§23. Optimization of Soft X-ray Spectra in the Water Window from Multi-charged Ion Plasmas

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Light sources based on spectral emission from unresolved transition arrays (UTAs), which originate from the highly charged ions (HCIs) in high-Z plasmas are of great interest in fundamental research and for industrial applications, such as extreme ultraviolet (EUV) lithography for future integrated circuits,[1] laser-driven water window soft x-ray (SXR) sources for single shot imaging of biological cells *in vivo*,[2] and material sciences.[3] UTA emission can provide high output power with high conversion efficiency of laser input energy to EUV or soft x-ray emission because the transitions responsible, which are of the type $4p^64d^n - (4p^64d^{n-1}4f + 4p^54d^{n+1})$ ($n = 4 - n = 4$, $\Delta n = 0$) originate from several charge states and appear at almost the same wavelength so that resonance lines from a number of charge states contribute.

UTA emission from $n = 4 - n = 4$ ($\Delta n = 0$) transitions in LPPs of other higher-Z elements occurs at wavelengths that can be used for other applications such as soft x-ray microscopy (SXM) in the water window SXR region from 2.3 to 4.4 nm and the carbon window which lies between 4.4 and 5 nm. We have shown that the strong resonance UTAs emitted by laser- and discharge-produced plasmas of high-Z elements ranging from $_{50}$Sn to $_{83}$Bi obey a quasi-Moseley's law.[4] Laser-produced bismuth (Bi) plasmas are one of the candidates for a water window SXR source, and consequently their spectrum has been recently analyzed. Laser-produced platinum (Pt) plasma emission is considered here as a candidate for a carbon window SXR source, and although the Pt spectrum was previously analyzed, the theoretical results presented in this analysis were valid only under optically thin conditions.[4] In addition, there are almost no radiation hydrodynamic simulation results available for higher atomic number plasmas with the exception of tungsten, because of its importance as a limiter material in fusion plasmas, but because of the low density in such plasmas the modeling is again for plasmas that are essentially optically thin. It is important to benchmark dense, higher-Z plasmas from the database point of view because of their potential use as light sources. Here, we focus on the spectral analysis and spectral behavior of laser-produced Pt plasma SXR sources for carbon window SXR emission.

Optically thinner LHD plasma spectra from Pt at the electron temperature of around 1 keV are shown in Fig. 1. It is noted that the strong line emission at 3.37 nm is originated from C^{4+}. The origin of a number of transition arrays observed in LHD plasmas that dominate Pt spectra in the 2.5–5 nm region are almost identified. According to the collisional-radiative (CR) model, the ion fraction is expected to be around $q \geq 30+$. The spectral structure would be reproduced by use of the atomic code of HULLAC in near future. [4]

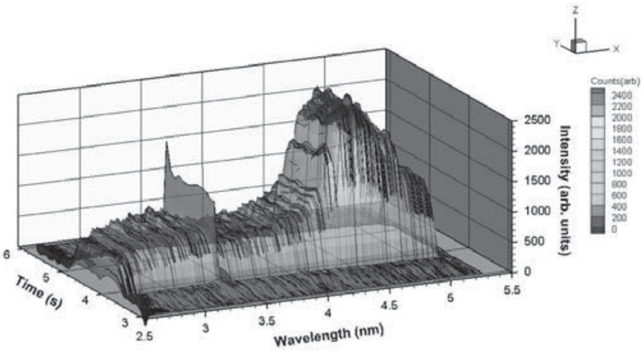

Fig. 1. EUV spectrum of highly charged Pt ions at the electron temperature of 1 keV in LHD.

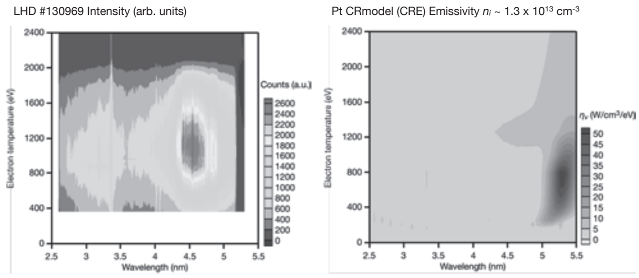

Fig. 2. Spectral behavior at different electron density in LHD. (a) Experiments and (b) numerical calculation by collisional-radiative model, respectively.

In summary, we have characterized the spectral structure of the EUV emission and the plasma parameters by the plasma diagnostics of a LHD-produced Pt plasma. The emissivity was also evaluated by use of atomic structure codes. The optimum electron temperature to produce the strong emission around 4.5 nm was evaluated to be 1 keV, corresponding to an average charge state higher than Pt^{30+} for carbon window SXR emission.

This work is performed with the support and under the auspices of the NIFS Collaboration Research program (NIFS13KLPH020). One of this works was also performed under the auspices of MEXT (Ministry of Education, Culture, Sports, Science and Technology, Japan) and "Project for Bio-Imaging and Sensing at Utsunomiya University" from MEXT.

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