Final Technical Report

"COMPACT ULTRAINTENSE FSEC LASER VIA RAMAN AMPLIFIER AND COMPRESSOR IN PLASMA"

PI: Prof. S.Suckewer,
Princeton University

1. Short Overview of the Basic of Raman Backscattering (RBS) Amplification and Compression of Femtosecond Laser Pulses in Plasma.

The laser system based on RBS steps in where the current technology of chirped pulse amplification (CPA) (extremely successful in developing ultra-short and ultra-intense laser pulses in last 2 decades) becomes difficult and very expensive to apply. Good base for such RBS laser was created by our recent experiments The one of the main objective of the present grant is improvement efficiency of energy transfer from pump to seed. Although we have significantly improved the efficiency η of energy transfer from pump to seed in last a few years reaching average value of η ~ 6%, but it is not sufficient to make practical "fsec-type plasma laser" (FPL) with pulse intensities of 1019 – 1020 W/cm2, which is the main goal of our research. Such laser requires average η ~ 20 %.
The basic , which will eventually lead to FPL, is as follows: moderately intense, but long, laser pulses can be scattered into ultra-short, very intense counter-propagating pulses in plasma through stimulated Raman backscattering (RBS). Raman amplification of ultrashort pulses in plasma relies on the three-wave interaction between the counter-propagating "seed" and "pump" pulses and the plasma waves. The plasma waves, with frequency ωpe (ωpe= 4pe2ne/me), are ponderomotively driven by the periodic intensity pattern created by the interference between the pump and the seed pulses. If the frequency detuning between the two pulses matches the plasma frequency ωpe, i.e., ωpe=ωpump - ωeed, then the seed can be amplified through the RBS of the pump.
We obtained, so far, the best experimental results worldwide and have reached important nonlinear regime. In the single- and double-pass experimental setup consisted of a Ti: Sapphire laser beam (central wavelength 803nm and pulse duration ~ 20ps) serving as the pump beam and a short pulse (~ 500 fsec) with central wavelength 878nm serving as the seed pulse , it was showed, using the autocorrelator, that the input seed pulse duration was compressed from 500fsec down to 90fsec in single pass experiment for seed intensity amplification of 10,000. For about twice higher amplification of ~20,000 during second pass seed was further compressed down to about 50fsec, reaching unprecedentedly high unfocused intensity of ~2.5Å~1016W/cm2 in plasma diameter ~ 30 μm.

2. Present Project

A. **Experimental setup:** In order to reach ultra-high intensity in focus of fsec plasma laser, FPL, our 2 J Ti/Sapphire amplifier (1.4 – 1.5 J after compressor) has to be used. Therefore, the experimental setup has to accommodate optical elements of significantly larger diameters for pump and seed beams, where the pump and seed beam diameters of ~0.2 - 0.25 mm have to propagate in plasma channel that is about 3 mm long and ~0.35 -0.45mm in diameter (more recent computer modeling of RBS experiments indicated that such plasma channel length and diameter are better suited to our experiment than earlier modeling suggestions of 4 mm long and ~0.3 - 0.4 mm in diameter plasma channel, Refs.1,2).Such plasma channel was created by combining shorter (200 psec) and longer (5-10 nsec) laser pulses using an axicon lens for shorter pulse and spherical lens for longer pulse as is illustrated in Fig.1(see Refs.1, 3 for details) .

