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# X-ray Laser Generation under Two-Pulse Irradiation of Targets on Picosecond SOKOL-P Facility

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## Introduction

The transient collisional excitation (TCE) scheme of x-ray laser (XRL) [1] makes possible attaining of extra-high peak gain factors - $g_{max} \geq 100$ cm$^{-1}$. This is promising for development of table-top XRL as well as progress in shorter wavelengths. X-ray lasing on 3p-3s transition of Ne-like titanium ions with TCE was demonstrated first in Max Born Institute [2]. In these experiments the flat titanium targets were irradiated by combination of 1.5 ns prepulse (energy up to 7 J) and 0.7 ps main pulse (energy up to 4 J). The experimental value of XRL gain was measured $g=19\pm1.4$ cm$^{-1}$. Similar experimental results, but with higher gain factor ($g=24$ cm$^{-1}$) were obtained in LLNL on the “Janus” facility [3].

A numerical simulation of hydrodynamics and level-by-level ion kinetics for the XRL active media under powerful picoseconds heating has been carried [4]. This simulation showed that active media length dependence of output XRL energy is determined, first of all, not by the peak value of the gain, but by the refraction of XRL beam in the strong density-gradient amplifying region, and by the effect of radiation lag. This dependence is resulted in obtaining of certain effective gain factor that not reflects the g values, really attainable in the XRL plasma. The gain value $g \sim 50$ cm$^{-1}$ was estimated in [4] for the XRL on 3p-3s transitions of Ne-like Ti ion.

Given work presents the results of the experiments that are similar to first experiments [2,3]. We realized TCE of X-ray laser pumping using the irradiation of titanium target (Z=22) by two sequential pulses too, but the duration of the basic heating pulse was 4 ps in our experiments. Specific pumping energy per unit of focal line was about 0.7 J/mm; laser flux density on the target – about $6\cdot10^{14}$ W/cm$^2$.

## 1. Experimental Setup

The experiments were conducted at laser facility SOKOL-P [5]. The facility represents picosecond chirped pulse amplification laser with maximum power about 10 TW. In these TCE experiments as a prepulse, creating the laser's active medium, a portion of energy of the chirp-modulated amplified pulse $t_{ch}$=400÷440ps long was used. Duration of the basic pumping pulse $t_p$ may be varied with a base compressor adjustment. The compressor was set for pulse duration $t_p$=4 ps. The picosecond pulse lag relative to prepulse was maintained constant, equal to 1.5 ns. Prepulse and main pulse energies ratio was 1:2.5. This ratio was also maintained constant; the prepulse energy was 2.5±0.3 J, the main pumping pulse energy was 6.3±1.0 J. The accuracy of position coincidence of prepulse and the main pulse beams, focused into a thin line on the target, is not worse than ±3 μm.

The focusing optics consists of a toroidal mirror, mounted in vacuum target chamber, and a meniscus lens, located in the air in front of LiF input window. This system assures the laser beam focusing into thin line with maximum length of 10 mm. To eliminate the target irradiation non-uniformity the parallel beam was blinded and the targets length was used not longer than 8 mm. In this case the droop of intensity on the target edges was below 15 % of its value in the center of the focal line.

X-ray images from pinhole-camera enabled the control of the focal line width and the irradiation uniformity as well. The target position in the pumping laser beam was not changed in experiments and the focal line was equal 35-40 μm in width. Thus, the laser light intensity at the target surface in prepulse was $2\cdot10^{12}$ W/cm$^2$, and in main ps pulse - $6\cdot10^{14}$ W/cm$^2$.

A grazing incidence spectrograph with flat diffraction grating (600 mm$^{-1}$) was used for the spectra registration in the wavelength region 120÷400 Å (see fig.1).

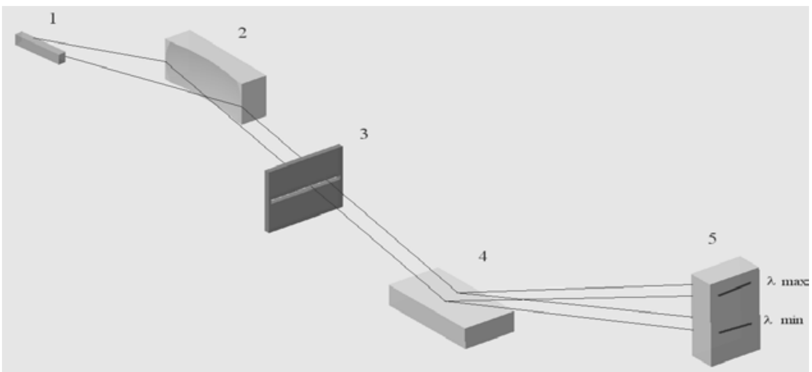


Figure 1. Layout of grazing incidence spectrograph. 1 – target, 2 – focusing mirror, 3 – spectral slot, 4 – diffraction grating, 5 – CCD-matrix.

