
LASERS AND DETECTOR SESSION SUMMARY

Chairs: John Degan and Ivan Prochaska

The Czech Technical University reported the latest results on their space-qualified photon counting module for the Chinese Laser Time Transfer Project [Prochazka et al]. The silicon K14 SPAD has the following properties at 532 nm:

- Active area: 25 micron diameter
- Quantum Efficiency: 10%
- Timing Resolution: 75 psec
- Dark Count Rate: < 8 kHz @ 20°C
- Operating Temperature Range: -30°C to 80°C (no cooling)
- Power Consumption: <400 mW
- Mass: 4 g

In addition, it is highly resistant to solar and ionizing radiation (100 krad) damage and has an expected lifetime of greater than 10 years in space.

Andreev et al reported on a very different laser approach based on Stimulated Raman Scattering (SRS) pulse compression which produced 25 psec, 1 mJ pulses, at a 1 kHz rate and with good spatial mode quality ($M^2 = 1.1$). Using a Nd:YAG Master Oscillator (MO) and three single pass Nd:YAG amplifiers in conjunction with a Ca_8F_{16} SRS cell, they generated 100 mJ, 350 psec pulses at 1319 nm. They used this radiation to pump a $\text{Ba}(\text{NO}_3)_2$ SRS-MO and two SRS amplifier cells to obtain 50 mJ, 30 psec pulses at an eyesafe wavelength of 1530 nm and a 100 Hz rate. It was observed that the Raman conversion efficiency decreased noticeably at kHz rates for the higher peak pump powers.

Gao et al reported on diode-pumped lasers for tracking satellites and space debris. For SLR, 10 psec pulses are generated from a SESAM (Semiconductor Saturable Absorber Mirror) mode-locked laser oscillator, regenerative amplifier, and power amplifier. For debris tracking, they use two nanosecond pulses from a 230 Watt multistage system consisting of a single frequency oscillator, preamps, power amplifiers and SBS cells.

Photon Counting Module for Laser Time Transfer Space Mission

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Abstract

We are presenting the results of research and development of the Single Photon Avalanche Detector (SPAD) for application in a Laser Time Transfer (LTT) space mission.

For the joint project with the Shanghai Observatory, Academy of Sciences of China, we have developed the detector package dedicated for the project of synchronizing the hydrogen maser-based time scales by laser pulses. The technology demonstrator of a dual detector has been built and tested in our labs. The main parameters are: detection efficiency 10% at 532 nm, timing resolution 80 psec, dark count rate 8 kHz, non gated operation. The detector's active area is 25 μm in diameter. The total mass, including bias stabilizing circuit, is 2 grams, and the total power consumption is below 0.5 Watt per detecting channel. The detector can be operated in a wide range of temperatures ranging from -30°C to $+60^{\circ}\text{C}$ without any additional temperature control.

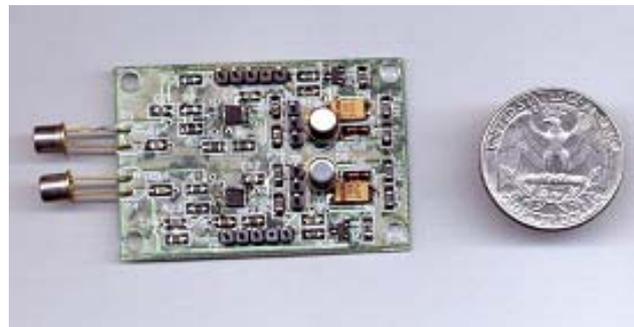


Figure 1: *The technology demonstrator of the dual photon counting detectors. The detection chips (protective caps installed for handling) are on the left.*

The ruggedness of the detector is superb. Optical power of 2 mW has been focused onto a sensitive area while the detector has been biased for 8 hours. No detectable degradation has been experienced. The overload tolerance negates the need for any mechanical Sun protection shutter in space. The recovery time from optical overload to full functionality is less than 0.1 second. The detector package has been successfully integrated into the LTT timing electronics and the pre-flight test was performed in China during the period July-September 2006.

