FW: DOE-Grant DE-FG02--05ER54828   Final Technical Report on

"Study Efficiency of Raman Backscattering Amplification in Plasma"

PI: Prof. S.Suckewer, Princeton University; PU acc: 150-6855

Note: This Report was submitted to DOE at the end of the project

1. General : Our major scientific achievements in Raman Backscattering (RBS) amplification and compression of short 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, which were supported by GPS grants. The main objective of the present grant was: **improvement efficiency of energy transfer from pump to seed**. The results surpassed our expectations; we improved the efficiency of energy transfer from pump to seed by a factor of 6 compared to the best of our previous results and amplified seed pulse compressed down to about 50 fsec.

The more detailed explanation of these results are 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 ultra-short pulses in plasma is based on the three-wave interaction between the counter-propagating "seed" and "pump" pulses and the plasma waves. The plasma waves, with frequency ω_{pe} ($\omega_{pe}^2 = 4pe^2n_e/m_e$), are ponderomotively driven by the periodic intensity pattern created by the interference between the pump and the seed (sub-psec) pulses. If the frequency detuning between the two pulses matches the plasma frequency ω_{pe}, i.e., $\boldsymbol{\omega_{pe} = \omega_{pump} - \omega_{eed}}$, then the seed can be amplified through the RBS of the pump

We obtained such good results by reaching 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. Fig.1 shows the autocorrelation signal of the input seed (the dashed lines; pulse duration of

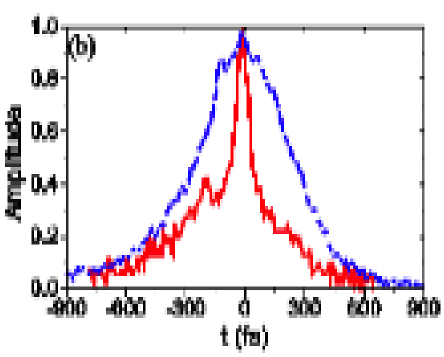

Fig.1 *Autocorrelator signals normalized by the autocorrelator factor of 1.4. Dashed line: input seed at energy of 15μJ, solid line: amplified seed at energy of 2.9mJ;*

~500 fsec at FWHM) and an amplified seed (the solid line; pulse duration of **~90 fsec** measured from "absolute" background - amplitude, and **~60 fsec** measured from the pulse "pedestal" at amplitude 0.4) for a amplified seed energy of **2.9mJ in single pass.**

In double-pass experiment the seed pulse after 1st pass was reflected by the dichroic mirror, which has high reflectivity at 878nm, and high transmission at 803nm and 1064nm. The pump pulse, after the first pass, was reflected by second dichroic mirror with high reflectivity at 803nm. The returned pulses interacted again in the plasma, and the amplified seed pulse was further amplified during this 2nd pass. **Fig. 2(b)** shows the output energy of the amplified seed after the 2nd pass versus the temporal delay of the pump pulse in relation to peak of seed pulse. For comparison **Fig. 2a** shows seed energy in the 1st pass. Assuming, as in case of single pass, that only 50 % of seed energy is in the first peak of ~50 fsec duration, we estimated output seed intensity (unfocused) to be~2.5×10^{16}W/cm^2.

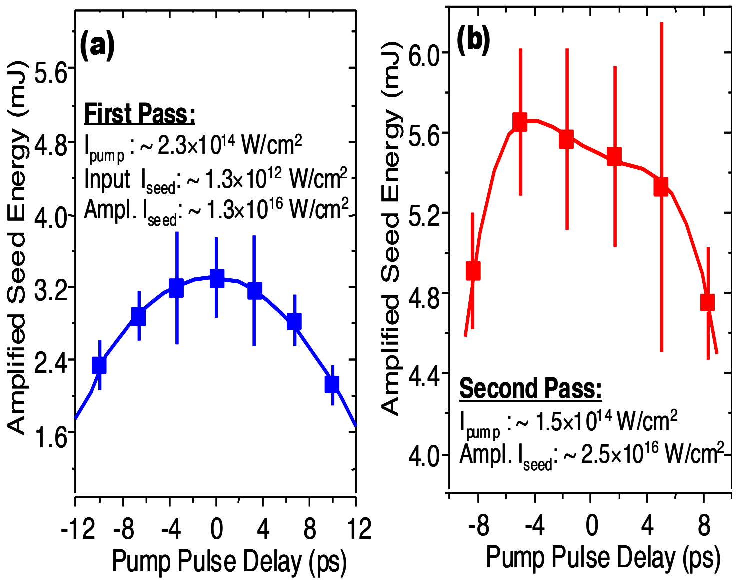

***Fig.2.** The amplified output energy. **(a)** The output energy versus the pump pulse delay time relative to the seed peak pulse for the first pass (with the input pump energy of ~ 87 mJ and the input seed energy of ~ 16 μJ), and **(b)** the second pass(with the input pump energy of ~ 56 mJ and the input seed energy of ~ 3.3 mJ from the first pass). The squares are the measured data; the solid lines are the curve-fitting results to guide the eye. The error bars represent the maximum deviation from the mean.*

Present Project **- Focusing** (in a vacuum) with a 2" F/1.2 off axis parabola mirror:
Mirror location: 1.5 m from the plasma for 25 mrad divergence with beam intensity of 10^{12}W/cm^2 on dielectric mirror (intensity safety limit on mirror according to CVI Inc. for 20 -30 fsec pulses) we should reach intensity at focus of **~1 x 10^{20} W/cm^2**
Project – Second Pass: ***In case the efficiency will be lower than theoretically predicted*** or larger diffraction limit we will increase output intensity by applying second pass.

2. Efficiency Study of RBS During AY 2010

In our earlier experiments the maximum efficiency in single pass we have measured η≈ 3.5% and η≈ 6.4% in two passes. Although it was orders of magnitude higher than in any other RBS experiments worldwide, nevertheless it is still to low for practical applications of RBS amplifier & compressor.

One of approach to obtain significantly higher efficiency was to increase plasma channel from 2mm long and 50μm in diameter to 4mm long and 300μm. However, we have encountered very large difficulties to create such channels. Although we dedicated very large effort to solve this problem, the maximum channel length we obtained for 300μm diameter channel lengths did not exceeded 2.3mm.

Nevertheless, we obtained already much higher efficiency > 7% in single pass, even channels were significantly shorter that optimal ones of 4mm.

In figures below examples of measured amplified seed pulses, hence efficiency are presented. We have measured amplified seed pulse (output beam) energy ~7mJ for pump beam ~100mJ, hence efficiency ~7%. Figs.3a and 3b show a little lower efficiency ~5% for about 3 times higher pump energy. This drop of efficiency we found out is due to still not very good plasma channel, which causes part of pump energy being loss via scattering.