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PPST Summer Undergraduate Internship
Sponsored by: PPST
Working with: Professor Szymon Suckewer and graduate student Qiang Chen
Collaboration with: Doc. Anatoli Morozov and Nick Tkach
Simulation of the 3-Wave equation and learning about lasers and plasma
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Introduction

Beginning in the 1960's lasers been developed with the help of methods like Q-switching, Mode Locking and Chirp Pulse Amplification, producing higher intensity laser beams and a duration of the pulse in the level of femtoseconds. The most successful of these methods, Chirp Pump Amplification, can produce laser intensities only up to a certain point, as the material used in the process has a thermal damage threshold, meaning that a too high intensity of the laser can damage the materials involved in the laser. Increasing the dimensions of the optical elements helps, but this increases the cost of the laser and presents multiple technical difficulties.

One of the solutions for this problem might be Raman Backscattering Amplification which uses plasma as an amplification medium and has the potential of providing laser intensities orders of magnitude higher than the CPA method.

The method of obtaining Raman Backscattering amplification is the following. We send two laser beams, a long pump pulse, and a short seed pulse, in a plasma tube. The pump pulse and the seed pulse have frequencies with close values. The interaction of the two waves creates a Langmuir wave in the plasma with frequency equal to the frequency difference between the pump and seed pulses. This Langmuir wave creates a vibrational energy level in the plasma. When a pump photon hits the plasma, it excites it to a virtual energy level, from where it can de-excite to the vibrational energy level of the Langmuir wave. What results from the de-excitation is a scattered photon with frequency equal to the frequency of the seed pulse and in the direction of the seed pulse, resulting in the increase of energy of the seed pulse. In this way the Langmuir wave mediates the transfer of energy between the longer pump pulse and the shorter seed pulse. Energy gets transferred to the seed pulse which gets broadened during the initial, linear stage of the amplification, but gets strongly compressed during the non-linear part of the amplification process. Because of the energy transfer from the pump, and of the resulting shorter duration of the seed pulse, the seed pulse has a very high intensity at the end of the amplification process. This amplification is limited by factors that will not be discussed in this presentation.

My Work

In the first weeks at Prof. Suckewer's lab I studied general notions of lasers and laser amplification techniques, effects such as homogenous and inhomogeneous broadening of laser emissions.