GOALS

- Fast photon counting detectors for the Laser Time Transfer space mission, China
- BACKGROUND
the K14 SPAD detectors have been launched onboard MARS 96 (Russia) and NASA Mars Polar Lander (USA) space missions
- REQUIREMENTS
 - low mass, power, bias voltage
 - high radiation in - sensitivity (> 5 years in space)
 - high temperature range
 - extreme optical damage threshold (full Solar flux, no shutter)



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„LTT Module in Space”, China, 2007-2008

- GOALS
- to synchronize the rubidium clocks in space, hydrogen masers in a future.
- Laser Time Transfer (LTT) between space and ground
- employing the existing China Satellite Laser Ranging network consisting of 5 fixed and 2 mobile systems
- required ~ 100 ps timing accuracy
- expected accuracy improvement >> 10x over RF techniques



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Detector Requirements - version LTT China

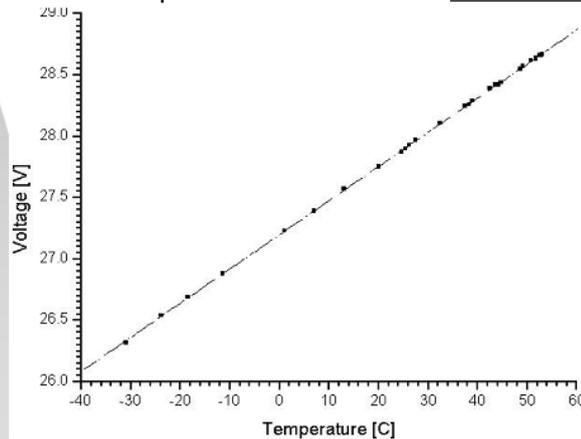
- single photon timing K14 SPAD chips
two channels
- aperture 25 μm each
- timing resolution < 100 psec
- power, mass < 2 W , 100 grams
- operating temperature -30 ... +60°C
- lifetime in space > 5 years
- high opt. damage threshold direct exposure to the Sun (!!)
in a focal plane of 2 mm aperture collecting optics
no Sun safety shutter will be installed
- design & construction 3 months (!) 😊



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SPAD Bias Temperature Control

- SPAD break down voltage 29 Volts
- bias accuracy required 100 mV
- temperature range requested -30 ... + 60° C
- no temperature control or cooling
- SPAD break voltage temperature drift - 30 mV / K
- => temperature controlled bias circuit

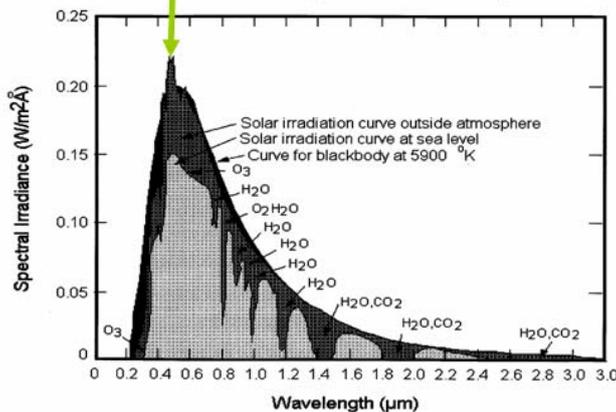


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Optical Damage Threshold

Solar Spectrum

Total insolation outside the atmosphere: 1373 W m⁻² (solar constant)



