Picosecond lasers with Raman frequency and pulsewidth conversion for range finding

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Abstract

We review design issues for short-pulse lasers with Brillouin and Raman pulse compression and frequency conversion. In particular, scheme and material development has enabled us to provide output pulsewidth of 25 ps by SRS at a repetition rate of 1 kHz. Also, advantages of advanced laser ranger based on eye-safe high-power laser are discussed.

Introduction

Solid-state lasers generating high power picosecond pulses are attractive for a wide range of applications. Conventional mode-locked lasers with complex scheme emit ps pulses of widened spectral width at low pulse energies (less than 1μJ) [1-3]. Slightly higher energies are produced by microchip lasers with passive [4] and active [5] Q-switch. Such laser may generate pulses as short as 56 ps [5] with high repetition rate. However, the pulse energy in this case is not higher than a few μJ if $\tau \leq 500$ ps. In both cases such pulses require further amplification in regenerative and multipass amplifiers. But a direct amplification of picosecond pulses is complicated and negatively affects the quality of the beam. The other method to increase the peak power of laser pulses is to use the pulse compression via Stimulated Raman and Brillouin Scattering (SRS and SBS) [6-8].

We present here the results of using SBS and SRS for an efficient temporal compression and frequency conversion of Q-switched laser pulses for range finding systems. High conversion efficiency and simple optical approach make this method rather attractive for the pulses up to several picoseconds. But there non-linear optical pulse compression was applied in pulsed lasers with low repetition rate. Earlier experiments were submitted where for the first time SBS pulse compression technique for diode-pumped solid state lasers (DPSSL) has been demonstrated [9].

It is known that the pulse compression ratio of up to ~17÷20 could be achieved in the optimal pumping geometry of SBS. Besides pulse compression, the phase conjugation (PC) and beam cleanup by SBS have been widely employed in the double-pass laser amplifiers. However, the spatial-temporal distributions and energetic stability of output Stokes pulses dramatically degrades for the pump pulses approaching ~3ns due to unwanted self-focusing or SRS in conventional SBS-active liquids, such as CCl_4, $SnCl_4$, and D_2O. Therefore the short pulses of ~160ps duration and ~0.3mJ energy attained presently in SBS-compressors by neglecting poor energy stability and accompanied by thermal and diffraction distortions introduced by subsequent multi-pass amplifiers.

It is shown here that SBS-cell filled by high purity heavy fluorocarbons C_8F_{18} is capable to maintain order of magnitude higher intensities of pump radiation without the risk of optical breakdown. This allowed us for the first time to incorporate SBS-compressor into the scheme of double-pass amplifier and employ it as phase conjugate mirror for the beam cleanup. As a result, the exceptionally smooth and diffraction-free Gaussian beam has been achieved at the output of SBS-compressor. Moreover extraordinary high reflectivity (>97%) of novel SBS-mirror allows efficient energy extraction from double-pass amplifier.

This scheme has been incorporated into custom design Nd:YAG lasers (see Fig.1) for plasma and ultrafast flow dynamic research. High-quality spatial and temporal distributions are assured by a two-pass Nd:YAG amplifier with SBS-compressor. The MO is protected by Faraday isolator from unwanted backward high-intensity amplified Stokes radiation.

