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HYDRODYNAMIC AND RAY-TRACING SIMULATION OF SEEDED SOFT X-RAY LASER AMPLIFYING STAGES

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Abstract. Coherent X-ray radiation has a wide range of applications, from femtobiology to plasma diagnostics and lithography. Seeding a high density amplifier plasma with high harmonics has been demonstrated recently. This scheme allows to obtain a coherent X-ray source with excellent optical properties. The energy of the beam can be amplified using a multi-stage setup, in which the X-ray beam is injected in several plasma amplifiers, so as to obtain the energy needed for the applications. As the density and temperature profile of the amplifier plasma have a strong impact on the quality of the amplified beam, simulations are needed to taylor these plasmas in order to optimize the optical quality and minimize the refraction undertaken by the laser beam.

The 2D hydrodynamic code with radiation transport, ARWEN, has been coupled with the 3D ray-tracing in non-homogeneous media code, SHADOX, via a gain calculation. With both codes coupled we can study the impact of micro and macroscopic hydrodynamic effects (such as target rugosity, spatial inhomogeneities of the pumping laser, 2D plasma expansion effects, size of the plasma...) in a single amplifier stage. It is also possible to simulate a full amplifier setup, with several stages. Simulations of different amplifying plasmas have been carried out, studying the topics pointed above.

1. Introduction

Soft x-ray lasers have a wide variety of applications in different fields such as femto-biology (diffraction, single shot holography...), atomic physics, astrophysics, etc... The pulses used in these fields must have *high* energies (of the order of mJ or more), high spatial coherence, a good wavefront and also they must be short (femtosecond pulses). Seeded Soft X-Ray Lasers (SSXRL) have the potentiality to produce a beam with these characteristics as they combine the high spatial coherence and good wavefront of high order harmonics with the possibility of high energies using several amplifying stages, as shown in fig. 1.

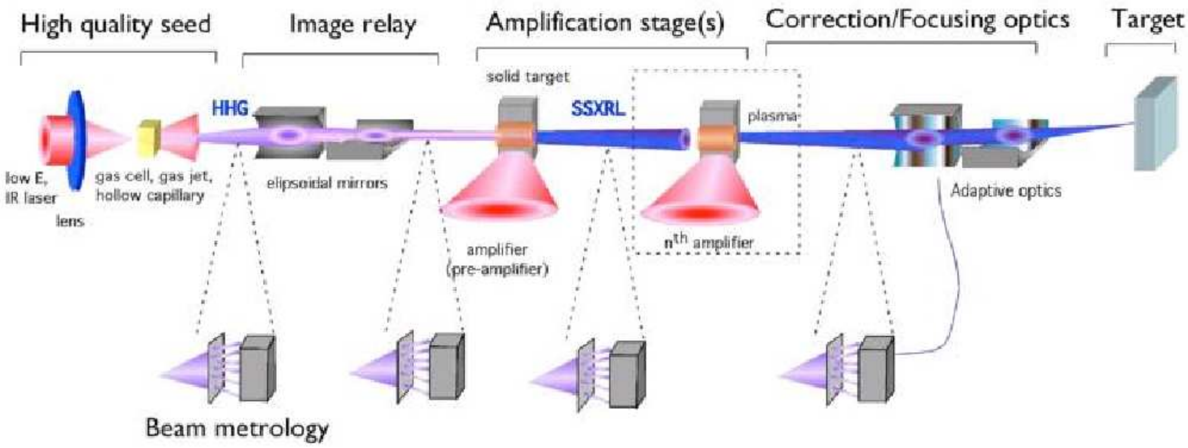

Figure 1. Seeded soft x-ray laser scheme.

The amplifier where the high harmonics beam is seeded, is a plasma created with a *long* (ns) pulse and pumped with a *short* (ps or less) pulse to create the population inversion needed for amplification.

Seeding has been demonstrated recently in [2] and [3]. The use of solid targets allows to obtain higer energies but, on the other hand, amplified spontaneous emission (ASE) may dominate the output beam. In addition to this, refraction effects of the amplified beam could appear, as the density of the plasma is higher. Consequently, a careful tailoring of the amplifying stages is needed in order to obtain a good quality x-ray laser beam (avoiding plasma inhomogeneities, refraction of the laser beam out of the gain zone, timing long and short pulses to have the optimum electronic density and gain, etc...).