Source: The University of Texas at Austin, Center for Space Research

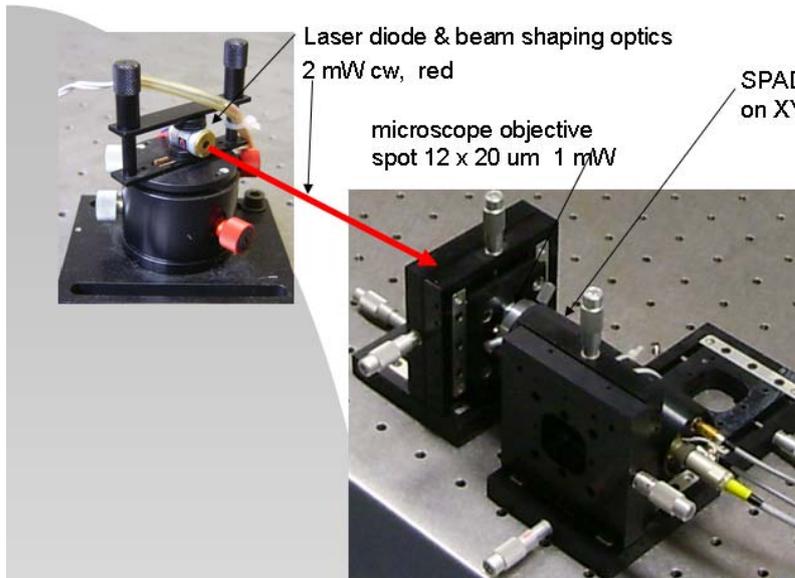
- Irradiance 0.2 W/m²/0.1 nm @ 532nm wavelength
- receiver
 - aperture 2 mm
 - f / d ~ 1.0
 - field of view ~ 0.5°
 - entire Solar disc
- bandwidth 100 nm
- blocking glass filter
- => 1 mW max. on SPAD

Surprisingly, the total flux on the detector aperture is not exceeding 1 mW /100 nm for any aperture (!), due to the field of view limitation.

Larger telescope is not capable to focus all the incoming Sun light onto small SPAD aperture.

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Optical Damage Tests

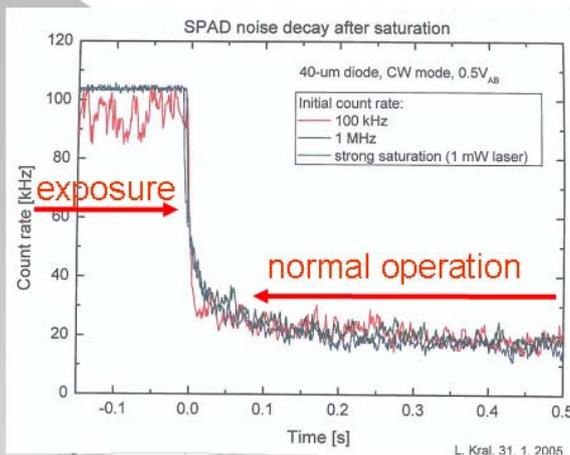


- exposure tests :
- no bias 3 x 8 hr
- biased 3 x 8 hr

- NO detectable detector degradation after all optical irradiation tests
- Any size telescope with SPAD detector may be pointed toward the Sun without the damage (< 100 nm bandwidth)

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Optical Saturation Recovery



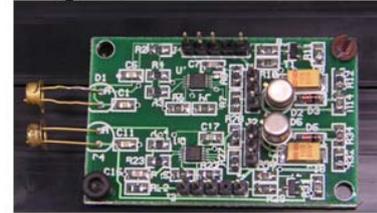
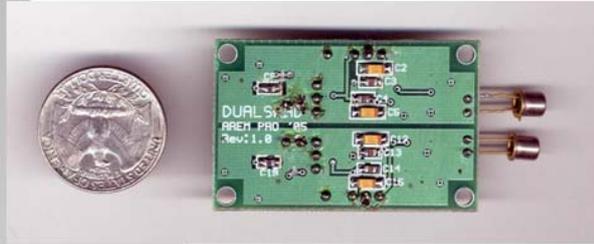
- Detector operation recovery after strong optical signal exp.
- detector illumination
 - ambient light 100 kHz
 - attenuated laser 1 MHz out of range when illuminated
 - full laser 1 mW NA out of range when illuminated
- instrument time constant ~ 0.02 s

