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New X-Ray laser pumping method and experiments planning at TEWALAS

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Ionization dynamics in Transient Collisionaly Excited (TCE), Grazing Incidence Pumped (GRIP) Mo X-Ray laser (XRL) was investigated. The generation of the active medium for an XRL by irradiation of a solid target was simulated using three pulses in order to obtain a better control of the gain and ionization dynamics. It was found that using two short pulses provides a better gain for the x-ray laser. Experiments are planned in the near future at the TEWALAS laser system in Magurele, Romania.

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1. Introduction

In the recent years, since the transient collisional excitation (TCE) scheme started to be implemented in different X-ray applications, important progress towards higher repetition rate, higher efficiency and reduced size of soft X-ray lasers has been obtained [1]. The nickel-like scheme, proposed firstly by Maxon *et al* (1985) has proven to be successful for short wavelength amplification below 10 nm (MacGowan *et al* 1987, 1990) at the Lawrence Livermore National Laboratory (LLNL) [2]. The first TCE XRL system has been realised using a nanosecond long pulse and a short main pulse of the order of picosecond. There was a significant reduction in the pumping power needed for inducing lasing so this new pumping method has opened the way to XRL for few Joule laser systems. Another step in reduction of the pumping energy needed was achieved in 2003 by the GRIP (Grazing Incidence Pumping) scheme. The principle of the method is based on the fact that a chosen electron density region of a pre-formed plasma column, produced by a longer pulse at normal incidence onto a slab target, is selectively pumped by focusing a short pulse of 100 fs - 10 ps duration laser at a determined grazing incidence angle to the target surface [3]. The exact angle dependents on the pump wavelength and relates to refraction of the drive beam in the plasma. In this way, the absorption of the pump pulse is taking place several tens of micrometers away from the critical density region, in the gain region.

2. New X-Ray Laser pumping method

A Transient Collisionaly Excited, Grazing Incidence Pumped X-Ray laser (TCE-GRIP-XRL) for a Mo solid target, having the principal lasing line at 18.9 nm, was analyzed in [4]. To create the plasma active medium we used one long pulse and two short pulses in order to provide a better gain in the active medium of the X ray lasers. The classical method uses one single short pulse as it is depicted in Fig. 1(a).

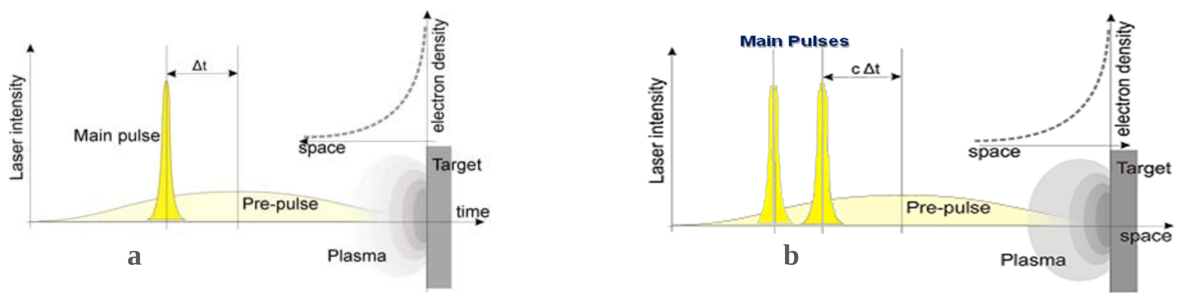


Fig. 1. Schematic representation of the improved TCE XRL: a) first case using one short pulse; b) second case using two short pulses.

In our case, the first pulse (named prepulse) will create highly ionized plasma (named preplasma), the second and the third pulses (named main pulses) will create population inversion in this plasma and a gain region which travels along the plasma line. This travelling heated region can be associated with the gain region of the

XRL. The numerical simulation was performed using EHYBRID program.

3. Results of the simulations

Two cases were analyzed: in the first case, we used one single main pulse. In this case the prepulse duration is 400 ps and the main pulse duration is 2 ps. The delay between the prepulse and the main pulse is the same as in the first case (450 ps). We determined the average charge along a perpendicular axis at the target and the gain profile on different sequences of time referring on the second pumping pulse arrival on the target (figure 2). In the second case we used three pulses: the prepulse duration is 400 ps and the duration for both main pulses is 2 ps. The delay range considered between the main pulses is 5-15 ps with 5 ps step. The delay between the prepulse and the first main pulse is 450 ps. Prepulse energy is 300 mJ and the total amount of energy for the two short pulses is 150 mJ. We determined the dynamics for the gain profile and for the average charge along a perpendicular axis at the target on different sequences of time referring to the second and the third pumping pulses arrival on the target. The parameters correspond to the ones in a planned experiment at TEWALAS laser facility at our host institute.

