29. Development of Transient Collisional Excitation X-ray Laser with Ultra Short-pulse Laser

Masataka KADO, Tetsuya KAWACHI, Noboru HASEGAWA, Momoko TANAKA, Kouta SUKEGAWA, Keisuke NAGASHIMA, and Yoshiaki KATO
Advanced Photon Research Center, Kansai Research Establishment,
Japan Atomic Energy Research Institute
8-1 Umemidai Kizu-cho, Souraku-gun, Kyoto 619-0215, Japan

We have observed lasing on Ne-like 3s-3p line from titanium (32.4nm), Ni-like 4p-4d line from silver (13.9nm) and tin (11.9nm) with the transient collisional excitation (TCE) scheme that uses combination of a long pre-pulse (~ns) and a short main pulse (~ps). A gain coefficient of 23cm^{-1} was measured for plasma length up to 4mm with silver slab targets. We have also observed lasing on Ne-like and Ni-like lines with new TCE scheme that used pico-seconds laser pulse to generate plasma and observed strong improvement of x-ray laser gain coefficient. A gain coefficient of 14cm^{-1} was measured for plasma length up to 6mm with tin targets.

Keywords : Transient collisional excitation, Ultra short-pulse laser, Fillamentation instability

1. Introduction

X-ray lasers have a potential to be used for biological imaging[1], plasma probing, and interferometers. However most of the works to generate x-ray lasers have been done with large laser facilities such as LLNL, Rutherford, and ILE. Recently there are several studies reported with compact table-top laser systems using transient collisional excitation[2,3,4,5] (TCE).

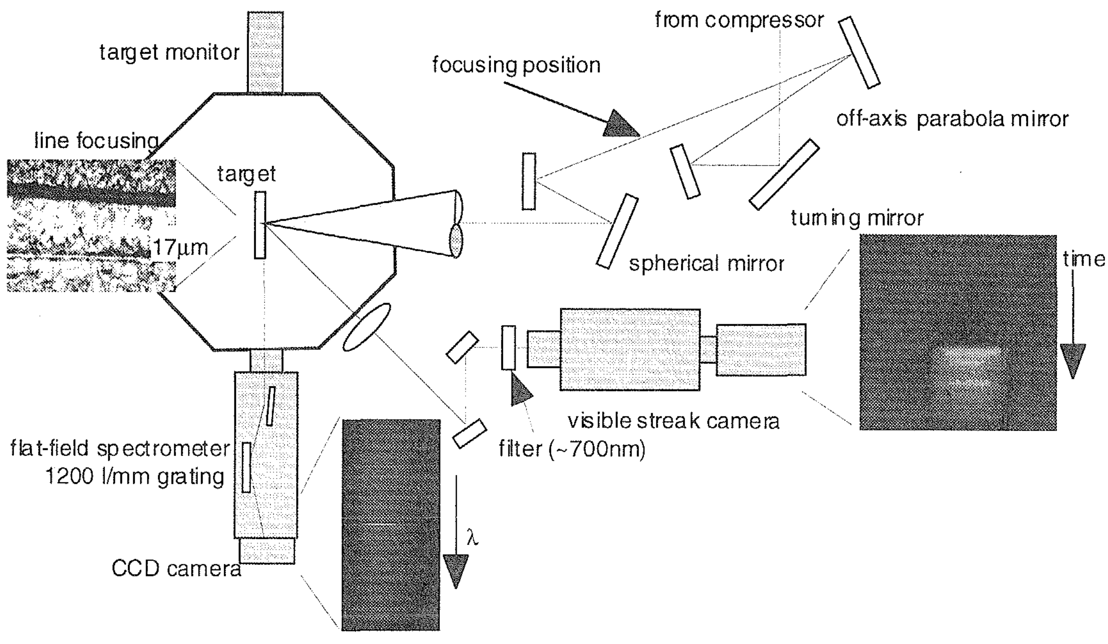

Fig.1 Experimental setup for the x-ray laser generation. The laser pulses were focused onto slab targets with a combination of an off-axis parabola mirror and a spherical mirror. The x-ray spectrum was measured with a flat-field spectrometer. The scattered emmision from the gain plasma was measured with a filtered visible streak camera.