- Detector recovery time after saturation is well below 100 ms
- within this time, the dark count rate drops to 1.1 times the standard value

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Photon Counting Module for Space Mission LTT

Technology demonstrator
Prague, March 2005

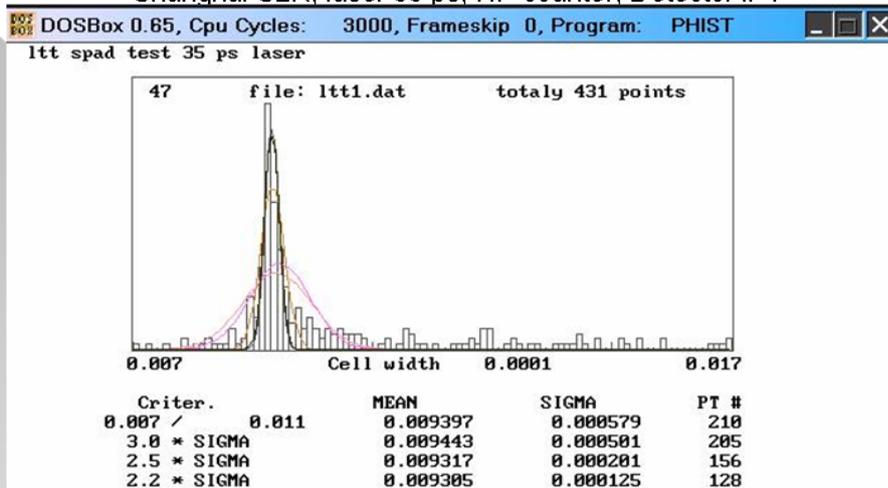


Detector package sample
for pre-flight tests
Shanghai, China, July 2006

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SPAD Timing Resolution Tests, Shanghai July 2006

Shanghai SLR, laser 35 ps, HP counter, Detector # 1



- Jitter detector # 1 125 psec
- detector # 2 120 psec
- Detection delay difference 440 +/- 20 psec

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Dual Single Photon Counting Module Detector Technology Demonstrator - Specifications

- configuration dual photon counting detector based on Silicon K14 SPAD
- quenching active
- active area circular 25 um diameter
- quantum efficiency ~ 10 % @ 532 nm
- timing resolution 75 psec
- dark count rate < 8 kHz @ +20°C
- operating temp. -30 ... +60°C
no cooling, no stabilisation
- power consumption < 400 mW
- mass 4 grams
- optical damage th. full Solar flux 100 nm BW, > 8 hr
- lifetime in space > 10 years



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CONCLUSION Photon Counting Module for Space Mission LTT

- the Technology Demonstrators have been completed
Prague, March 2005



- the Flight Unit detector version has been completed
Shanghai, July 2006
- Solar flux resistant using moderate wavelength filtering
- radiation resistant, 100 kRads without parameter change
=> lifetime in space > 10 years
- pre-flight tests, Shanghai, Beijing, fall 2006

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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 1 μ J) [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 μ J 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 $\sim 17 \div 20$ 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 ~ 3 ns 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 ~ 160 ps duration and ~ 0.3 mJ 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

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.

