Laser Technology

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Nd:YLF Laser for Airborne/Spaceborne Laser Ranging

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***Abstract* - In order to meet the need for light weight, long lifetime, efficient, short pulse lasers a diode-pumped, Nd:YLF oscillator and regenerative amplifier is being developed. The anticipated output is 20 mJ per 10 picosecond pulse, running at a repetition rate of 40 Hz. The fundamental wavelength is at 1047 nm. The oscillator is pumped by a single laser diode bar and modelocked using an electro-optic, intra-cavity phase modulator. The output from the oscillator is injected as a seed into the regenerative amplifier. The regenerative amplifier laser crystal is optically pumped by two 60W quasi-cw laser diode bars. Each diode is collimated using a custom designed micro-lens bar. The injected 10 ps pulse from the oscillator is kept circulating within the regenerative amplifier until this nanojoule level seed pulse is amplified to 2-3 millijoules. At this point the pulse is ejected and sent on to a more standard single pass amplifier where the energy is boosted to 20 mJ. The footprint of the entire laser (oscillator - regenerative amplifier - amplifier) will fit on a 3' by 4' optical pallet.**

I. INTRODUCTION

There are a number of programs at NASA's Goddard Space Flight Center which are driving the need for compact, efficient, diode-pumped lasers. These programs fall within the headings of Ranging, Altimetry, Metrology, LIDAR, and Communications. One of the primary leaders in this technology push has been the Geodynamic Laser Ranging System (GLRS) which proposed to perform both sub-centimeter ranging to retro-reflectors placed at geodynamically interesting regions as well as sub-decameter altimetry to the Earth's surface, ice sheets, cloud tops, etc.[1] The original requirements were for a spaceborne, 5 year lifetime, diode-pumped, Nd:YAG laser having an output of 200 mJ in 100 ps at the fundamental wavelength (1064 nm). This light was then frequency doubled and tripled to produce a resultant 100 mJ at 1064 nm (IR), 60 mJ at 532 nm (green) and 40 mJ at 355 nm (UV). The green and UV light were to be used for 2-color ranging in an attempt to back out atmospheric refraction effects. The IR radiation was for altimetry operations. Due to the complexity of the GLRS instrument and the still unresolved technological challenges, it was decided to divide the instrument into 2 separate instruments. The ranger is now called GLRS-R and the altimeter, GLRS-A. The work being described in this paper deals with the development of a laser source for an aircraft instrument to proceed and be a "stepping-stone" to the GLRS-R instrument. The requirements for this mission were derived and scaled down from the GLRS requirements and are meant to push the technology to produce a proof-of-concept breadboard for the GLRS-R instrument. This GLRS breadboard laser is required to be: diode pumped, compact (fitting on 3' x 4' palette), greater than 6% efficient, low maintenance, long lived (10^8 shots), low cost, and flyable.

II. BREADBOARD DESIGN

The overall design for the breadboard laser is shown in Fig.1. The laser consists of 3 sub-sections: the oscillator, the regenerative amplifier, and a final power amplifier, with the doubling and tripling left as future tasks . The oscillator produces low energy, short pulses which are used to seed the regenerative amplifier, where their energy is amplified 6 orders of magnitude. The output of the regenerative amplifier is sent to a standard amplifier where the pulse energy is increased by a factor of 20. The required output is an energy of 20 mJ per 10 ps pulse occurring at a repetition rate of 40 Hz. Each of the 3 sub-sections are now described in greater detail. The oscillator is a diode pumped, FM mode-locked laser (Fig.2)[2]. The Nd:YLF laser crystal (the choice of Nd:YLF over Nd:YAG will be described later) is end-pumped by a CW SDL-2482 3 Watt laser diode operating at 796 nm. The highly diverging light from the 500 x 1 µm emitting aperture is collimated and focused using a high NA Fujinon F35B compound lens array and a 12.0 mm cylindrical lens. A spot size of less than 500 µm can be maintained for 4 mm leading to efficient end-pumping of the Nd:YLF rod since the cavity mode size at the rod is also 500 µm. The Nd:YLF rod is 12 mm long with a 6.35 mm diameter. The one end is cut flat and anti-reflection coated for the pump wavelength of 796 nm and high-reflection coated for the lasing wavelength of 1047 nm. The opposite end of the rod is Brewester cut. The only intracavity element is an electro-optic phase modulator which FM mode-locks the laser. In order to keep the laser output stable, a feed-back loop has been designed which keeps the RF modulation frequency (200 MHz) of the phase modulator equal to the cavity mode frequency (c/2L). In a previous experiment performed at NASA/GSFC using a Nd:YAG crystal, stable 15 ps pulses were obtained at a modulation frequency of 344 MHz. An output energy of 5 nJ per pulse is expected for the Nd:YLF oscillator.