In section 2 we enumerate the different effects that have been observed to play a significant role in the amplification [1] and have to be taken into account in the study of those amplifying plasmas. In section 3 we make a description of the codes ARWEN and SHADOX, that have been modified to overcome the above difficulties. In section 4 we present briefly a simulation of three amplifying stages coupled, as an example of the capability to simulate the full amplification chain by ARWEN and SHADOX. Finally, conclusions are presented in section 5.

2. Hydrodynamic effects

The impact of small-scale defects on target surface and laser spatial profile were studied in [1], showing that surface defects imprint strongly the electronic density and thus the amplified beam, as showed in fig. 2. In addition to this, it was also shown that refraction effects of the short pulse in the plasma already created must be taken into account. Finally, it was discussed that 2D hydrodynamic effects could affect the electronic density in small plasmas, lowering the gain. As all those effects are bidimensional, in order to taylor the plasma and study the amplification of the laser beam, a 2D hydrodynamic code (like ARWEN) must be used. The amplification, saturation and refraction of the amplified beam in the plasma is studied with SHADOX.

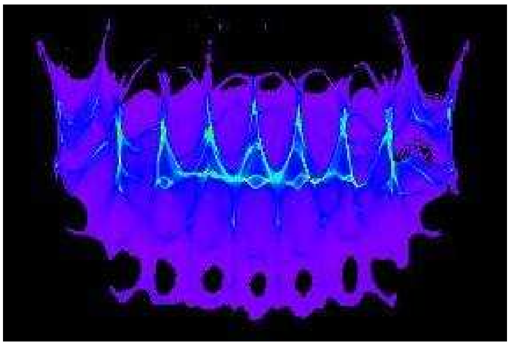

Figure 2 X-ray laser output amplified by an inhomogeneous plasma created in a rugous target

3. Computational tools

ARWEN [6] is a 2D hydrodynamic code with electronic conduction and radiation transport in AMR (Adaptive Mesh Refinement). The deposition of the laser energy is treated with a ray-tracing subroutine, used to take into account refraction effects in the plasma. A simple gain calculation is done in order to create the input of SHADOX, a parallel 3D ray-trace code used to study the amplification, saturation and refraction of the injected beam [7]. Several parameters (injection angle, focusing optics...) can be studied by this code. Both codes have been coupled to simulate the kind of problems treated in the previous sections.

4. Simulation of three coupled amplifying stages

An amplification chain, consisting on three plasmas, has been simulated. The hydrodynamics of the plasmas has been studied with ARWEN, whereas the injection and amplification of the laser beam has been done with SHADOX. The three plasmas are created with different sizes varying the laser focus: 200 μm x 1mm, 1mm x 1mm and 2mm x 1mm, being 1mm the distance traversed by the injected beam in the three iron plasmas, as the amplifying medium is Ne-like iron (λ = 25.5 nm) . Hydrodynamic data is postprocessed in each simulation to create the three inputs for SHADOX. Then, each stage is simulated with SHADOX using the resulting energy as an input for the

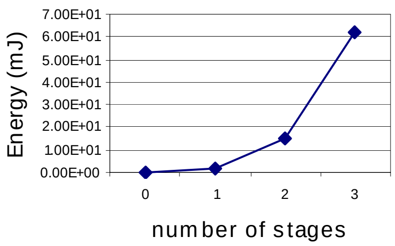

Figure 3. Energy amplification with trhee stages. The seeded energy was 1.0e-4 mJ

next stage simulation. The amplification obtained for these schem is shown in fig. 3. The energy extracted in the third stage is five orders of magnitude greater than the energy injected. As there are many parameters to vary (injection angle, lateral size of the plasma, etc...) optimization is required.

5. Conclusions

As shown in [1], the amplifying stages must be designed carefully, paying special attention to the plasma properies. Specific computational tools must be used in order to study the effects that can imprint the output beam (ray-tracing, bidimensional codes, etc...) and the different parameters that can be varied to optimize the chain (injection angle, plasma size, x-ray optics...). We have modified and coupled the 2D hydrodynamic with electronic conduction and radiation transport in AMR code ARWEN with the 3D ray-trace code SHADOX allowing us to simulate the full amplifying chain. A single simulation of a three stage chain is presented, demonstrating the potential of achieving high energies with several stages.

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