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Amplitude of spontaneous emission of 112-nm Al^{3+} ion 3s-3p transition in neon-like aluminum laser plasma

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Since the invention of lasers, research on laser oscillation with various wavelengths and pulse widths has been conducted. In particular, research for short-wavelength lasers have been carried out extensively. The transient electron collision excitation (TCE) scheme [1] is one of the mechanisms for generating an inverted population in plasma x-ray laser oscillations. Using nickel-like and neon-like TCE methods, laser oscillations have been observed with wavelengths ranging from a shortest of 7.3 nm using Sm to a longest of 87.6 nm using Si, respectively. If an amplitude of spontaneous emission (ASE) for aluminum is realized between Al^{3+} 3s-3p transition, it is the longest wavelength of 111.9 nm by this scheme. It is expected to have various applications as it falls in the intermediate region between currently existing ultraviolet lasers (F_2 laser: 157 nm) and soft x-ray lasers. This study aims to demonstrate the ASE of 111.9-nm vacuum ultraviolet (VUV) wavelength in neon-like Al laser plasma for the first time.

In the TCE scheme, an aluminum target in the vacuum chamber was irradiated with two lasers (1064 nm wavelength), that is, pre-pulse and main pulse, with a time delay between them. The pre pulse was line-focused onto the Al target normal to the target surface to generate a low-density and low-temperature plasma (pre-plasma). After an appropriate time delay, the main pulse was injected and further heated the pre-plasma (axial pumping). However, optimal plasma density heated by the main pulse ($\sim 10^{18}$ cm^{-3}) efficiently is much higher than the critical density (10^{21} cm^{-3}) of 1064-nm pump laser, so that the gain coefficient is even low due to both density mismatch. Therefore, the main pulse was irradiated onto the target at a grazing angle of ~4 degree, by which the effective critical density in the gain region was similar with the density of 10^{18} cm^{-3}. By varying several parameters, such as, time intervals between both pulses and each laser intensity, VUV spectra were measured with a normal incident VUV spectrometer. Besides, the incident angle and the position of the main pulse to heat the plasma was also varied in the experiments. Figure 1 shows a schematic diagram of the experimental setup. Two apertures were placed to reduce intense stray light (note that the axial pumping was used). The experimental conditions were determined based on the scaling laws [2], Saha equation, and radiation hydrodynamic simulation (Star2D).

Under conditions of the incidence angles of 3.5~4°, very sharp spectrum of 111.9 nm was at pre-pulse energy of 2.5×10^8 W/cm^2 and main pulse of 4.2×10^{13} W/cm^2. The result at 4° is shown at FIG.2. According to the NIST database [3], the spectral wavelength of the transition of neon-like ion 3p ($^1S_0$)-3s ($^1P_1$) is 111.9 nm, and thus we can demonstrate ASE of the longest wavelength by the TCE scheme. In this study, intense ASE was not observed due to the instability caused by the pump laser energies and pulse interval (timing jitter), thus making it impossible to optimize plasma parameters and laser irradiation conditions precisely.

In the future, we plan to improve the jitter of the pre-main pulses by stabilizing the pump lasers, and by optimizing the laser energies, pulse time intervals, as well as the incident angle and position, we will aim to achieve prominent ASE signal of the 111.9 nm spectrum with high signal to noise ratio.

References

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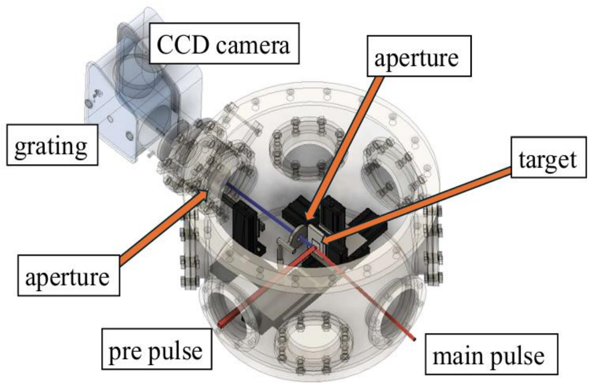

FIG. 1. A schematic diagram of the experimental setup for VUV wavelength ASE measurement.

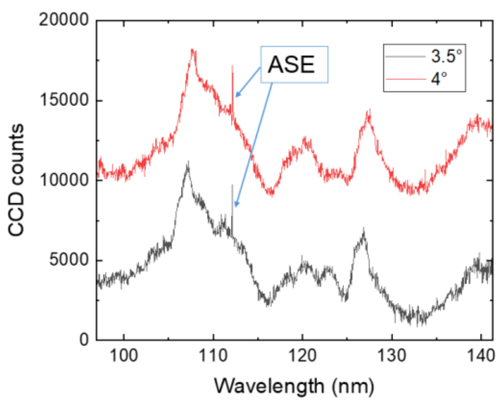

FIG. 2. Typical VUV spectra of laser produced Al plasma. Around 112 nm, sharp line spectrum is observed.