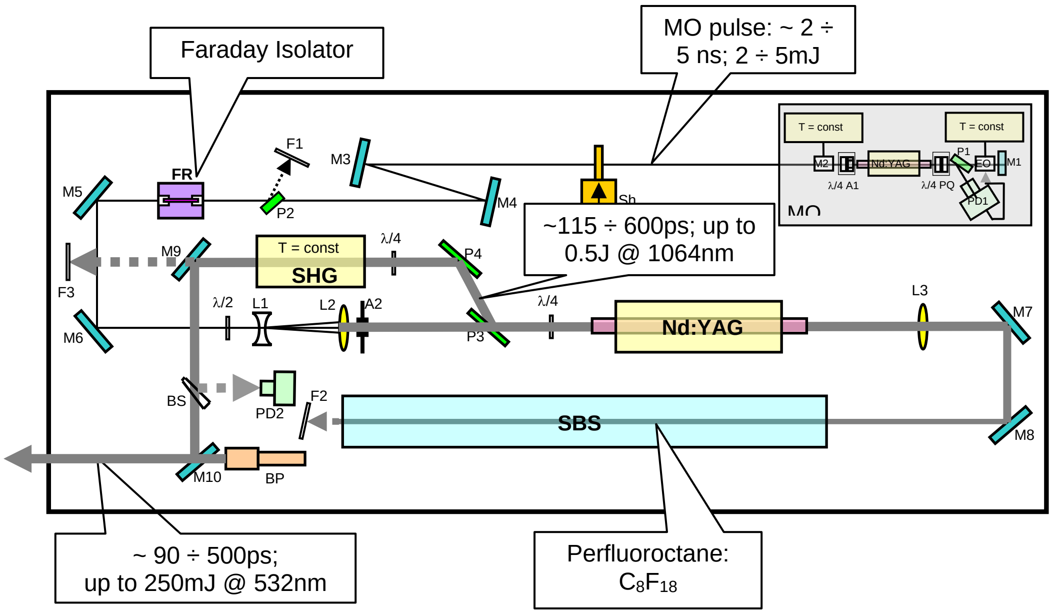

Fig.1. *Schematic of the laser with the SBS compression stage*

In optimised SBS focusing geometry laser provides output pulses of ~100ps at 532nm. RMS energy stability of output laser pulses at 532nm (114ps; 90mJ) was +/- 2.5 ÷ 3%; temporal jitter < 100 ps (RMS deviation) respectively the signal of fast electrical trigger.

The subsequent solid-state SRS-compressor based on $Ba(NO_3)_2$ crystals combined with SBS-compressor allows us to increase compression while ensuring a diffraction-limited output Stokes beam as well as to get output wavelength in a wide range (in particular, in eye-safe range), because of high value of Raman frequency shift. As a result of these investigations, a robust and reliable Nd:YAG laser (see Fig.2, as it is at the operational site for SLR) for satellite ranging has been created. This laser was installed in Altay Optical\Laser Center of Institute for Precision Instrument Engineering.

Here the laser pulses with a pulse width of 3 ns and energy of 1 mJ come from a master oscillator (MO) to the power amplifier (laser heads PA1 and PA2). A Faraday rotator FR was installed between the MO and the power amplifier to protect the MO from residual backward radiation. After positive lens **L2**, we have got a collimated beam with a diameter of about 7 mm, which is a bit smaller than the diameters of Nd:YAG rods (8 and 10 mm) in the laser heads. After the first pass through laser heads **PA1** and **PA2** a laser pulse is reflected in the SBS-cell. Then the laser pulse passes second time through quarter-wave plate, changes its polarization into orthogonal and leaves the power amplifier with the help of a polarizer. A two-stage SRS pulse compressor was used to provide high efficiency of laser energy into the picosecond region.