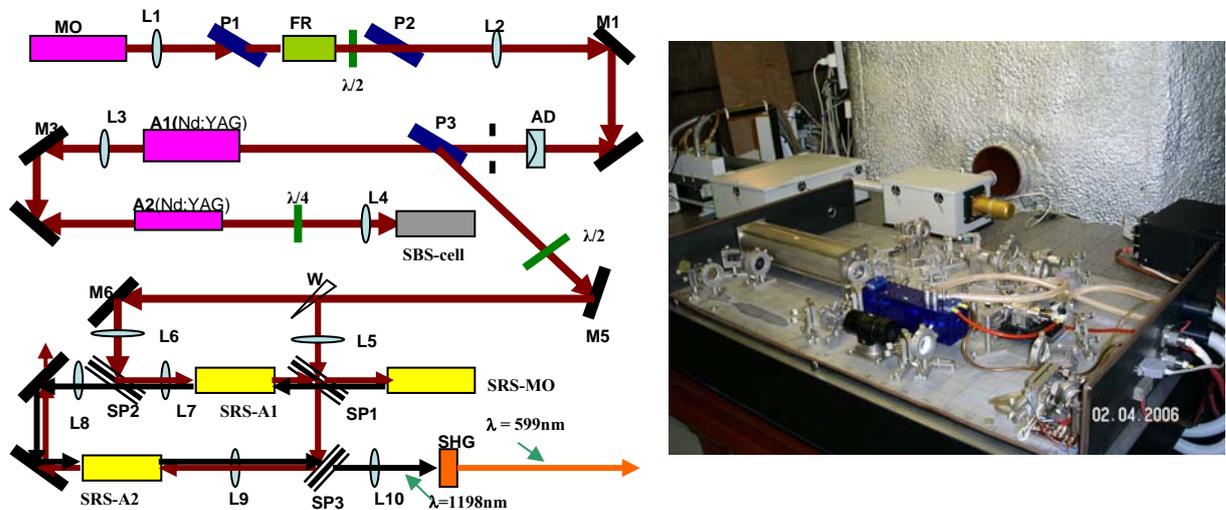


Fig.2. Scheme and view of the laser with the SRS and SRS compression stages

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(NO₃)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.

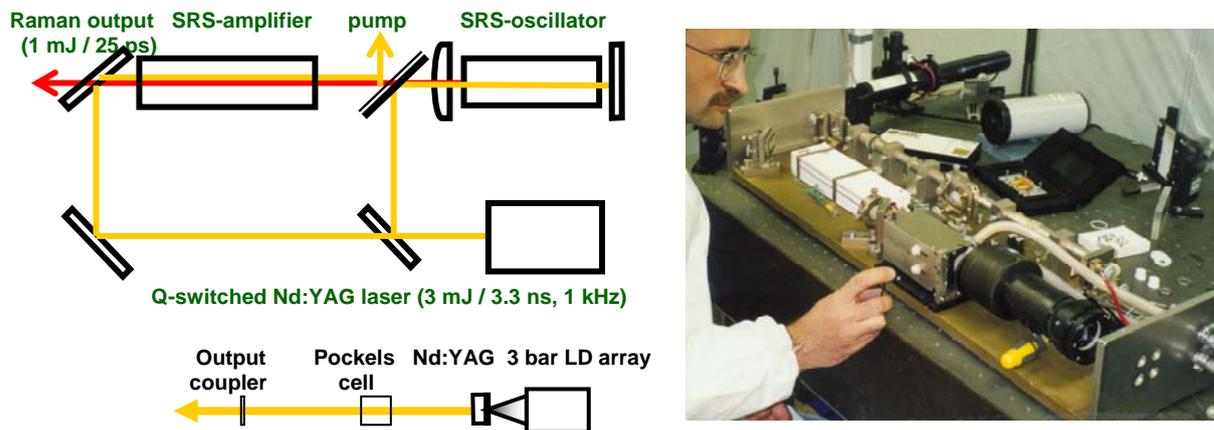


Fig.3. Scheme and view of 1-kHz diode-pumped Raman laser

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.

References

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Advanced Solid State Laser Systems for Space Tracking

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Abstract

A new generation of advanced solid state laser systems has been developed at EOS for space tracking applications.

A completely diode pumped laser system consisting mode-locked laser oscillator, regenerative amplifier, power amplifier and non-linear device with 10 pico-second pulse width has been developed for satellite laser ranging.

A multi-stage and multi-channel completely diode pumped laser system consisting single frequency oscillator, pre-amplifiers, power amplifiers, SBS cells and imaging relays with 2 nano-second pulse width and 230 W output power has been developed for tracking space debris.

Both systems have been in service for more than 2 years with excellent performance and reliability.