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Charge exchange spectroscopy of multiply charged ions for the development of the EUV light source for the next generation photo lithography

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As a candidate of an extreme ultra-violet (EUV) light source for a next generation lithography, laser produced plasmas (LPP) of Xe and Sn have been investigated intensively in this decade because these plasmas have a strong emission around 13.5 nm which had been determined as the wavelength for the EUV lithography. This emission was considered to be due to multiply charged Xe and Sn ions in hot plasmas. However, the detail atomic spectroscopic data of these multiply charged heavy ions had not been reported yet. To provide atomic data for the understanding and development of the LPP as the EUV light source, we have observed the EUV emission spectra from individual charge states of Xe and Sn ions by means of a charge exchange spectroscopy method. Multiply charged Xe^{q+} (q=7-23) and Sn^{q+} (q=5-21) ions were produced with a 14.25 GHz electron cyclotron resonance ion source, and a charge-selected ion beam was directed into a collision chamber, where the ion interact with a target gas of He and Xe. EUV emissions from the collision center were observed with a compact flat-field grazing-incident spectrometer equipped with a liquid nitrogen cooled CCD camera. In experiments using Xe ions, we have found only Xe XI has a strong UTA (unresolved transition array) around 13.5 nm. On the other hand, various charge states of Sn from VIII to XIV contribute to the 13.5 nm emission. Identification of the transition lines was carried out by calculations using the Hebrew university Livermore laboratory atomic physics code and the Cowan code. Most of the emissions in the EUV region are attributed to the 4p-4d and 4d-$n\ell$ ($n\ell$ = 4f, 5p, and 5f) transitions. However, the 4d-4f transitions have approximately constant differences of about 0.5 nm between the experimental and theoretical results. This can be explained by considering the strong configuration interactions in the n=4 subshells. Using the experimental transition wavelengths of multiply charged Sn ions, theoretical modeling of radiative properties of Sn plasmas and radiation hydrodynamics simulations had been performed for the optimization of the LPP EUV light source.