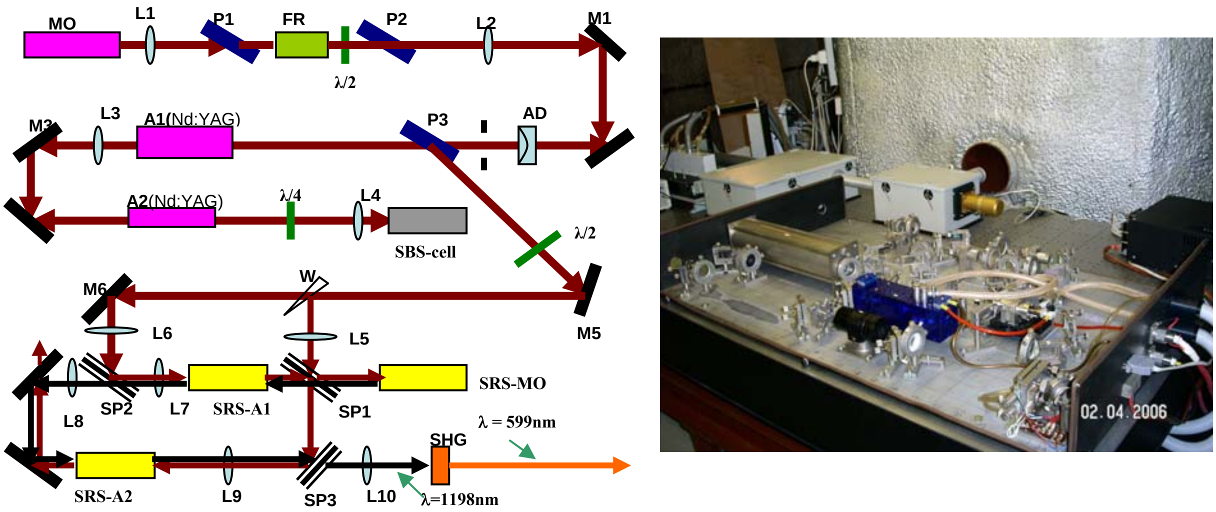

Fig.2. *Scheme and view of the laser with the SBS and SRS compression stages*

On the input to Raman compressor a beam-splitter **W** (a glass wedge) after our Nd:YAG laser reflects about 0.5% of laser output to pump the Raman oscillator. The remaining radiation is sent to pump crystals of the first Raman amplifier by a mirror **M6** and a spectrum-splitter **SP2**. The first Raman amplifier is placed between two spectrum splitters **SP1** and **SP2** - dichroic mirrors which are transparent for the Stokes wavelength of 1198 nm and high-reflected for the 1064 nm pump. For optimal time matching between pump and Raman pulses, the both Raman amplifiers were shifted along optical axes. When pulse compression conditions are met, 100 mJ 30 ps pulses will be generated at appropriate repetition rates, i.e., the Raman pulses' width is more than 10 times narrower compared to that of the pump pulses, as was measured at the previous stage of the project. After the first Raman compression stage, the conversion efficiency of pump radiation to the Raman output is about 10-20%. It is due to a comparatively low output energy from the Raman oscillator (~ 0.01 mJ) and the length (~ 7-8 cm) of the Raman amplifier crystals relative to the pulse width. The conversion degree was increased by up to 50% - 60% by arranging an additional path of counter-running Raman and pump beams through the second Raman amplifier. As a result, the laser produces spectrally limited pulses of 30 ps duration and ~100 mJ energy at 1198 nm with RMS energy stability of 4%. Moreover, the second harmonic generation was used at the laser output to meet requirements of ranger system specification. In this case we have got output laser energy of 50-55 mJ in 25-30 ps pulses at 599 nm.

Also, an eye-safe high-power Raman picosecond laser is developing now for a project of an advanced laser ranger. Next to atmospheric turbulence, range is the dominant source of uncertainty in acquired laser ranger and tracker Time Space Position Information data. State-of-the-art ranging systems have an operating range and accuracy far below the needs for performance testing and model validation. A new, eye-safe, long operating range, accurate (order of cm) ranger will be developed using an ultrashort pulse (e.g., picosecond) laser system in conjunction with time-of-flight measurement methods. This laser has the similar scheme as in Fig.2, but a four-pass power amplifier with three laser heads is used instead of two-pass one with two laser heads in Fig.2. In this case Nd:YAG MOPA scheme produces pulses (pulse width ~ 0.35 ns) of energy up to 100 mJ at 1319 nm to pump Raman compressor scheme. The Raman compressor produces Stokes output pulses with wavelength of 1530 nm and picosecond pulse width. As a result of the development of the eye-safe picosecond Raman laser, we achieved the following set of parameters: output of 25-30 ps pulsewidth and 50 mJ pulse energy at 1530 nm and repetition rate of 100 Hz.