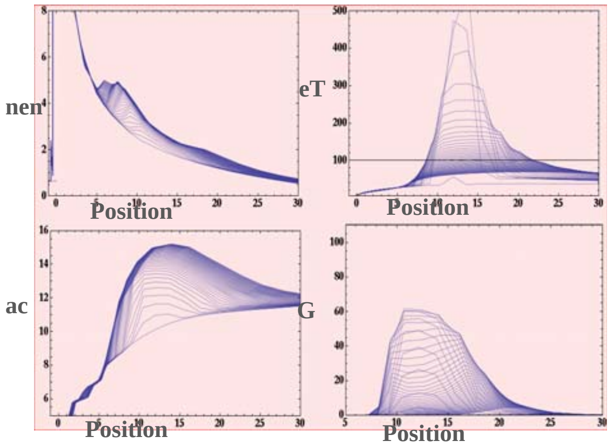
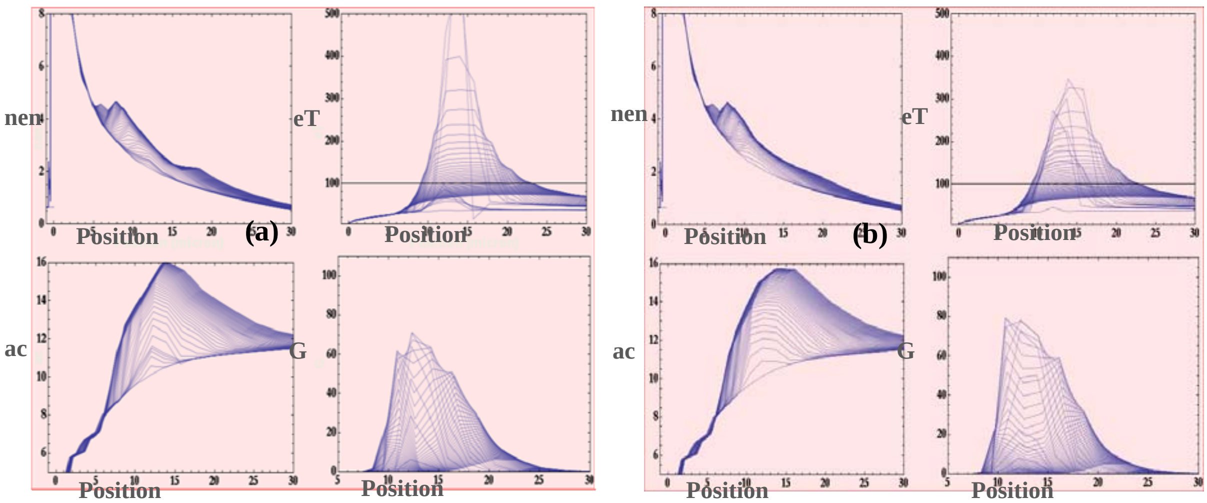
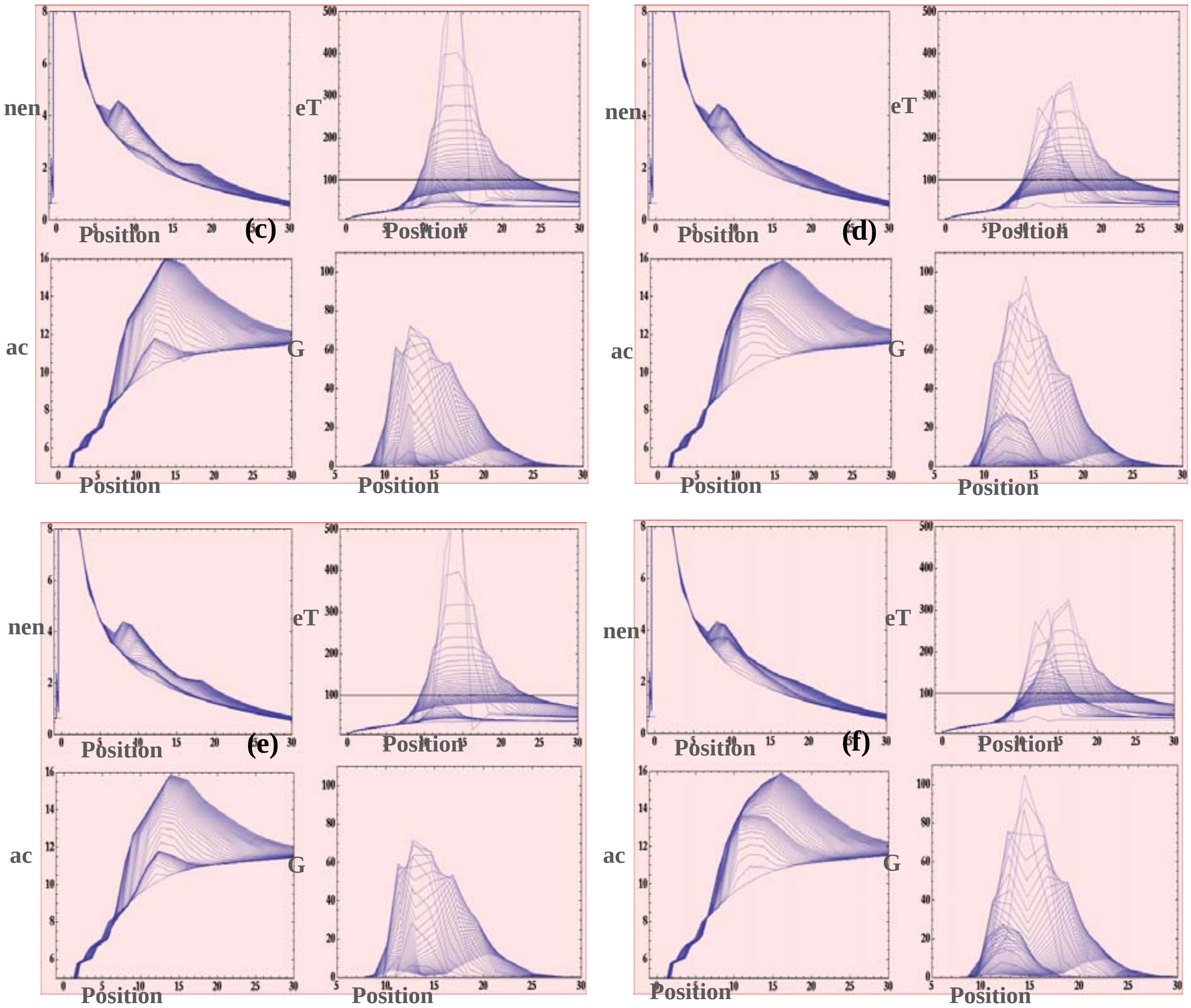


