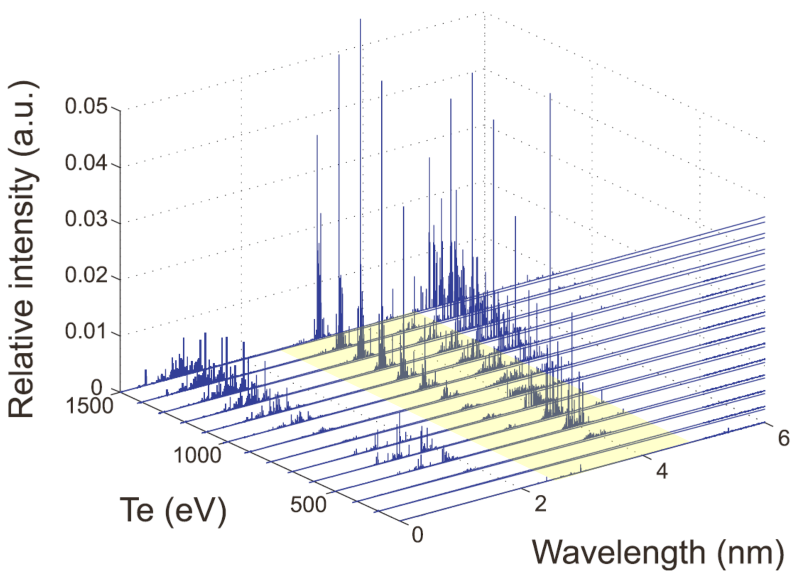


Fig. 1 Calculated spectral variation as a function of electron temperature T_e [2].

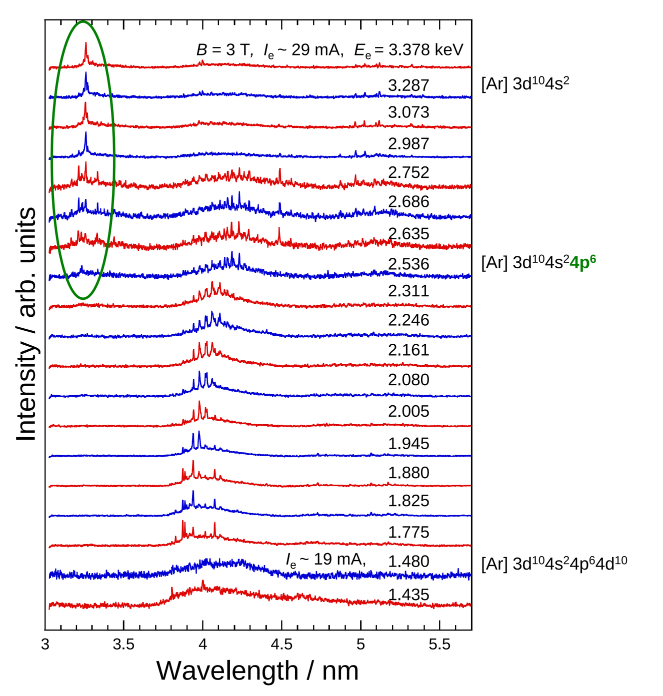
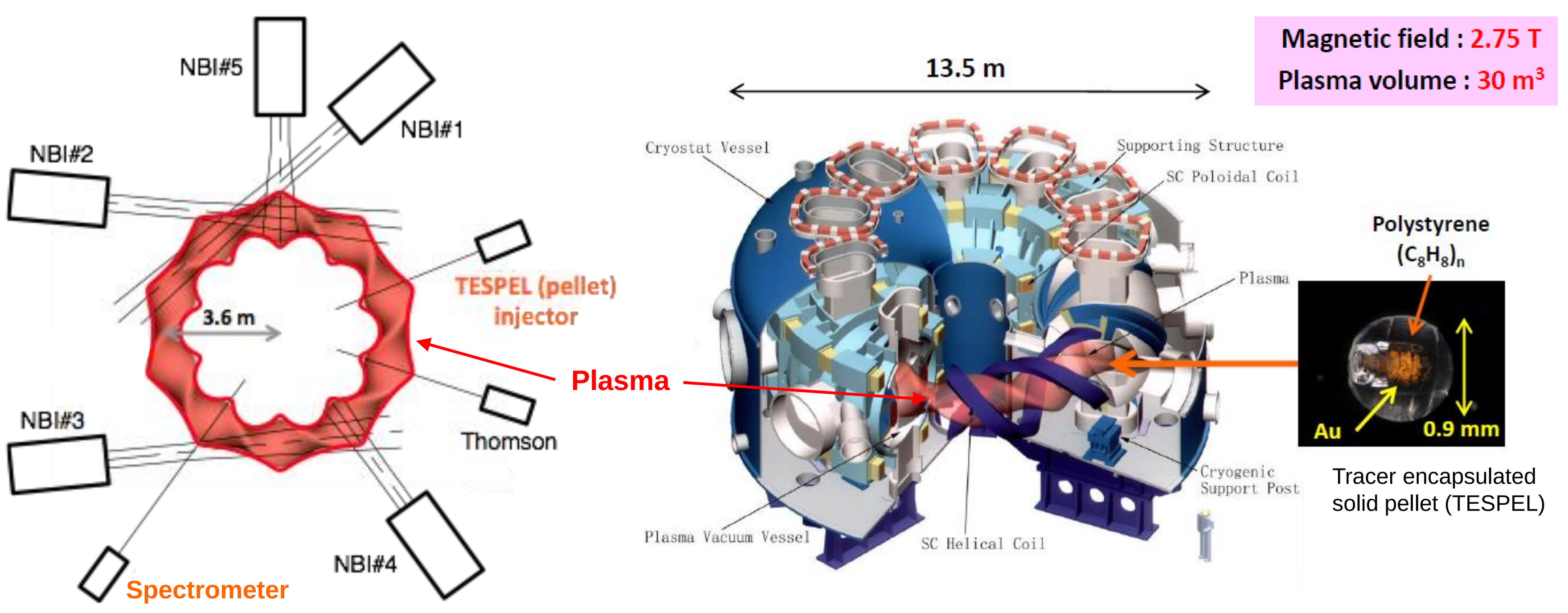