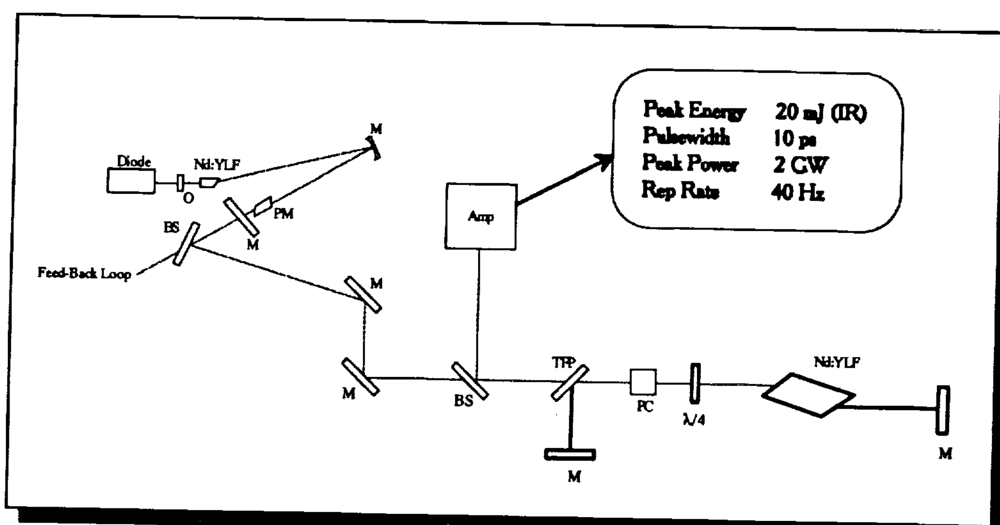

Fig. 1. Breadboard Design

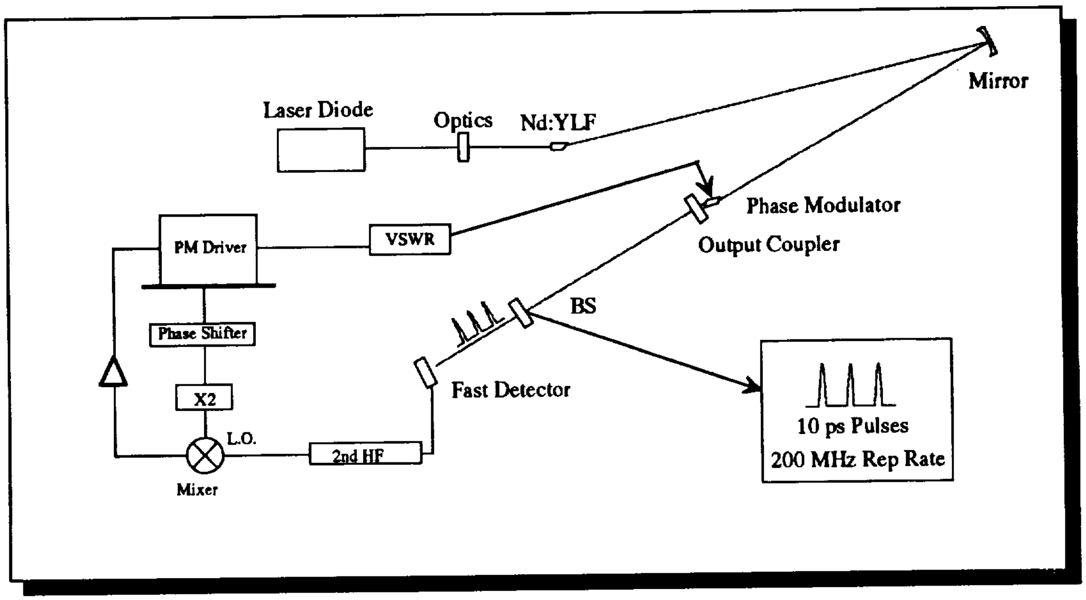

Fig. 2. FM Mode-Locked Laser and Feed-Back Loop

The regenerative amplifier is essentially a Q-switched, cavity dumped oscillator with an injected seed pulse. The seed pulse is trapped electro-optically in the cavity and circulates through the gain medium until the energy of the pulse has been amplified to the desired level. The regen designed for this breadboard (Fig. 3) uses laser diode side-pumped Nd:YLF as the gain medium and a combination of polarizers and a very fast rise-time Pockels cell (3-4ns) to switch the seed pulse into and out of the regen. The laser diodes used to pump the Nd:YLF crystal are Spectra Diode Labs model 3230 which have an output energy of 60mJ within a 500 μs pulse and a repetition rate of 40 Hz at 796 nm. The 10 x 0.001 mm aperture of the diode leads to a divergence of the emitting light of 10° by 40°. In order to collimate this highly diverging light, a unique lens has been utilized that was created at Lawrence Livermore Labs.[3] First the theoretically perfect lens for collimation of the fast axis is created in bulk form. As with optical fibers, this bulk lens is then pulled down to a 200 μm diameter microlens while still retaining the original hyperbolic shape of the bulk lens. Slices of these microlenses are attached to the output facet of the laser diode giving a collimated output of 500 μm at 3 cm. The output from two collimated diodes is delivered through the top of the 2 x 5 x 15 mm Nd:YLF slab (Fig. 4.). The lenses are ~80% efficient leading to ~50 mJ being delivered to the surface of the crystal.

As previously mentioned, control of the number of round trips the seed pulse makes within the regen is accomplished by a very fast electro-optic switch made by Medox Electro-Optics. By rotating the polarization of the traveling pulse through the Pockels cell, the light will either see the Thin Film Polarizer (TFP) as a mirror or a window. After a sufficient number of round trips within the regen, the energy of the seed pulse will have been amplified from 5 nJ to 2mJ. For our design, optical damage puts the ultimate limit on the number of round trips and therefore the gain of the regenerative amplifier.

The third sub-section is a standard single pass diode side-pumped Nd:YLF amplifier which will increase the energy per pulse from 2 mJ to 20 mJ (Fig. 1.).