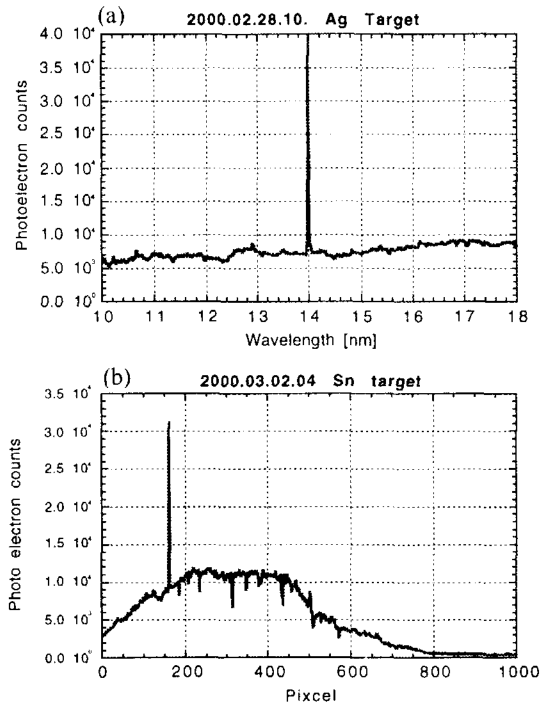

Fig2 Time integrated axial spectrums. Figs. 2 (a) and (b) are the spectrum of the x-ray from Ag and Sn targets, respectively.

The TCE scheme uses a long pre-pulse (~ns) to generate plasmas and a short main pulse (~ps) to excite electrons. The electrons are excited from ground state to excite state faster than the electron relaxation time. This scheme produces larger x-ray laser gain than the gain produced with ordinary collisional excitation scheme and pumping laser energy required to generate x-ray lasers of 10nm in wavelength is only 10J. The new TCE scheme is also proposed[4] to reduce the laser energy furthermore, which uses short laser pulse (~ps) to generate plasmas instead of long laser pulse. Using short laser pulse for generating plasmas, high electron temperature and high electron density are obtained at same time and high collisional ionization rate is created.

Hybrid laser system with Ti:sapphire front end and Nd:glass amplifiers has been developed. This laser system is designed and optimized for the TCE x-ray laser experiments. The x-ray laser experiments with TCE scheme and new TCE scheme have been conducted with this laser system.

2. Experimental setup

In our experiments two sets of pre-pulse and main pulse combination were selected. One was 1.5ps pre-pulse and 1.5ps main pulse combination and another was 600ps pre-pulse and 1.5ps main pulse. Pulse separations of pre-pulse and main pulse for the both cases were 1.2ns. The energy ratio of the pre-pulse and the main pulse was 1:5 for the 1.5ps-1.5ps combination and 1:2 for the 600ps-1.5ps combination. The pulse separation was monitored with an S-20 type streak camera. Target surface was monitored with two sets of long distance microscope with magnification of 25x.

Shown in figure 1 is the experimental setup of the x-ray generation. The laser pulses were focused onto slab targets with a combination of an off-axis parabola mirror and a spherical mirror. The focused spot size of the pumping laser pulse was estimated by a crater size on the titanium

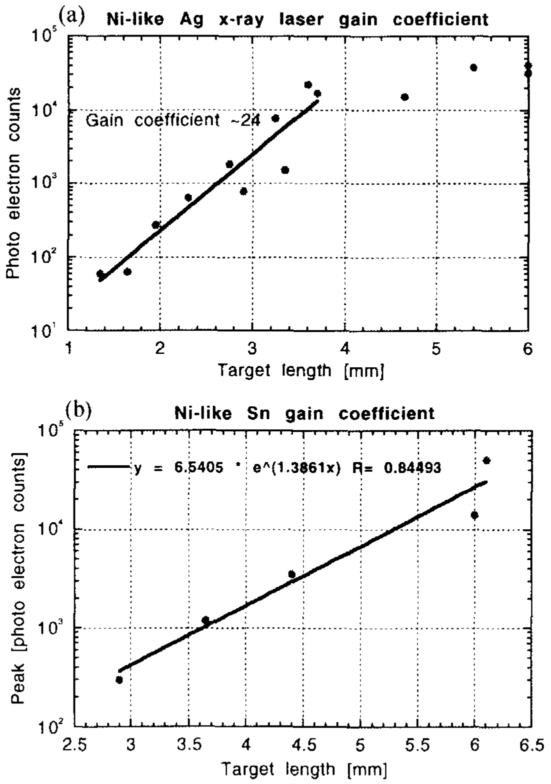

Fig.3 Output intensity of x-ray lasers vs. target length. The gain coefficients were determined by fitting the Linford formula to those data in the exponential region, to be 23cm-1 for Ag (a) and 14cm-1 for Sn (b).

target, which was 6mm long and 17μm width.

The primary diagnostics along the target surface was a flat-field grazing incidence x-ray spectrometer with a 1200 lines/mm aperiodically ruled grating. The spectrometer was coupled with a back illuminated CCD camera. The spectral range of the spectrometer was 10 to 40nm. Al and Si_3N_4 filters were used to provide variable attenuation for different x-ray laser wavelengths. The time and spatial resolved scattered light from the plasmas was measured with the S-20 type streak camera to monitor the laser plasma interaction such as the filamentation instability. Filters were used to cut the laser fundamental and second harmonics scattered light and detected mostly 700nm wavelength, which is mainly scattered from the quarter critical density region and is sensitive to the laser filamentation instabilities.