Setup for Compact Ultra-High Intensity RBS in Plasma

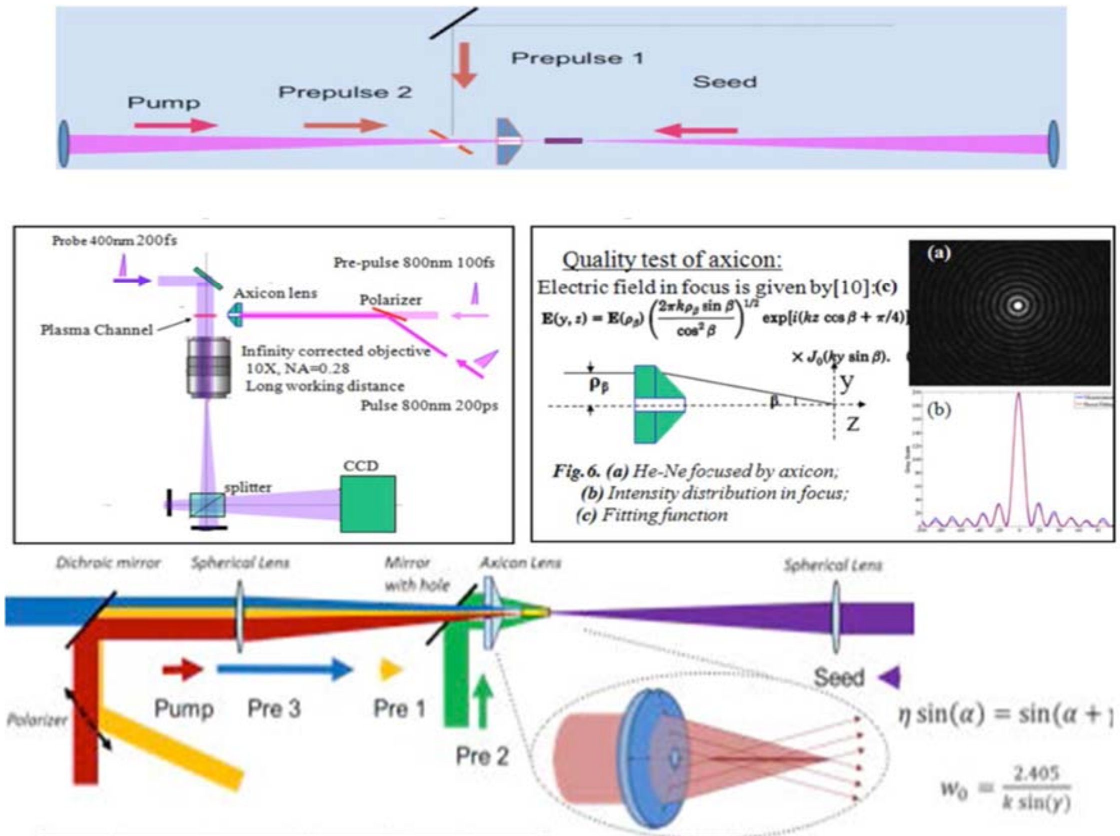

Fig.1. *Illustration of a new experimental setup with 1.4 – 1.5 J pump beam for present project with a new method of creation plasma channels*

The creation of an appropriate plasma channel for present RBS experiment for development plasma amplifier & compressor for ultra-high intensity laser pulses was crucial and unexpectedly very difficult task. It took us much more time and effort than initially planed. However, by applying additional fsec pre-pulse 3, as can be seen in the bottom part of Fig.1, we further improved our method of creation very uniform, large diameter and long plasma channel.

B. The very good channel quality is illustrated in Fig.2.

Example of Very Good Plasma Channel Created by Improved Method

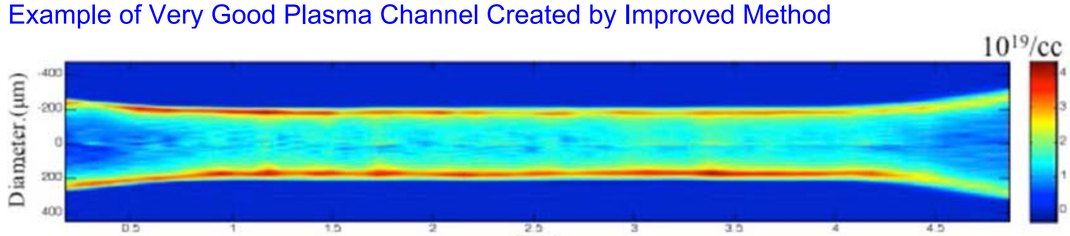

Fig.2. *Example of plasma channel of very high uniformity of length ~3mm with diameter of ~0.3 – 0.4mm, suitable for propagation of 0.20 – 0.25mm diameters of the pump and the seed laser beams*

C. New Diagnostics for Our SRBS Experiments : Soon after the advent of lasers, it was realized that the problem with measuring an ultrashort pulse was that there was no shorter event with which to measure it! Therefore, the widely-used solution for decades was to produce an autocorrelation signal, which uses the pulse to measure itself. This involves splitting the pulse in two, variably delaying one with respect to the other, and overlapping the two pulses in some nonlinear optical medium such as a second-harmonic-generation (SHG) crystal. The signal pulse intensity is proportional to the product of each beam's intensity.

Fortunately, it is now possible to fully characterize a laser pulse using a host of tools that have been developed under the umbrella of **FROG (**Frequency-Resolved Optical Gating), which is single-shot measurement. The measurements are insensitive to noise, and feedback about the quality of the data virtually eliminates the possibility thatsystematic error could cause one pulse to mimic another. Furthermore, FROG is most simply a spectrally-resolved autocorrelator, so it utilizes technologies that are already widely available in laser laboratories and is thus very accessible.

D. Computer Modeling related to RBS Amplification Saturation : In parallel to experimental SRBS research, we have been involved in intensive computer modeling of our experimental data, and in particularly on potential saturation mechanisms and optimal plasma channel configurations for maximum seed pulse amplification and compression. Although in this calculation all processes indicated in Refs.3-5 were taken into account, which could have negative effect on SRBS amplification, no significant effect was seen in this modeling for sufficiently high gain.

E. Education Benefits: Two graduate students successfully defended their PhD dissertations on RBS research :
<u>Shuanglei Li</u> : PhD dissertation on: ”Ultrashort and Ultraintense Laser Pulses by Stimulated Raman Backscattering Amplification and Compression in Plasma”, Final Public Oral : Princeton University, March 14, 2013
<u>David Turnbull</u>: PhD dissertation on: ”Identifying New Saturation Mechanisms Hindering the Development of Plasma-Based Laser Amplifiers Utilizing Stimulated Raman Backscattering” , Final Public Oral :Princeton University, February 12, 2013

References:

1. Li, S.:”Ultrashort and Ultraintense Laser Pulses by Stimulated RamanBackscattering Amplification and Compression in Plasma”, Princeton University, March 2013
2. Ren, J. et al.: “Overcoming the Saturation Limit in Stimulated Raman Backscattering”, Internal Report
3. Turnbull, D.: ”Identifying New Saturation Mechanisms Hindering the Development of Plasma-Based Laser Amplifiers Utilizing Stimulated RamanBackscattering” , Princeton University, February 2013
4. Turnbull, D., Li, S., Morozov, A., & Suckewer, S.: “Possible origins of a time resolved frequency shift in Raman plasma amplifiers. Physics of Plasmas, 19, 073103 (2012).
5. Turnbull, D., Li, S., Morozov, A., & Suckewer, S. (2012). Simultaneous stimulated Raman, Brillouin, and electron-acoustic scattering reveals a potential saturation mechanism in Raman plasma amplifiers. Physics of Plasmas, 19,083109 (2012).