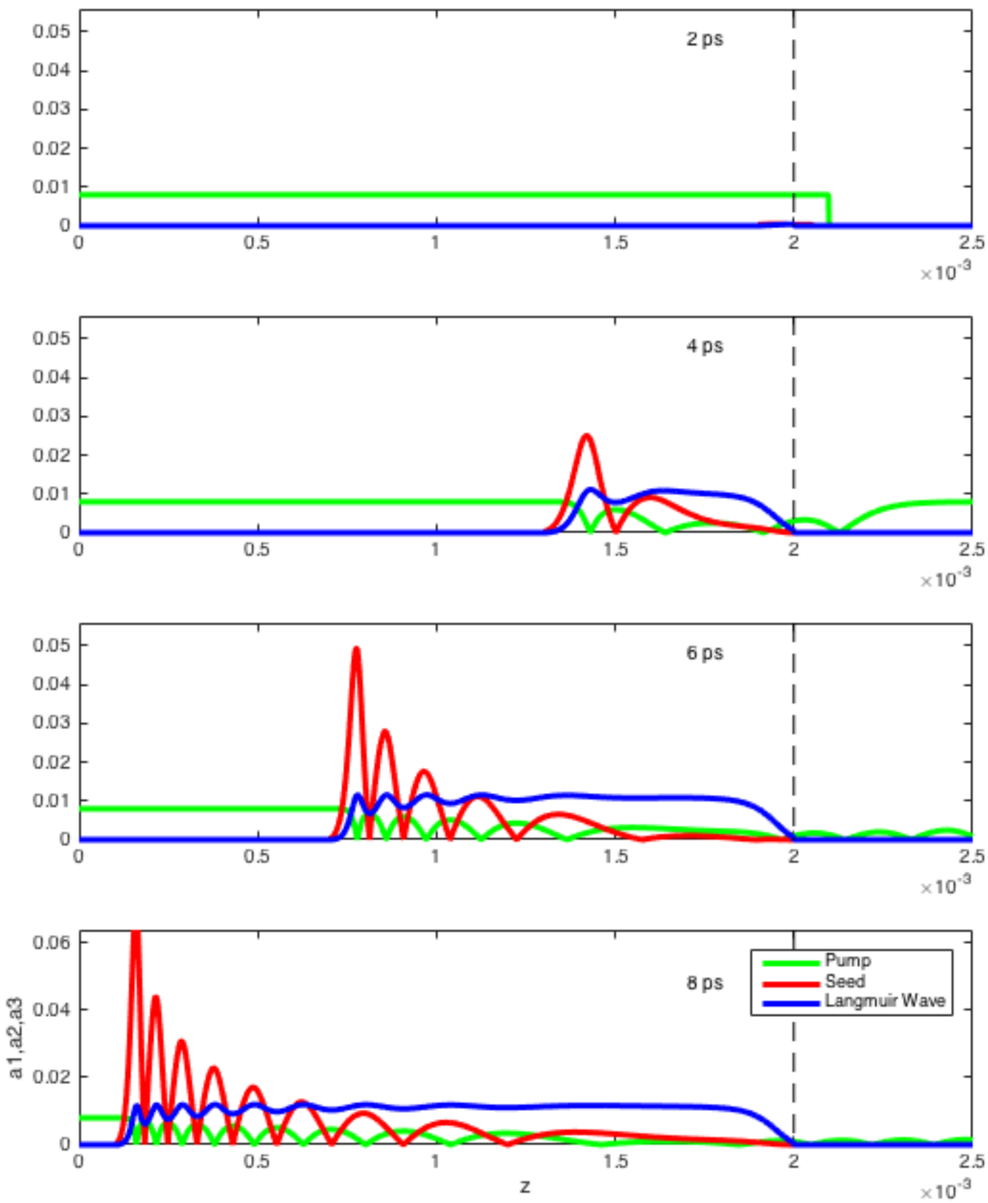
I also did laser safety training and lab safety training as required by the university, along with high voltage safety training so that I may be able to attend experiments. Nick Tkach gave me helpful advice on electrical hazards and risks in the laser lab. Doc. Anatoli Morozov helped me with Laser Safety notions and introduced me to the hazards related to class 4 and class 3 lasers.

After that I began studying Raman Backscattering, how to model the interaction between the two laser waves and the wave induced in plasma. I read the previous theses regarding Raman Backscattering and articles published on the subject so I may understand the process. I decided that my project would deal with simulating the interaction of the 3 waves(Pump, Seed and Langmuir). Using the appropriate approximations, one can describe the process with the help of 3 partial differential equations, and depending on the desired level of complexity for the simulation, one can include effects such as Landau Damping, Collisional Damping and relativistic effects. The difficulties in creating the simulation came from the fact that I needed to understand exactly how to put the boundary conditions for the equations and in the fact that I had to learn how to think about making the waves move and interact properly at the interface between vacuum and plasma.