Fig. 2 Emission spectra of Bi ions in EBIT [3].

The Large Helical Device (LHD) is a large-scale facility for magnetically confined torus plasma with high-T_e (> 1 keV) and optically thin (electron density n_e = 10^{12}–10^{14} cm^{-3}) conditions. The controllability of T_e and n_e that can be measured directly and precisely produces benchmarking experimental data.

Experimental setup



- 2-m grazing incidence Schwob-Franchel spectrometer
- 600 grooves/mm grating
- Observed wavelength range: 2.5–5 nm (available range: 1–35 nm)
- 2 micro-channel plats with phosphor screens and a photodiode array

Fig. 3 Schematic diagram of LHD and main characteristics.

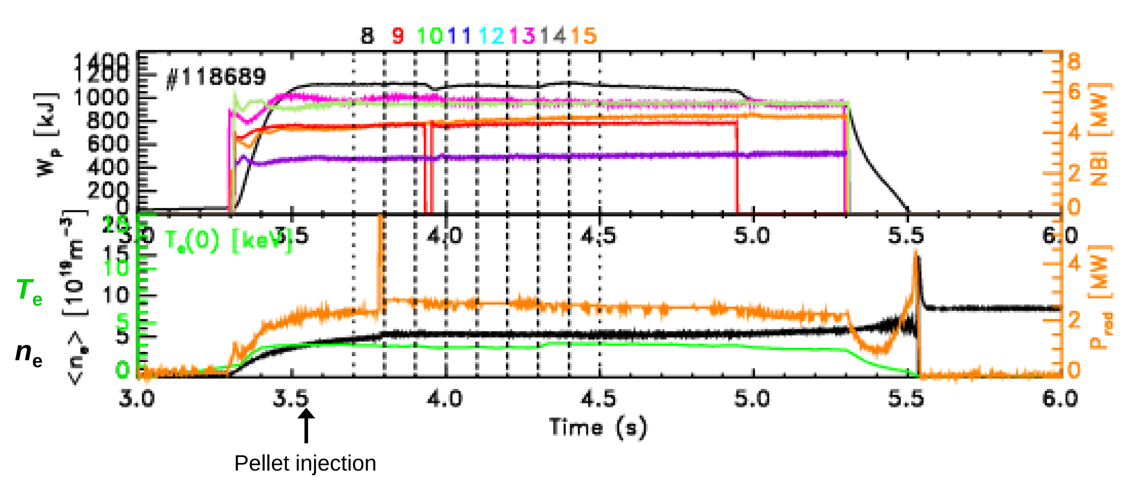


Fig. 4 Typical time sequence of each parameter in the LHD operation.

