Gain and ionization dynamics in transient, collisionaly excited X-ray lasers

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Ionization dynamics in Transient Collisionaly Excited (TCE), Grazing Incidence Pumped Mo X-Ray laser was investigated. The generation of the active medium for an XRL by irradiation of a solid target was performed 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.

1. Introduction

In the last 10 years, important progress towards higher repetition rate, higher efficiency and reduced size of soft X-ray lasers has been attained by implementing the transient collisional excitation (TCE) scheme. The first TCE XRL system has been realised using a nanosecond long pulse and a short main pulse of the order of picosecond [1]. There was a significant reduction in the pumping power needed for inducing lasing compared with previous experiments with nanosecond long pulses so this new pumping method has opened the way to few Joule pumped XRL systems [2]. Another step in reduction of the pumping energy needed was achieved in 2003 by the GRIP (Grazing Incidence Pumping) scheme [3]. The principle of the method relies 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 relative to the target surface [4]. The exact angle depends 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 in the gain region where it is needed. Here we investigate such GRIP XRL system based on simulations for Ni-like Mo solid target.

Modeling of the XRL in general is based on magneto-hydrodynamics (MHD) codes for plasma description coupled with rate equations programs for the plasma ionization and population inversion dynamics for analyzing the gain of the XRL. In order to obtain a better control of the gain and ionization dynamics, we propose with our simulations a new method to generate the active medium for an XRL using three pumping pulses which irradiate a Mo solid target.
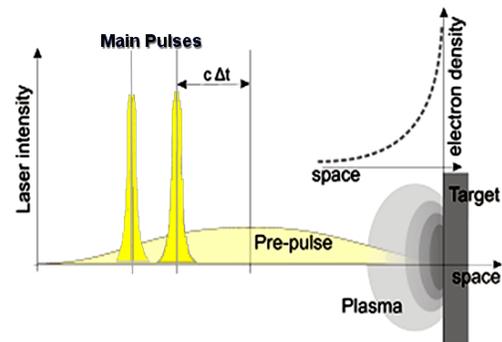

Fig. 1. Schematic representation of the proposed TCE XRL: laser pulses intensities, the target and the plasma electron density are represented in the spatial extension.
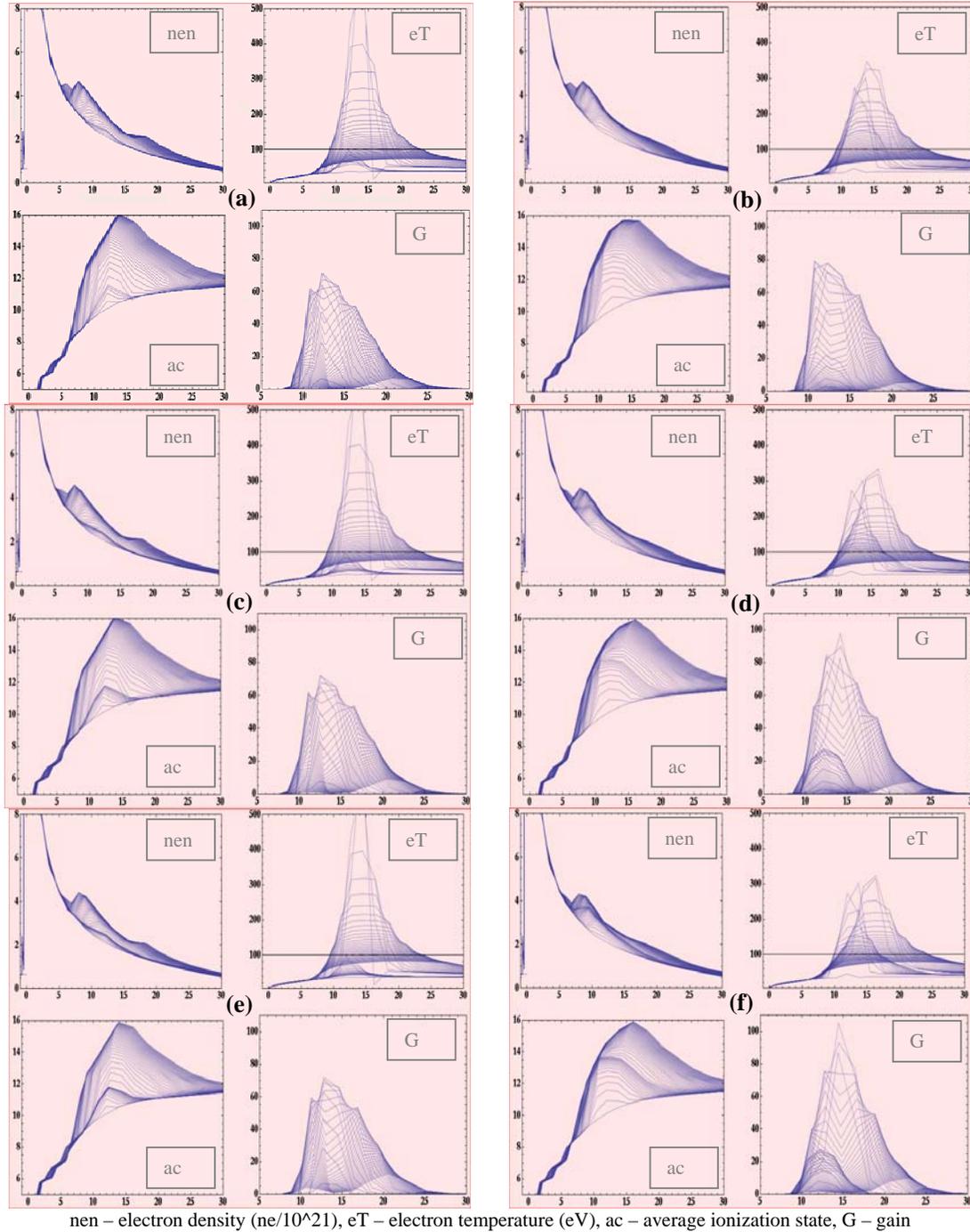
2. The pumping method