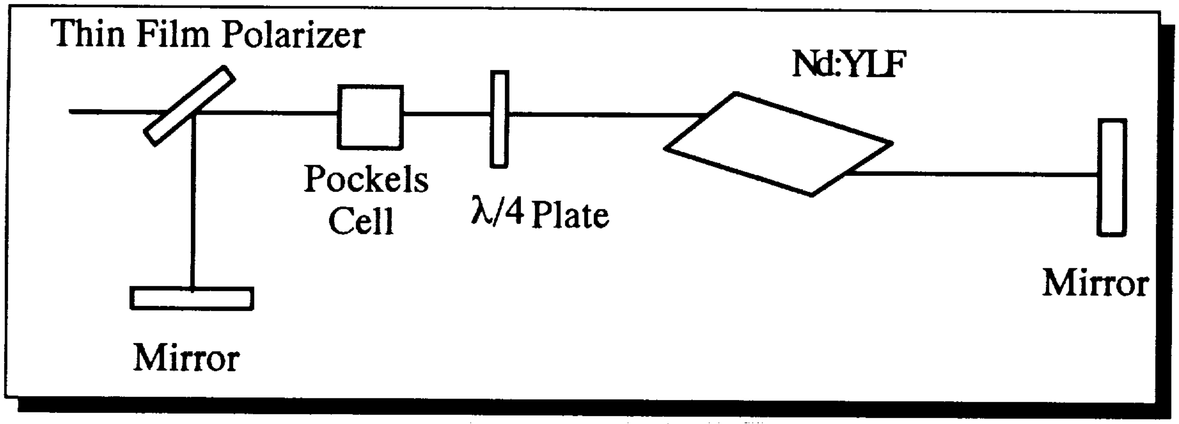

Fig. 3. Regenerative Amplifier

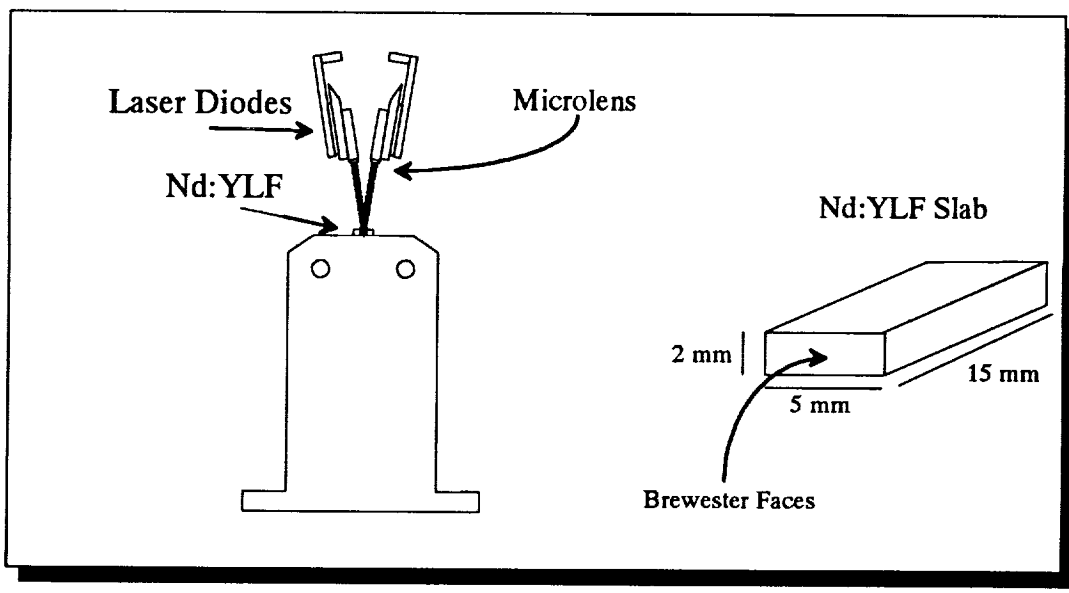

Fig. 4. Diode Collimation and Pump Scheme

III. Nd:YLF vs Nd:YAG

Since the absolute ranging accuracy is increased as the laser pulse width is decreased, the design of this breadboard encompasses the use of Nd:YLF versus Nd:YAG (the crystal of choice in the original GLRS design). From the equation for the pulse width achievable from an electro-optic phase modulated mode-locked laser[4];

$$\tau(FM) = \frac{\sqrt{2\sqrt{2\ln 2}}}{\pi}\left(\frac{g_o}{\delta_c}\right)^{1/4}\left(\frac{1}{f_m \cdot \Delta f}\right)^{1/2}$$

where f_m is the modulation frequency, Δf is the bandwidth of the lasing medium, g_o is the gain and δ_c is the effective single-pass phase retardation, it is apparent why it is desirable to use Nd:YLF with a bandwidth of 420 GHz instead of Nd:YAG with a 120 GHz bandwidth for short pulse generation.

	Nd:YLF	Nd:YAG
Lasing Wavelength	1.047 μm	1.064 μm
Stimulated Cross Section	3.0×10^{-19} cm^2	6.5×10^{-19} cm^2
Upper State Lifetime	480 μs	240 μs
Bandwidth	420 GHz	120 GHz

Table.1 Nd:YLF vs Nd:YAG

In addition, Nd:YLF has the advantage of having an upper state lifetime approximately 2.5 times greater than Nd:YAG allowing for approximately 2.5 times the energy storage, hence a larger gain as well. YLF is also naturally birefringent making it resistant to thermally induced birefringence and the concomitant undesired polarization dependent losses. Other advantages include less thermal lensing, and a nonlinear index less than three times that of YAG. Although thermally induced stress fracture has been reported in Nd:YLF, we have not encountered this problem.

IV. SUMMARY

The design for a compact, efficient, diode pumped Nd:YLF laser has been shown. The expected output is 20 mJ per 10 ps pulse at a repetition rate of 40 Hz. The size, weight and power consumption makes this design ideal for aircraft ranging. Some of the areas to be investigated so that this technology may successfully make the transition to a spacecraft instrument include: the reduction of pulse width and its implications to optical damage, shot lifetime of laser diodes, efficient and stable collimation of laser diodes, high voltage Pockels cell driver and mode locker lifetimes, and overall system efficiency.

[1] S.C. Cohen, J.J. Degnan, J.L. Bufton, J.B. Garvin, and J.B. Abshire, "The Geoscience Laser Altimetry/Ranging System," IEEE Trans. Geosci. Rem. Sens., vol GE-25, 581, 1987.

