Sub-nanosecond strong pulse generated by backward Raman scattering

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Hundreds picosecond strong short-wavelength pulses have been generated by a backward Raman oscillator amplifier pumped with a 10-J KrF laser from Heaven-1 MOPA system. Not only high power but also high energy laser pulses have been obtained with an energy conversion efficiency up to 17%. 640-picosecond pulse duration was observed in our experiments by a 1.5-GHz-bandwidth oscilloscope corresponding to 34 times of pulse compression rate.

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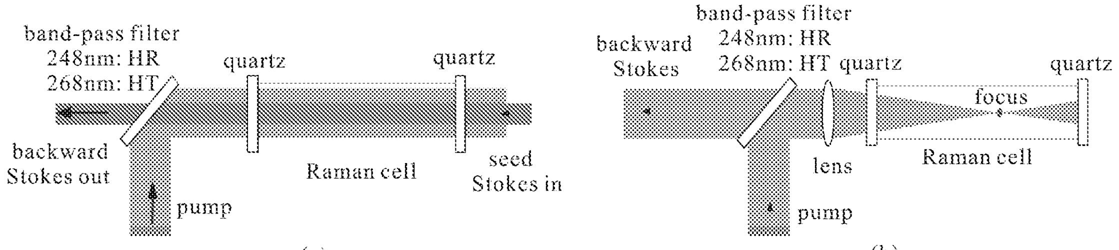
Scientific progress has been made in past decades toward the goal of producing commercial nuclear power using inertial confinement techniques(ICF), particularly after the appearance of the fast ignition concept in 1994[1]. KrF laser with short wavelength (248 nm) is one of the candidates as the laser driver to achieve high energy absorption without complicated frequency shift. Further, a strong pulse is required of not only high power but also high energy[2] for the driver and other nuclear investigations.

Although backward Raman amplification has been widely used as an efficient technique to generate high-power and high-energy laser pulse, the traditional experimental configuration is of less flexibility as shown in Fig. 1(a). In our work one-step focused geometry of Raman oscillator amplifier was employed (Fig. 1(b)).

However the generation of backward first Stokes is critically limited by the growth of self-generated forward Stokes light and by the generation of backward second Stokes radiation. These two processes deplete pump energy ahead of interacting with backward Stokes light. Earlier investigations[3] show that under transient conditions second Stokes radiation grows slowly as the first Stokes pulse keeps comparatively with dephasing time of the Raman medium, while self-generated forward scattering is effectively suppressed by using conical pump configuration to compensate for the forward-to-backward asymmetry (Fig. 1(b)). With convergent pump configuring, the pump intensity is much lower at entrance and continuously increases as closing to the focus. As a result, the most intense part of pump light near focusing region interacts with backward-travelling Stokes light



(a) (b)

Fig. 1. (a) Traditional configuration for the backward Raman amplification; (b) one-step geometry of Raman oscillator amplifier.

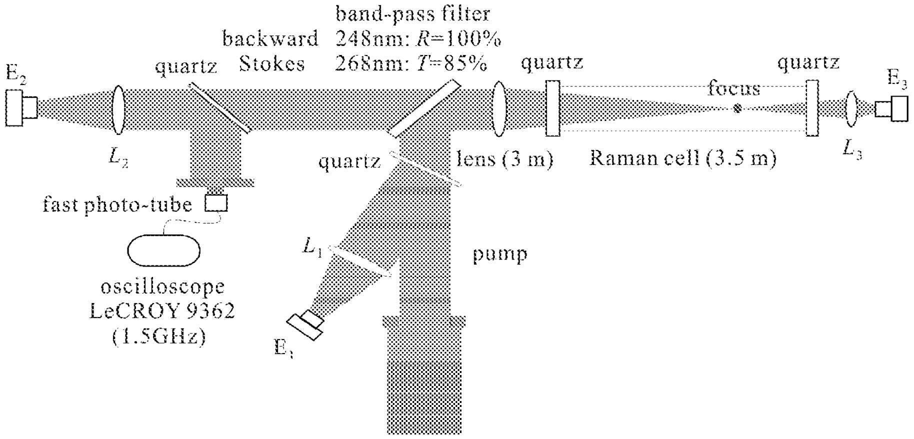


Fig. 2. Sketch of the experimental set-up.

ahead of forward processes evidently taking place, and fortunately diverging Stokes beam after the focus eliminates the growing of second Stokes.

The experimental setup is shown in Fig. 2. The pump beam comes from one of the six-beam lasers of Heaven-1 KrF MOPA system with angle multiplexer located in China Institute of Atomic Energy[4]. The wavelength, pulse duration (FWHM) and bandwidth is 248 nm, 22 ns and 0.45 cm^{-1}, respectively. The effective energy focused into the Raman cell was 10 J with beam diameter of 80mm at the lens. The most critical component is the fuse-silica band-pass mirror with high reflectivity (R=99.5%) at 248 nm and high transmittance (T=85%) at 268 nm with incidence angle of 45°. The damage threshold of the mirror is 15 $\mathrm{J/cm}^2$ for 15 ns-laser pulses, according to the supplier's data. The mirror was not found any damage in the optical performance test after the experiments. The Raman cell is a 3.5-meter long stainless steel tube with two quartz end windows. A 100-mm-diameter convex lens with focal length of 3 meters was placed in front of the entrance window. The time waveform of backward Stokes light was recorded by a fast photoelectric tube connecting with a LeCROY 9362 oscilloscope (1.5-GHz bandwidth), while the energy was simultaneously measured by a pyro-electric energy meter. The pump light was monitored by another pyro-electric energy meter.