A focusing spherical mirror was mounted between target and grating. This mirror collected the target radiation in the plane perpendicular to the target surface in the angle 0.035 rads. The target center was set in meridional focal plane of the mirror, which forms almost parallel beam of x-rays. The width of this beam for the x-ray laser radiation is determined by XRL divergence and, for all other registered spectral lines – by the collection angle of mirror. Thus, this diagnostic makes possible analysis of the XRL beam divergence in the plane perpendicular to the target surface. The spectrum is recorded with x-ray CCD-camera PI-SX:400. Spectral resolution $\lambda/\Delta\lambda$ for the wavelength of XRL $\lambda_g$=326 Å was about 140. A special attention in the experiments was paid on thorough adjustment of the spectrograph relative to the axis of the x-ray laser beam. The error of the spectrograph slot alignment about the beam axis was apx. ±3 mrads.

## 2. Experimental Results

Fig. 2 shows a spectrogram, obtained from the experiment with 6 mm target.

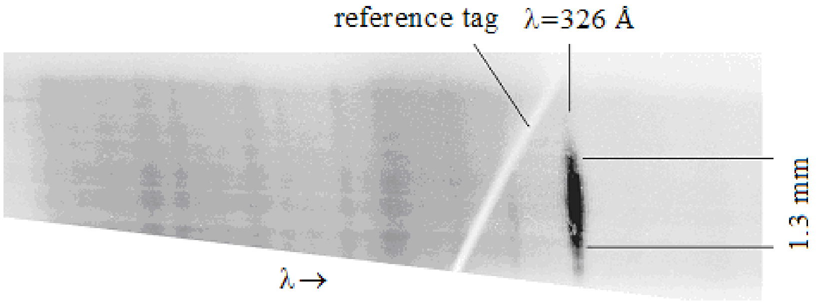


Figure 2. Spectrogram of the shot with 6 mm target length.

Bright spectral line with wavelength $\lambda$=326 Å is dominating in the spectrogram. The target length was varied in the experiments from 2 to 8 mm. Fig.3 shows dependence of x-ray laser intensity on the target length. As far as pumping energy during the experiments was not strictly constant (experimental scattering ±16%), the experimental points on the plot are arrow-accompanied to point the trends in variation of the recorded in the case when the pumping energy would be nominal value - 6.3 J. For 2 mm targets XRL output was founded out below the diagnostic threshold sensitivity. Downward direction of the arrow means that given experimental point is actually the upper limit of XRL output. Fitting our data for targets' lengths of 2-4 mm to Linford's formula with account to the abovementioned corrections of pumping energy instability give the gain value g =30±5 $cm^{-1}$. Maximum energy of the x-ray laser beam turned to be equal to about 0.4 μJ; its divergence 9±3 mrads.

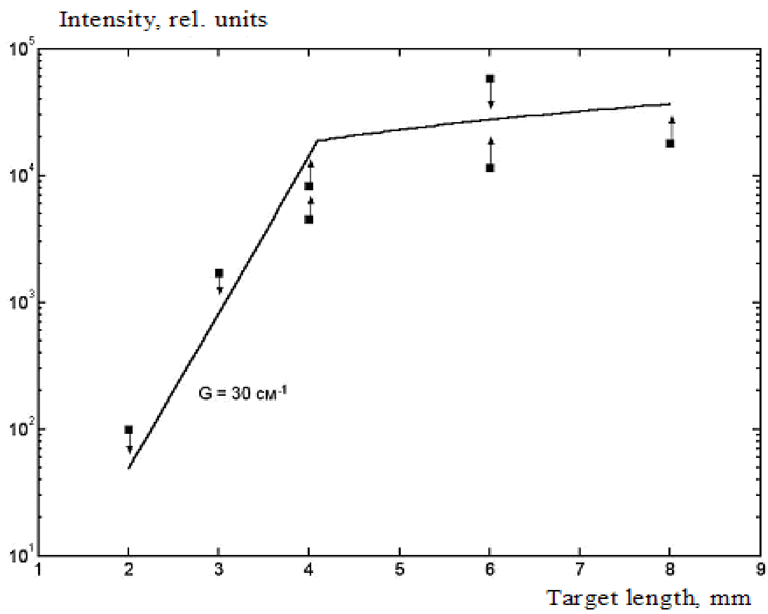


Fig 3. Dependence of XRL intensity on target length.

**Conclusions**

Results of experiments in this work have demonsrated XRL generation of 3p-3s Ne-like Ti ion in the TCE scheme. This scheme was realized at sequential irradiation of targets with two laser pulses of 0.4 ns and 4 ps duration, focused into thin line. Pumping energy density per unit of focal line length was about 0.7 J/mm. Maximum energy of the x-ray laser beam turned to be equal to about 0.4 μJ; its divergence 9±3 mrads. The experimentally founded small signal gain 30±5 $cm^{-1}$ turned to be close, but some lower than simulation gain value of ~ 50 $см^{-1}$ [4]. It seems the result of simulation is overestimated on the score of imperfect model of XRL radiation transport under strong refraction conditions.

**References:**

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