[2] G.T. Maker and A.I. Ferguson, "Frequency-Modulation Mode Locking of a Diode-Pumped Nd:YAG Laser," Optics Letters, vol. 14, **15**, 1989.

[3] J.J. Snyder, P. Reichert, and T.M. Baer, "Fast Diffraction-Limited Cylindrical Microlenses," Applied Optics, vol. 30, **19**, 1991.

[4] D.J. Kuizenga and A.E. Siegman, "FM and AM Mode Locking of the Homogenous Laser-Part I: Theory," IEEE J. Quantum Electron., vol. 6, **11**, 1970.

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ALTERNATIVE WAVELENGTHS FOR LASER RANGING

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To accomplish multicolor laser ranging we should consider :
* the nature of the atmospheric dispersion and absorption,
* the Satellite/Lunar/Ground retro array characteristics,
* Ground/Satellite ranging machine performance.

The existing atmospheric dispersion models [1,2] are perhaps valid up to 1 cm accuracy. It is evident, the higher time interval difference of a chosen pair, the requirements on the ground / satellite instrument are less stringent. The energy balance and jitter budget have to be considered, as well.

The existing Satellite / Lunar retro arrays show serious limitation to accomplish a multicolor experiment [3].

The fieldable picosecond lasers, considered up to now, have the origin on the NdYAG transition (1.06um) and its harmonics (0.53 um, 0.35um), Raman Stokes transition (0.68 um) of 0.53 um in Hydrogen [4,5], Titanium Sapphire (0.8 / 0.4 um) and Alexandrite. We do propose the Raman Stokes / Raman Anti Stokes pair of 0.53 um (0.68 um/0.43 um) and Cr:LiSAF (0.8/0.4 um).

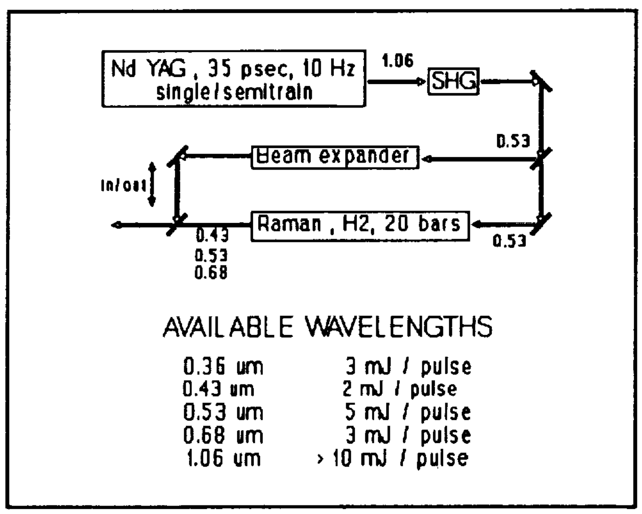

Figure 1 Multiple wavelength laser transmitter
The 3HG may replace the Raman tube

The streak detector experiments carried out in Prague on a ground target (0.53/0.35 um), (0.53/0.68 um) [4], (0.53/1.06 um) and in Graz [5] on Ajisai and Starlette satellites proved the expectancy, however, indicated the complexity. On the other hand, the solid state detector technology offers a remarkable simplicity and compactness with the access to the near infrared. The experiment (0.53/0.68 um) accomplished in Graz [6] indicates a chance, if data averaging requirements will be fulfilled.

Since several years ago, Alexandrite based Fundamental / SHG lasers do not show to much progress. Using the Titanium Sapphire based laser, the scheme is becoming quite complex because of short relaxation time (3 useconds) of the metastable level of the active medium.

The new material Li:SAF [7] tunable around 800 nm, having 66 usec relaxation time, looks promising related to the spectral response of existing vacuum and solid state detectors and the atmospheric propagation and dispersion, as well.

At the conclusion : the existing Satellite / Lunar retroreflectors seem to be not adequate for the future experiments. The Raman Stokes/Anti Stokes (0.68/0.43um) plus solid state detector look as a promising instrumentation satisfying the Ground/Satellite and Satellite/Ground ranging machine requirements on the precision, compactness and data processing.

WAVELENGTHS PAIRS SELECTION

Graz SLR, 2.5 echo/sec/w., 45 deg.elev.

wavelengths	prec.req.	aver.time
0.35*/ 0.53 um	5.3 psec	0.8 minute
0.4 / 0.8 um	4.1 psec	1.6 minute
0.43 / 0.68 um	3.3 psec	2.6 minutes
0.53 / 0.68 um	1.6 psec	10 minutes
0.53 / 1.06 um	2.9 psec	5.2 minutes

* energy budget problems at this wavelength

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Figure 2 The wavelength pair selection. The two wavelength ranging setup using SPAD is expected, the mean elevation 45 degrees is expected, the SPAD jitter dependence versus wavelength is taken into account.

References:

1. Marrini J.K., Murray C.W., report GSFC X-591-73-351
2. Abshire J., Applied Optics, Vol.19, 1980
3. Prochazka I., in this Proceedings
4. Gaignebet J. et al, Hamal K. et al, Proceedings of the 6th International Workshop on Laser Ranging Instrumentation, Antibes, 1986, p565-577
5. Hamal K et al, to be published at IQEC'92, Vienna, June 1992
6. Kirchner G. et al, to be published at IQEC'92, Vienna, June 1992
7. Hamal K, Richardson M., in this Proceedings

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NEW METHODS OF GENERATION OF ULTRASHORT LASER PULSES FOR RANGING

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INTRODUCTION

To reach the millimeter satellite laser ranging accuracy, the goal for nineties, new laser ranging techniques have to be applied. To increase the laser ranging precision, the application of the ultrashort laser pulses in connection with the new signal detection and processing techniques, is inevitable. The two wavelength laser ranging is one of the ways to measure the atmospheric dispersion to improve the existing atmospheric correction models and hence to increase the overall system ranging accuracy to the desired value.