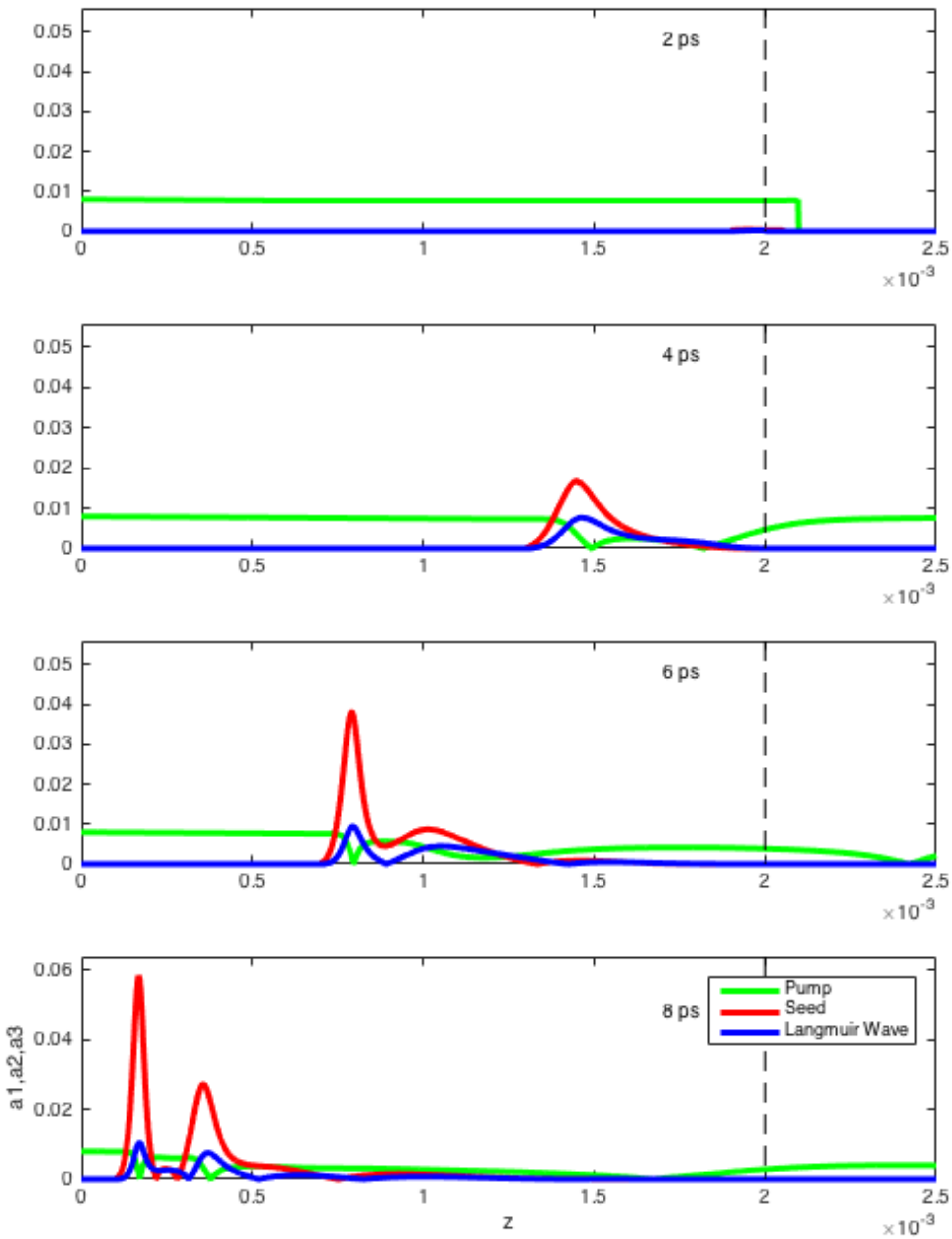
The simulations without damping help me visualize the energy transfer between the pump and the seed, as the pictures provide a very clear image of what happens when the three waves interact and presents exactly how the depletion of the pump, corresponds to a Langmuir wave that transfers energy.

The simulations are done in a simple manner, using initial rectangular shaped seed and pump pulse.

Simulation for wave without damping
Initial Pump: I_a1=7*10^14 (W/cm^2)
Final Seed: I_a2=5.7*10^16 (W/cm^2)



Simulation of wave with damping
Initial Pump: I_a1=7*10^14 (W/cm^2)
Final Seed: I_a2=3.9*10^16 (W/cm^2)



Results

The interesting part in this project was to try to understand a subject, Raman Backscattering Amplification, without much previous knowledge it, and to try to model this process and obtain some simulation results that could help me understand the process better. A useful thing that I learned when doing simulations was to solve partial differential equations numerically, which is a quite different process from solving ordinary differential equations. Realizing that I have to simplify the process at certain points was also important in moving the simulation forward. Also, the programming experience gained with MATLAB was useful and thinking about how one should use the parameters such as energy and time of the pulses was useful in understanding the problems of the simulation.

Linking the effects on the screen with the code was a very useful experience in realizing what is missing in certain sections of the code.

Future work

Future work will be done during the year together with Prof. Suckewer and his group in observing experimental results and comparing them with the simulations. Also more work will be done in refining the simulations, and better understanding the damping effects. At this moment the damping effects offer mostly qualitative information.