The pressure dependence of backward first Stokes conversion efficiency is shown in Fig. 3 for 10 J of pump energy. Approaching to 5 atm of methane pressure, it shows the maximum conversion efficiency of the first backward Stokes up to 17%. Then the conversion efficiency decreases as the pressure continuously increases, accompanied with enhanced forward Raman processes and four-wave mixing process resulting in pump energy depletion.

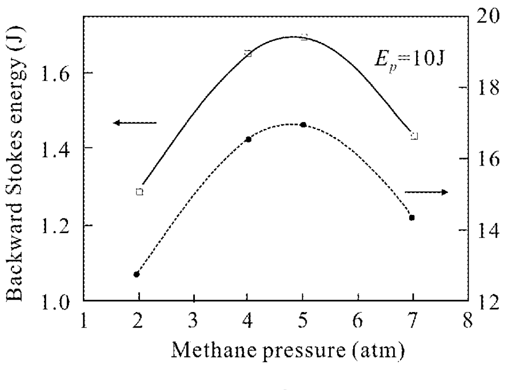


Fig. 3. Pressure dependence of energy conversion efficiency at pump energy of 10 J.

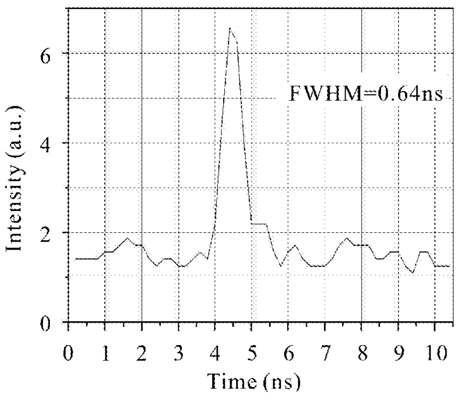


Fig. 4. Temporal shape of the backward Stokes.

The temporal evolution of backward Stokes pulse is shown in Fig. 4. A single high-intensity pulse was observed without other apparent post-pulses occurring, which verified that only the backward first Stokes had been detected. The recorded pulse duration (FWHM) was 640 ps corresponding to 34 times compression rate. In fact, this pulse duration was measured with the response limitation of the detecting device. By replacing the input signal with a 130-fs laser pulse, we got the same pulse duration (FWHM) of 640 ps. This suggests a reliable possibility of further pulse compression.

The mechanism of pulse steepening has not been well known yet and the compressed backward Stokes pulse is considered to grow from a Raman scattered spike initiated in the focal region with local high gain. The pulse then interacted with the pump pulse and dramatically extracted energy from the pump within 5-ns time scale. Earlier in 1960s, Maier[5] indicated that transient pulses initiated by self-focusing in CS_2 could be amplified to 20 times the pump intensity with a pulse duration of approximately 30 ps, as short as dephasing time of the Raman media. A probable causation for the short pulse initiation is abrupt onset of backward Stokes scattering emission near focus accompanying with occurrence of self-focusing in that region. Theoretically[6], the mechanism was supported by analytical solutions of the radiation transfer equations under different initiation conditions.

The practical use of this scheme is presently blocked by laser-induced photochemical reactions between CH_4 and the inner faces of the Raman cell optics causing soot build-up on the surfaces. Decreasing the photochemical dissociation of CH_4 by adding H_2 is considered as a possible way to solve the problem. Surplus of H_2 will shift left the reaction equilibrium of $CH_4 \rightarrow C+2H_2$ to depress the carbon generation. The further experimental optimization is anticipated.

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References

1. M. Tabak, J. Hammer, M. E. Glinsky, W. L. Kruer, S. C. Wilks, J. Woodworth, E. M. Campbell, and M. D. Perry, Phys. Plasmas **1,** 1626 (1994).
2. S. Hain and P. Mulser, Phys. Rev. Lett. **86,** 1015 (2001).
3. J. R. Murry, J. Goldhar, D. Eimerl, and A. Szöke, IEEE J. Quantum Electron. **15,** 342 (1979).
4. X. T. He, X. M. Deng, D. Y. Fan, X. M. Zhang, Z. Q Lin, N. Y. Wang, Z. J. Zheng, and J. R. Liu, Fusion Engineer Design **44,** 57 (1999).
5. M. Maier, W. Kaiser, and J. A. Giordmaine, Phys. Rev. Lett. **17,** 1275 (1966).
6. M. Maier and W. Kaiser, Phys. Rev. **177,** 580 (1969).