We are presenting a review of several nonstandard techniques of ultrashort laser pulses generation, which may be utilized for laser ranging:

* Compression of the nanosecond pulses using stimulated Brillouin and Raman backscattering
* Compression of the mode-locked pulses using Raman backscattering
* Passive mode-locking technique with nonlinear mirror
* Passive mode-locking technique with the negative feedback

BRILLOUIN AND RAMAN BACKWARD SCATTERING

The idea of obtaining a single subnanosecond light pulse by temporal compression of a nanosecond laser pulse was suggested in [1] and the compression cascade by backward stimulated scattering of passively Q-switched Nd:YAG laser pulses was experimentally demonstrated in [2]. We had been investigated the generation of monopulse from Q-switched Nd:YAP oscillator [3]. The experimental setup is in Fig.1. The resonator was formed by the concave mirror M1 and the plane output mirror M2 deposited on the front surface of the Nd:YAP laser rod (Nd:YAP1). The b-axis of the crystal Nd:YAP yields linearly polarized light

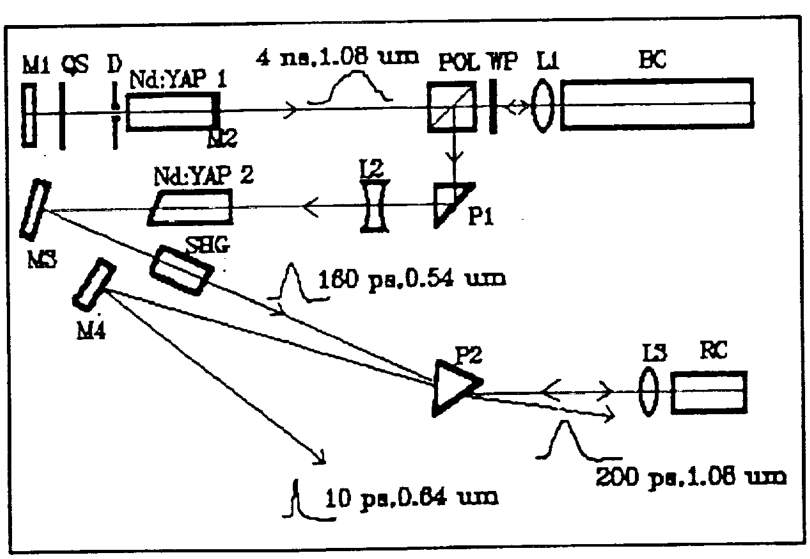

Figure 1 Experimental setup for two-stage pulse compression via stimulated backward scattering

mirror M1 and the plane output mirror M2 deposited on the front surface of the Nd:YAP laser rod (Nd:YAP1). The b-axis of the crystal Nd:YAP yields linearly polarized light output at $\lambda_1 = 1.0795$ μm. Q-switching was performed by the plastic BDN foil QS. The length of the resonator was 20 cm and together with low initial transmission of the Q-switch enable generation of pulses with duration $\tau_1 = 4$ ns (Fig.2a). The pulse energy in TEM_{00} mode was 7.5 mJ. This setup of short resonator gives most stable output pulses [4].The oscillator radiation passing a cube dielectric polarizer POL and a quarter wave plate WP, was focused by lens L1 into SBS compressor - a 70 cm long cell BC filled with CCl_4. When the necessary condition for SBS was fulfilled, the backward Stokes pulse was generated. The compressed Stokes pulse passing prism P1 and a negative lens L2 is amplified by the single pass Nd:YAP amplifier (Nd:YAP2) to the energy 30 mJ. The diverging beam is recollimated by the concave mirror M3. After frequency doubling in a SHG crystal, the pulse ($\lambda_2 = 0.54$ μm) has an energy of 10 mJ. The radiation at different wavelengths is spatially separated by the dispersion prism P2. The 0.54 μm pulse is then focussed with lens L3 into the second compressor consisting of the Raman cell RC filled with methane at 18 bars.

Temporal characteristics of the pulses in subnanosecond range were measured by the streak camera Imacon 500 with readout system consisting of SIT television camera, single frame memory and computer. The temporal resolution of the whole system was better than 2 ps [5]. Fig.2b shows the pulse after the first stage compression and the frequency doubling ($\lambda_2 = 0.54$ μm). The mean pulse duration was $\tau_2 = 160$ ps. Streak camera record of the backward Stokes pulse ($\lambda_3 = 0.64$ μm) from the Raman cell is on Fig.2c. The mean value of the pulse duration τ_3 for given focussing optics depends on pump energy. The minimum length of pulse τ_3=9 ps was obtained for pump pulse energy 3-5 mJ.