Results & Discussion

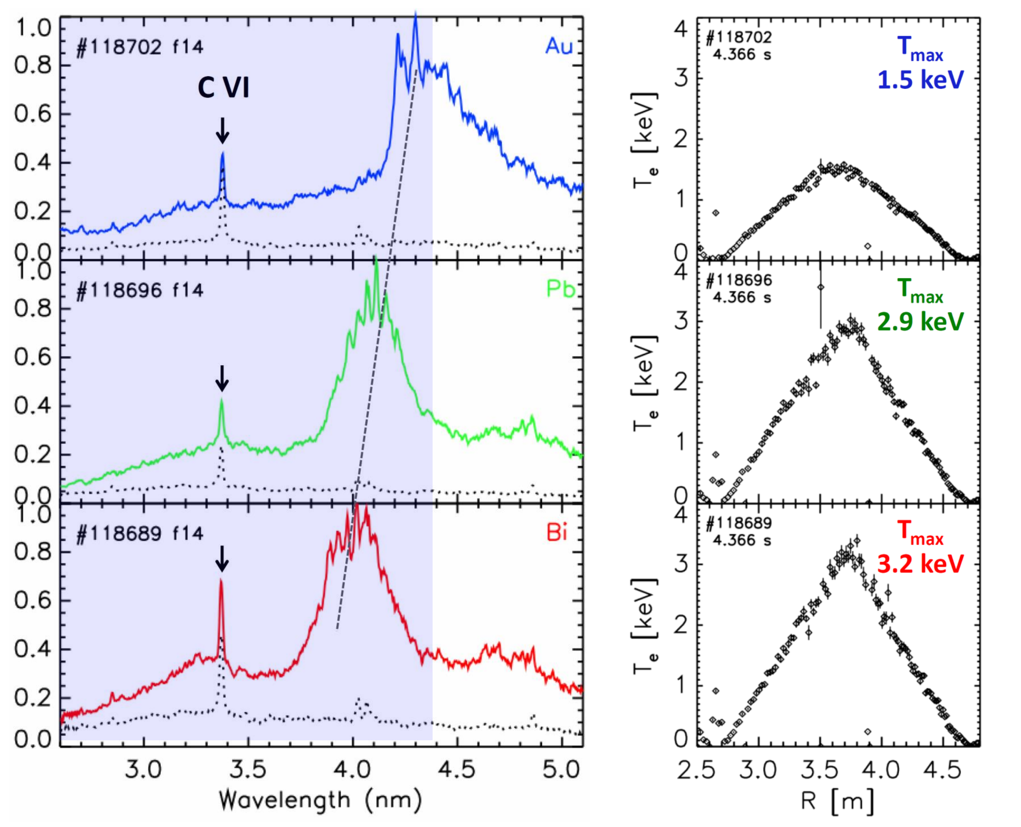


Fig. 5 LHD emission spectra and spatial temperature distributions for Au ,Pb and Bi. Dotted lines show background LHD spectra just before TESPEL injections.

Quasi-Moseley's law

$$\lambda_{UTA} = 21.86 \times R_\infty^{-1}(Z - 23.23)^{-1.52}$$

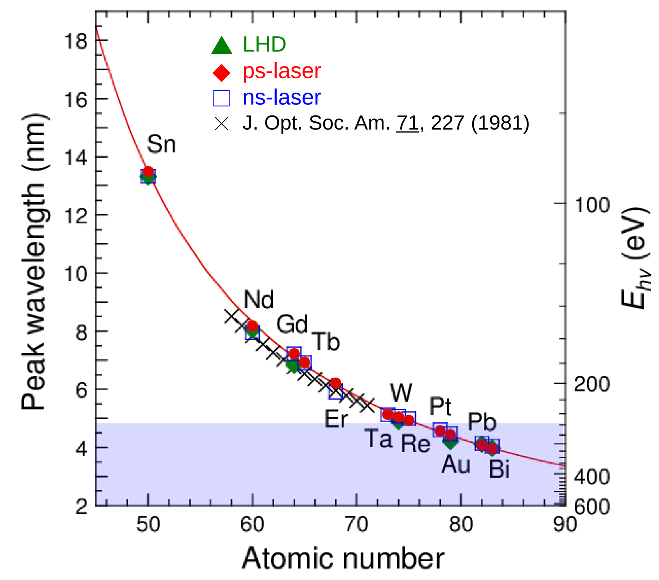


Fig. 6 Atomic number dependence of the peak wavelength of 4-4 UTAs in LHD and LPP spectra [4].