Fig. 2. Spatial and temporal evolution of the plasma parameters (electron density, electron temperature, average charge and the gain) for the Mo solid target using a prepulse and a main pulse.

In Fig. 2, which describes the evolution of the plasma parameters in the standard pumping scheme which uses only one main pulse, one can see that the gain value is about 65. We conclude the fact that the optimal ionization state and a high temperature are not reached at the same time and this affects the gain. In the single short pulse case, when plasma first reaches 14+ average ionization state, the temperature of the electrons dropped already to about 200 eV, which is not enough for reaching an optimal value of the gain.

In the case with three pulses, the total energy was divided between the prepulse and the main pulses in 50:50 and 10:90 ratio. In this case the first pulse is normal to the target and the short pulses have the incidence angle of 70 degrees (grazing angle).





nen – electron density (ne/10^21), eT – electron temperature (eV), ac – average ionization state, G – gain

Fig. 4. Spatial and temporal evolution of the plasma parameters for the case using three pulses where the energy ratio between main pulses is: (a), (c) and (e) 50% and (b), (d) and (f) 10% and the delay between them is: (a) and (b) 5 ps, (c) and (d) 10 ps and (e) and (f) 15 ps.

Fig. 4 synthesises the modelling results for the case with two short pulses, namely the spatial and temporal evolution of the plasma parameters where the energy ratio between main pulses is: (a), (c) and (e) 50%-50% and (b), (d) and (f) 10%-90% (first main pulse-second main pulse) and the delay between them is: (a) - (b) 5 ps, (c) - (d) 10 ps and (e) - (f) 15 ps.

The plots illustrate the temporal and spatial dynamics of the four parameters of interest starting with the arrival of the main pumping pulse: electron density distribution normalized to the critical electron density, electron temperature, average ionization state of the plasma and the gain for the strongest lasing line, at 18.9 nm (4d-4p transition). We plotted a curve every picosecond. The lower curves represent the initial distributions of the mentioned parameters as a function of distance to the target.