Further, Raman compression in the field of two counterpropagating pump beams has been studied for the first time both theoretically and experimentally [10]. It was shown that this geometry allows further increasing the compression ratio of incident laser pump pulses up to 150. To check it experimentally, we used a diode pumped electro-optically Q-switched Nd:YAG laser as a pumping source for the solid-state SRS pulse compressor based on $Ba(NO_3)_2$ crystals (see a lower/left corner of Fig.3). This laser (Master Oscillator for Raman compressor stage) produced single longitudinal mode near-diffraction-limited pulses of 3.3 ns duration and 3 mJ energy at a pulse repetition rate of 1 kHz.

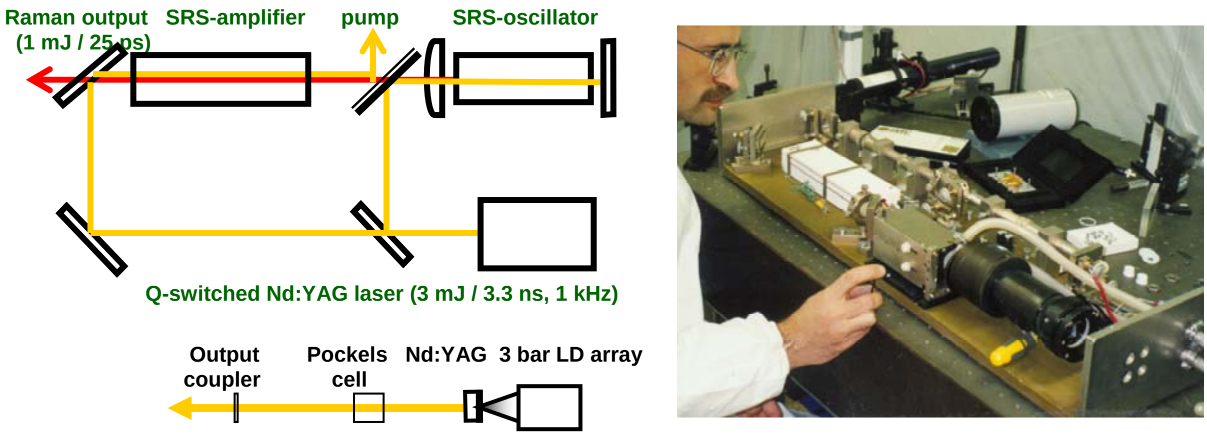

Fig.3. *Scheme and view of 1-kHz diode-pumped Raman laser*

Then the beam-splitter after the Nd:YAG laser reflected 20% of laser output to pump the SRS-oscillator. The rest laser radiation was sent to pump crystals of the SRS-amplifier. It was placed between the couple of dichroic mirrors which were transparent for Stokes wavelength 1198 nm and high-reflected for the 1064-nm pump. The high-reflected mirror for the both wavelengths was placed close to output from the SRS-generator. The alignment of its reflection in back direction provided the SRS threshold decrease by some times. It depended on focusing sharpness and pulse width. For the optimal time matching of pump and Raman pulses the SRS-amplifier was shifted along optical axes. With the carefully adjusted focusing of pump pulses into the crystal we obtained “pump – to Raman” energy conversion efficiency as high as 53% (for 1 kHz). When pulse compression conditions were held, 0.8 mJ - 1 mJ, 25 ps - pulses were generated at 1 kHz repetition rate, Raman pulses’ width being narrower than that of the pump by more than 100 times. Output beam was near-Gaussian shape, i.e. the beam quality was close to the diffraction limit. However, in the “pulse compression mode” the pump to Raman conversion efficiency dropped to 28%. It was caused by the insufficient total length (25 cm) of crystals in the SRS-amplifier relatively to pulse width. However, the conversion energy efficiency could be increased by the arranging an additional opposite-directed pass of Raman and pump radiation through the SRS-amplifier.

Earlier, to our knowledge, the SBS and SRS pulse compression has not been practically studied for high repetition laser pulses typical for diode-pumped solid state lasers.

As a conclusion, the short pulse lasers with non-linear optical pulse compression are very attractive for laser ranging applications because of appropriate set of output parameters, the scheme simplicity and reliability.

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