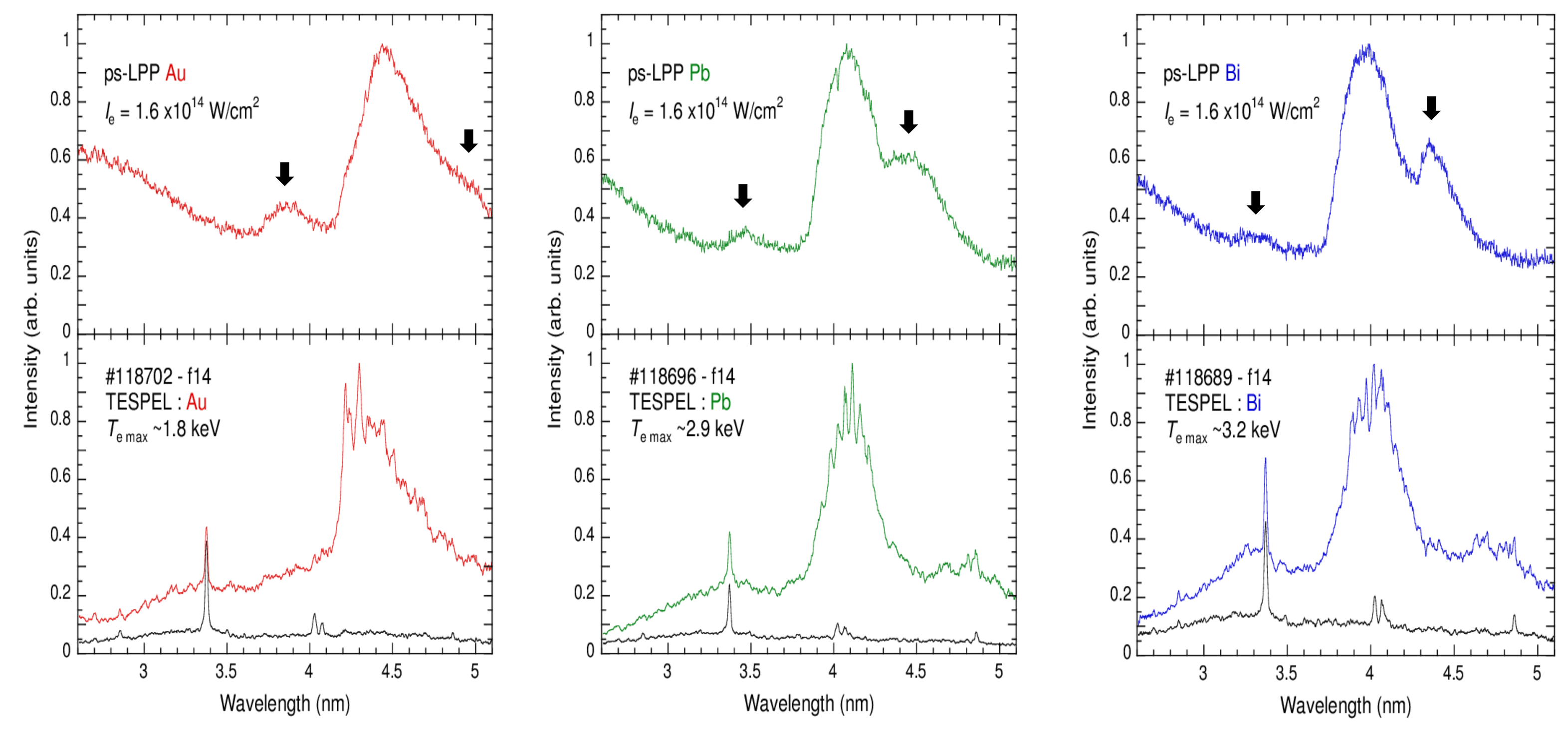


Fig. 7 Comparison of LHD plasmas with ps-LPPs for Au, Pb and Bi. Black lines show background LHD spectra just before TESPEL injections.

- Peak wavelength of UTAs (λ_{UTA}) for n = 4 - n = 4 transitions depends on the atomic number. (Quasi-Moseley's law [4]).
- The 3.2-nm emission of Bi ions were not observed as a prominent one.
- Comparing with LPP spectra, some structures were weak or missing in LHD spectra due to the difference in excitation processes with low-n_e and high-T_e (LHD) and high-n_e and low-T_e (LPP) conditions.

Summary

- Characteristics of soft x-ray emissions were investigated for optically thin high-T_e LHD plasmas with Au, Pb and Bi.
- While the data with low-n_e and low-T_e is necessary to say in detail, the 3.2-nm emission in previous calculations is considered as a result of an overestimation of the inner shell excitation processes.
- Quasi-Moseley's law is useful in the estimation of appropriate elements for soft x-ray and extreme ultra-violet light sources at a specific wavelength. .

References

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