It can be observed that the electron plasma density is slightly influenced due to the ionisation. The initial average ionization is below 12+ in the region of interest, so the first pulse main pulse has to ionize the plasma to Ni-like (14+ in the case of Mo). In the 10:90 pulses energy ratio case, this is not successful, even if one waits 15 ps (fig. 4e), while in the case of 50:50 case this is achieved in less than 10 ps. So, in the 10:90 case, the second pulse has to further ionize the plasma to 14+, while in the 50:50 case the main use of the second pulse is to heat the plasma to produce a strong electron collisional excitation, and, in consequence, higher gain.

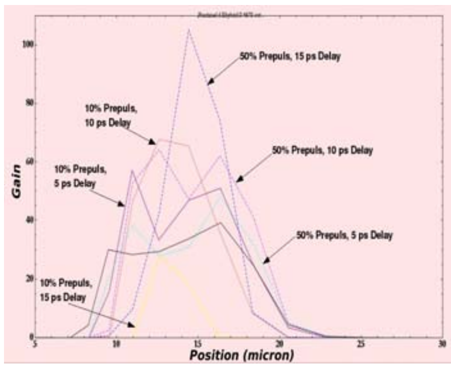


Fig. 5. Temporal evolution of the gain in plasma for the case using two pulses (black curve) and the case using three pulses where the delay between the main pulses is 5, 10 or 15 ps.

For a comparison, one can observe in figure 5 the maximum value for the gain in the second case (three pulses) is 105 with a main pulses delay of 15 ps and the energy ratio between main pulses is 50%. We plotted for comparison the gain in the plasma for all the cases at the same instance of time. In the single main pulse case, when plasma first reaches 14+ average ionization state, the temperature of the electrons dropped already to about 200 eV while in the optimal case of second case with 50:50 pulses the electron temperature of the plasma is about 300 eV and this fact is reflected in the gain curves In the first case the maximum value for the gain is 65 and in this way we can conclude that by using three pulses we can provide a better gain in the active medium with 50% more than in the second case.

4. Multiple pulses generation method

A multiple pulses chirped pulse amplification (MPCPA) method was developed for producing the needed collinear short pulses needed to pump the XRL [4]. In order to generate the multiple pulses, a simple passive pulse shaping technique in the spectral domain is implemented. The ratio of the intensity of the pulses and the delay between them can be controlled. Two and three spectrally separated pulses with duration of 300 fs and energies in the mJ range were generated, with intensity ratios from 0.05 to 1 and delays up to 600 ps [5,6].

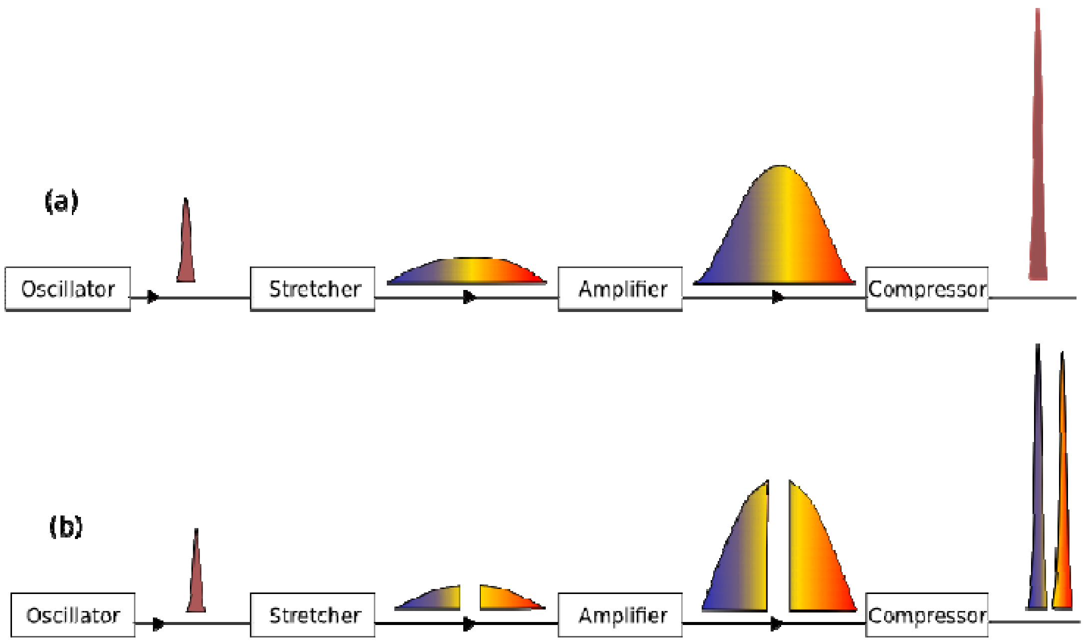


Fig. 6. Comparison between the standard CPA laser architecture (a) and multiple pulses CPA architecture (b.)