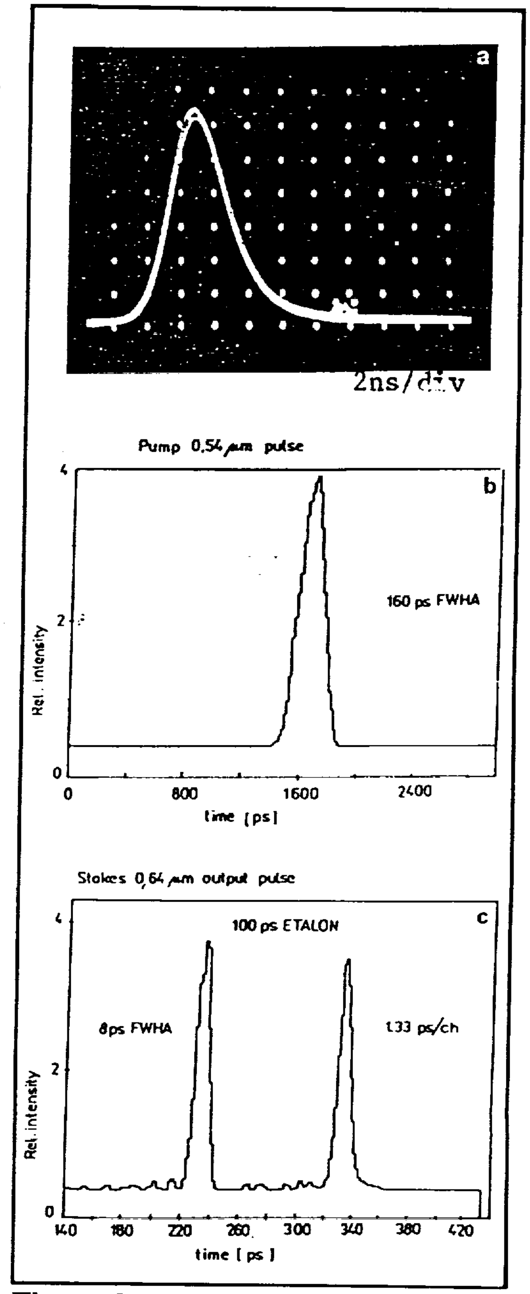

Figure 2 A records of compressed pulses

The advantage of this compression technique in comparison to the used mode-locked picosecond lasers, are the absence of the active and/or passive mode lockers used to generate a train of picosecond pulses, and the absence of a fast electrooptical shutter used to select a single pulse from a train of pulses.

RAMAN BACKSCATTERING PULSE COMPRESSION

The generation of single picosecond pulses through backward Raman scattering can start directly from the pulse train generated from a mode-locked laser. The experimental setup composes a passively mode-locked modified SFUR [6] loaded with 1/4"x4" Nd:YAG rod, delivering 30 mJ in a train of 4-5 pulses (FWHM) at $\lambda_1 = 1.064\ \mu m$ and with $\tau_1=24$ ps timewidth and an amplitude fluctuation of the highest pulse in the train of 13%. The radiation is then converted to the second harmonic in a KDP crystal using type II configuration, giving 10 mJ and $\tau_2=17$ ps timewidth, with a 20% amplitude fluctuation. The output train is then fed into the Raman cell, focussing it with a 160 mm focal length lens. The Raman cell was filled with 20 bars methane gas. On each shot, signals from fundamental, second harmonic $\lambda_2=0.532\ \mu m$ and Raman Stokes Backscattering at $\lambda_3 = 0.68\ \mu m$ were detected and stored for later processing. The Raman signal was checked to be the phase conjugated of the input second harmonic signal. Its energy was measured to be 3 mJ, giving an average green-to-red conversion efficiency of 30%. Time duration of the Raman pulses was $\tau_3=7.4$ ps with a 2.3 compression factor with respect to second harmonic pulses. On Fig.4a is oscilloscope record of the rest of mode-locked train pulses (positive trace) and a single generated Raman pulse (negative trace). Fig.4b shows streak camera records of the overlap of 100 second harmonic pulses (positive trace) and Raman Stokes pulses (negative trace). The second harmonic radiation and Raman output pulses were detected by the independent photodiodes, one of the photodiode output was inverted and both signals have been added on the oscilloscope input.

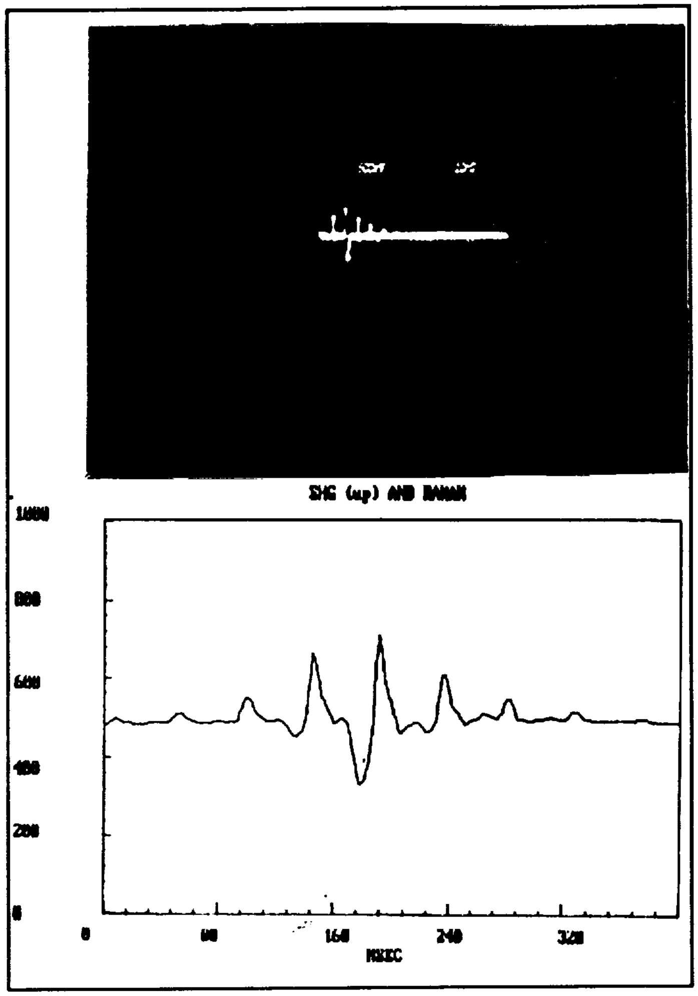

Figure 3 A records of the generated pulses

This technique gives possibility to generate one ultrashort pulse without expensive optical and electronic part as they are Pockels cell, polarizers, high voltage pulse forming circuitry, optostart, high voltage power supply,etc. which are obviously needed to select single picosecond pulse from mode-locked train.