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. To create the plasma active medium we used one long pulse and two short pulses, as depicted in Fig. 1. 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 for plasma description [5,6,7] which includes the effect of the incidence angle of the pulses 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.

3. Results and discussion

Two cases were analyzed: in the first 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. In the second 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). 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

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

Fig. 2. Spatial and temporal evolution of the plasma parameters for the 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.
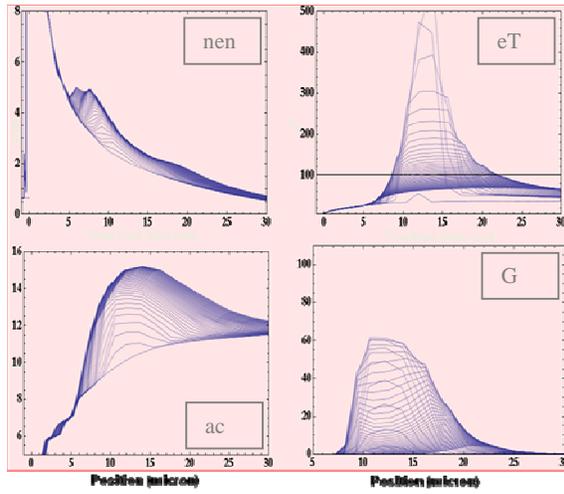
Fig. 3. Spatial and temporal evolution of the plasma parameters (electron density, electron temperature, average ionization state and the gain) for the case using one main pulse.

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.

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 prepulse has normal incidence to the target and the short pulses have the incidence angle of 70 degrees (grazing angle).

Fig. 2 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 show 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 seen that the electron plasma density is slightly perturbed 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. 2e), 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.

In Fig. 3, 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 is reduced compared with the cases with two short pulses. This is due to 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, while in the optimal case with 50:50 pulses the electron temperature of the plasma is about 300 eV and this fact is reflected in the gain curves.
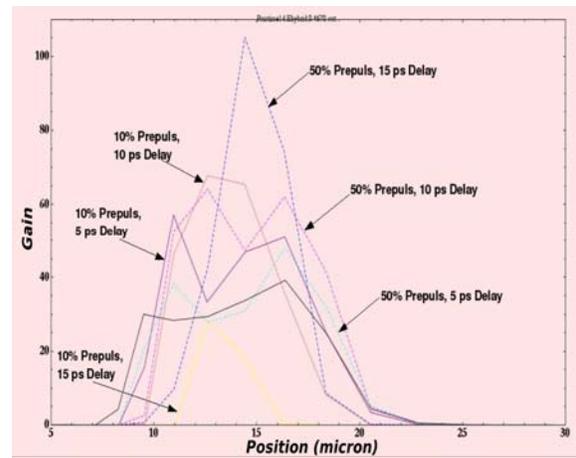

Fig. 4. Temporal evolution of the gain in plasma for the case using two pulses (black curve) and the case using three pulses where the delay between the main pulses is 5, 10 or 15 ps.

For a comparison, one can observe in Fig. 4 the maximum value for the gain in the first 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 second case (two pulses) the maximum value for the gain is 70 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. Conclusions

In this study we demonstrate that the charge distribution in plasma can be significantly modified using an improved pumping scheme with two short pumping pulses. We also optimized the pump parameters for this X-ray laser parameters. 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. The parameters used in this experimental modelling were selected to permit the

experimental testing of the method at the ultra-short and ultra-intense pulses laser TEWALAS facility, implementing a multiple pulses generation method.

References

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