A typical CPA system can be modified easily in order to produce two collinear pulses with complementary spectral components. A comparison of the standard CPA and multiple pulses CPA (MPCPA) architectures of the lasers is presented in the figure 6a. A laser oscillator produces ultra-short pulses with a broad spectrum. By introducing different optical paths for different spectral components, the pulses are stretched in time, thus reducing the peak intensity three to four orders of magnitude. Typically, the long wavelength spectral components ("red" part of the pulse) are coming earlier than the short wavelength spectral components ("blue" part of the pulse). The stretched pulses are amplified and recompressed to the initial short duration in the optical compressor. The modification of the laser pulse at the stretcher level in the MPCPA assembly takes place due to the insertion of a temporal gap in the stretched pulse (Fig. 6 (b)). In the MPCPA method described here, the duration of the gap and its position in the spectrum can be modified to match the experimental needs. Most of the pulse shaping techniques are related to the modification and control of the second and higher order terms of the Taylor series development (1) for the spectral phase of the ultrashort pulses Φ(w):

$$\Phi\,(w)=\varphi_0+\frac{\varphi_1}{1!}(w-w_0)+\frac{\varphi_2}{2!}(w-w_0)^2+\frac{\varphi_3}{3!}(w-w_0)^3+\frac{\varphi_4}{4!}(w-w_0)^4+\ldots.. \qquad (1)$$

where w is the electromagnetic field frequency and w_0 is the central frequency of the spectrum of the laser pulse. The main idea is to modify the first order term in the spectral phase distribution. This term corresponds to a simple temporal delay. The proper place to do this is after the first pass through the stretcher, where one has a collimated beam with spatial chirp. The same approach is possible in the optical compressor after the first pass [5].

The MPCPA approach will be implemented on the TEWALAS facility [7]. It consists in a Ti:sapphire laser system based on chirped pulse amplification. Oscillator femtosecond pulses, after passing through a booster and intensity contrast improvement module, are stretched up to 300 ps. The stretched pulses are amplified by a regenerative amplifier, two multi-pass amplifiers and re-compressed in a vacuum compressor. More than 10^9 intensity contrast of femtosecond pulses in relation to the amplified spontaneous emission was obtained. Amplified laser pulses, with as much as 440 mJ pulse energy, are compressed down to 23 fs at 10 Hz repetition rate [7]. In Fig. 7 it is illustrated the schematic ray tracing for the pumping of the XRL to be implemented on the TEWALAS facility. The rectangular area represents the optical table of the TEWALAS system which provides the stretched prepulse through a long delay line for the XRL which is located in the interaction chamber (big circle). The delay line is introduced here to adjust the optical path of the prepulse to be equal to the short ones. The small circle represents the optical pulse compressor where the two main pulses for creating the population inversion in the plasma are obtained. Preliminary test of the multiple pulse generation on the TEWALAS facility was successfully completed and the delay line will be soon implemented.

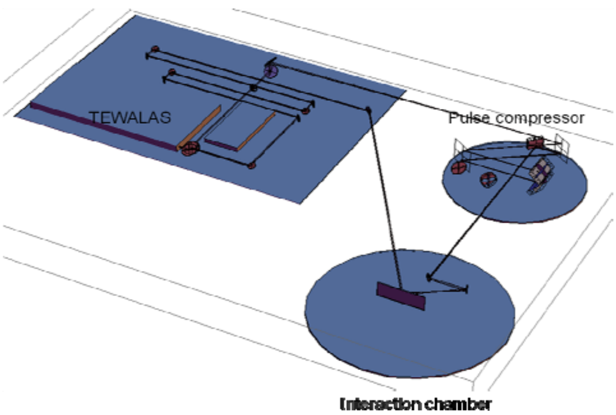


Fig. 7. XRL set-up at TEWALAS facility.

5. Conclusions and outlook

In this study we demonstrate that by using an improved transient collisional excitation (TCE) pumping scheme with two short pumping pulses the charge distribution in plasma can be significantly modified. It was found that the use of two short pulses provide a better gain in the active medium of the x-ray laser, in certain conditions. With this new pumping method it is possible to obtain a better control of the balance between ionization dynamics and temperature dynamics. In parallel, we identified the MPCPA method to produce multiple short pulses. The parameters used in this experimental modeling were selected to permit the experimental testing of the method at the ultra-short and ultra-intense pulses laser TEWALAS facility, implementing the multiple pulses generation method described in that paper.

Acknowledgments

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