GENERATION OF MODE-LOCKING PULSES USING A FREQUENCY-DOUBLING NONLINEAR MIRROR

The mode-locking technique based on intracavity frequency doubling offers new capabilities for generation of ultrashort laser pulses. A frequency doubler inside the cavity, together with an output mirror with high reflectivity at the second harmonic forms a nonlinear mirror, whose reflectivity at the fundamental wavelength can either increase or decrease when the input light intensity increases. When the phase condition facilitate increasing reflectivity, the device can be used as a passive mode-locker. First experiment with the nonlinear mirror was performed by K.Stankov [8]. With the Nd:YAG laser active medium he got 20 ps length of pulses. We investigated the attractive potential of the second harmonic nonlinear mirror to mode-lock lasers at quite different wavelengths. The laser cavity was formed by the dielectric mirrors. In all cases the rear mirror was a total reflector at the fundamental, the output mirror was dichroic and it was total reflector at the second harmonic and had 20-24% reflectivity at the fundamental wavelength (Fig.4). Using a single 30^0-cut $LiIO_3$ frequency doubler (20 mm long), mode locking at the 1.08 μm and 1.34 μm transitions of pulsed Nd:YAP laser was achieved [9]. Pulses as short as 40 ps and 15 ps at the corresponding wavelength were obtained. Mode-locking was achieved also in Er:YAP laser at 1.66 μm wavelength with pulse duration of 450 ps [10] and in Ti:Sapphire laser at 0.7 μm wavelength with pulse duration of 100-130 ps [11]. A comparative wavelength indicates that the minimum pulse duration is determined by the limited number of round trips only.

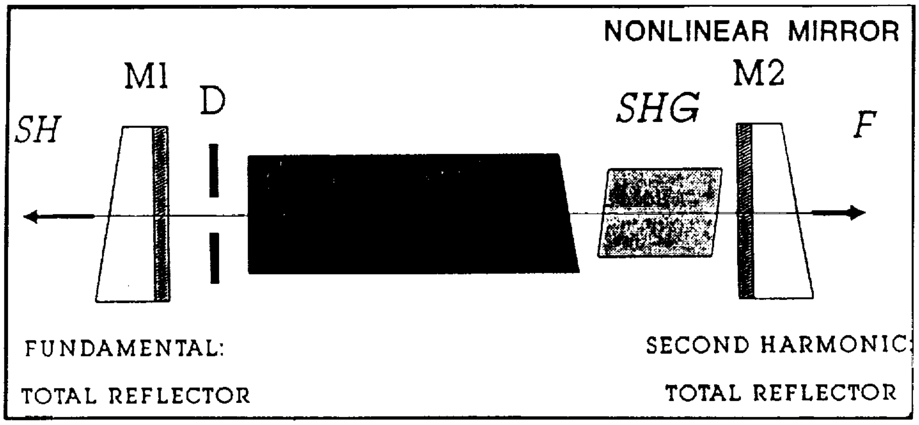

Figure 4 Experimental scheme

This experiment showed that nonlinear mirror technique allows to mode lock a number of solid state lasers ranging in wavelength 0.8 μm (Ti:Sapphire laser) up to 1.66 μm (Er:YAP laser). When the optimalization will be done and shorter pulses will be generated, the advantages of short pulse immediately with the generation of first and second harmonic radiation will be evident.

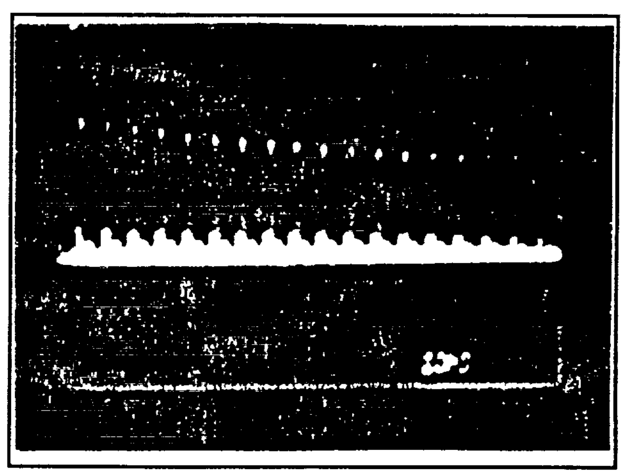

Figure 5 The mode locked Ti:Sapphire laser (10 ns/div)

PASSIVE MODE-LOCKING TECHNIQUE WITH THE NEGATIVE FEEDBACK

The solid state lasers with negative feedback through an electro-optic loss that limits the maximum intensity inside the cavity and prevents the rapid growth of the laser pulse, were successfully used for the generation of shorter reproducible pulses [12,13]. The possibility of using a passive two-photon absorption element instead of the active loss control, was also suggested and demonstrated [14,15,16]. Two-photon absorber (GaAs or CdSe) acts inside the resonator as a passive negative feedback element (NFE). The scheme of experiment with Nd:YAG or Nd:YAP laser is similar and it is schematically shown in Fig.6.