3. Experimental results

Time integrated axial spectrums were shown in Figures 2(a) and 2(b). Fig. 2(a) and Fig. 2(b) are the spectrum of the x-ray from Ag and Sn targets. The outputs from Ag target is completely dominated by the Ni-like Ag J=0-1 laser transition at 13.9 nm. The intensity of the laser line was attenuated by a 20nm thick Si_3N_4 filter to 15% to avoid saturation of the CCD detector. The output energy was estimated to be 4μJ. For the case of Sn target the laser line was not strong enough to dominate the x-ray spectrum.

The output intensity of the Ag and Sn laser were plotted in Figure 3 against plasma length. The plasma length was controlled with changing target length. The increase of the output intensity of the laser line is a simple exponential form with the plasma length less than 4mm for Ag and 6mm for Sn. The gain coefficients were determined by fitting the Linford formula to those data in the exponential region, to be 23cm^{-1} for Ag and 14cm^{-1} for Sn.

Shown in figures 4 (a) and (b) are temporal profiles of the plasma image measured with the filtered visible streak camera. The target for the both data are Titanium slabs. The pulse durations of the pre-pulse are 600ps for Fig.4 (a) and 1.5ps for Fig.4 (b). The image showed evidence of filamentation instabilities for the data with 600ps pre-pulse.

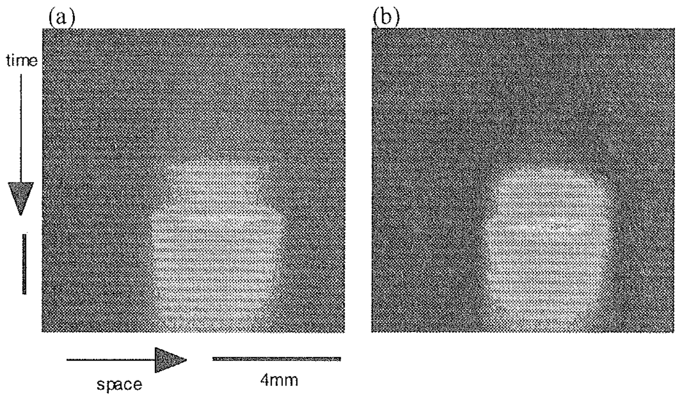

Fig.4 Temporal image of x-ray laser plasmas. Figs. 4(a) and (b) are the data with 1.5ps pre-pulse and 600ps pre-pulse with Titanium targets. The Fig. 4(b) shows the evidence of nonlinear scattering from a quarter critical density and self-focusing.

4. Summary

In conclusion, we have obtained x-ray laser emission from Ni-like Ag and Ni-like Sn with the TCE scheme (600ps prepulse and 1.5ps ,ain pulse combination) and also the new TCE scheme (1.5ps pre-pulse and 1.5ps main pulse combination). Gain coefficient 23cm^{-1} was obtained for the Ni-like Ag x-ray lasers with the ordinary TCE scheme. Gain coefficient 14cm^{-1} for the Ni-like Sn x-ray lasers with new TCE scheme, which was the shortest x-ray laser wavelength reported with the TCE scheme. The temporal image of plasma showed the evidence of fillamentation instabilities with the 600ps pre-pulse case.

References

[1] L. B. Da Silva, J. E. Trebes, R. Balhorn, S. Mrowka, E. Anderson, D. T. Atwood, T. W. Barbee, Jr., J. Brase, M. Corzett and J. Gray, Science **258**, 269 (1992).
[2] P. V. Nickles, V. N. Shlyaptsev, M. Kalachnikov, M. Schnurer, I. Will and W. Sandner, Phys. Rev. Lett. **78**, 2748 (1997).
[3] J. Zhang, A. G. MacPhee, J. Nilsen, J. Lin, T. W. Barbee, Jr., C. Danson, M. H. Key, C. L. S. Lewis, D. Neely and R. M. N. O'Rourke, Phys. Rev. Lett. **78**, 3856 (1997).
[4] J. Dunn, A. L. Osterheld, R. Shepherd, W. E. White, V. N. Shlyaptsev and R. E. Stewart, Phys. Rev. Lett. **80**, 2825 (1998).
[5] J. Dunn, J. Nilsen, A. L. Osterheld, Y. Li and V. N. Shlyaptsev, Opt. Lett. **24**, 101 (1999).
[6] M. Kado, A. Nagashima, K. Nagashima, T. Kawachi, N. Hasegawa, M. Tanaka, T. Hosokai, K. Sukegawa, A. Sasaki and Y. Kato, SPIE Proc. **3776**, 242 (1997).