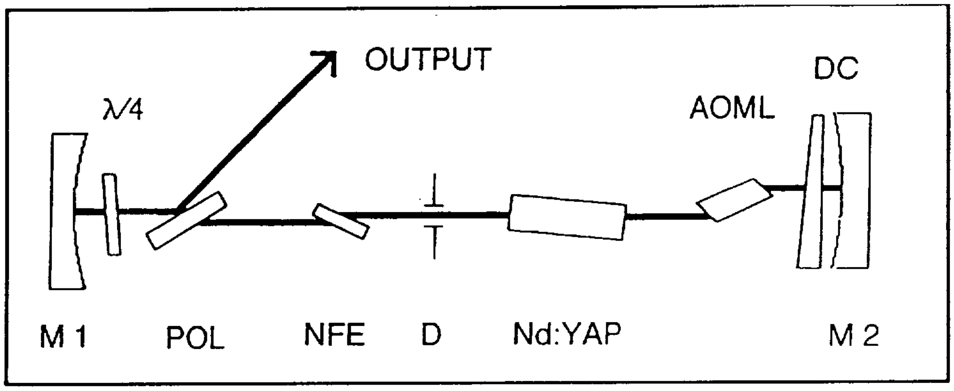

Figure 6 The experimental setup

The Fabry-Perot cavity is formed by concave mirrors M1 and M2(R=10m) having a reflectivity of 99.8%. The mirror M2 is in contact with a 0.5 mm thick dye cell (DC) containing flowing Eastman Kodak 9860 dye in 1,2-dichloroethane (T_0=30% at 1.08 μm). The output coupling of the resonator is achieved by means of a dielectric polarizer (POL), which, in combination with the quarter-wave plate keeps the output coupling at 50%. The active medium was Nd:YAG or Nd:YAP. The cavity round trip time was synchronized to the modulation period of the acoustooptic mode locker. With the Nd:YAG laser long trains of steady-state pulses was generated, with a single pulse time duration of 10 ns and an energy of 10 μJ,with cw comparable stability. The minimum of pulse duration was obtained for Nd:YAP laser with CdSe working as a negative feedback element. In this case, the pulses with 5 ps length was generated with an energy of 1 mJ.The example of the generated pulse trains for different negative feedback elements are in Fig.7.

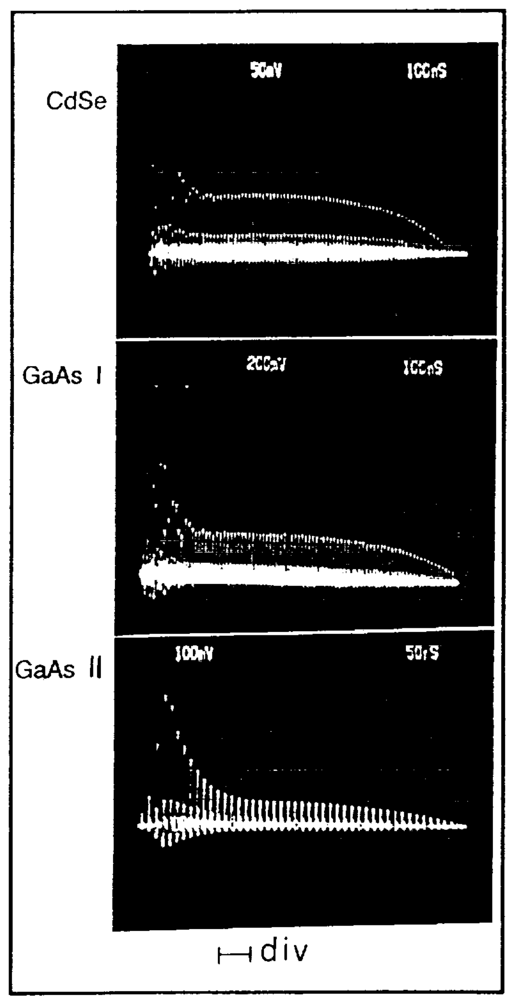

Figure 7 The records of the generated pulses

CONCLUSION

This review article shows some possibilities for generation of short and ultrashort laser applicable in laser ranging.

References

[1] M.Maier,W.Kaiser,J.A.Giordmaine: Phys.Rev.Lett.17 (1966) 1275

[2] R.R.Buzelis,A.S.Dement'ev,E.K.Kosenko: Sov.Journ.Quant.Electron.12 (1985) 2024 (in russian)

[3] V.Kubecek,K.Hamal,I.Prochazka,P.Valach,R.Buzelis,A.Dement'ev: Optics Commun.,vol.73,3 (1989) 251

[4] H.Jelinkova,K.Hamal,M.Vrbova:High Brightness Nd:YAG Oscillator,Preprint Series FJFI No.77/4

[5] I.Prochazka,K.Hamal,H.Jelinkova:Technical Digest Conference on Lasers and Electro-optics (Optical Society of America, Baltimore,MD) (1989) pap.THK42

[6] H.Jelinkova,J.Marek,P.Valach,K.Hamal,G.C.Reali,G.Gabeta:Optics Communications Vol.75,No.5,6,March 1990,p.447

[7] K.Hamal,H.Jelinkova,I.Prochazka,G.C.Reali:Czech Journal Phys.(will be published)

[8] K.A.Stankov:Appl.Phys.B45 (1988) 191

[9] K.A.Stankov,V.Kubeček,K.Hamal:IEEE Journal of Quant.Electron.,vol.27,No.9 (1991) 2135

[10] K.A.Stankov,V.Kubecek,K.Hamal,H.Jelinkova,I.Prochazka:Proceedings of the EQEC,Edinburg,UK,(1991)

[11] K.Hamal,K.A.Stankov,H.Jelinkova,I.Prochazka,M.Koselja:Proceedings of the VIIth Int.Symp. on Ultrafast Proc. in Spect.,Bayreuth,Germany,(1991),TU3-3

[12] K.P.Komarov,A.S.Kuchyanov,V.D.Ugozhayev:Opt.Commun.57,279 (1986)

[13] P.Heinz,W.Kriegleder,A.Lauberau: Appl.Phys.A,43,209 (1987)

[14] K.P.Komarov,V.D.Ugozhyaev: Opt.Spectrosc. 55,564 (1983)

[15] A.V.Babushkin,in Proceedings of Ultrashort Phenomena in Spectroscopy '89, Springer-Verlag,Berlin (1989), PTh20

[16] A.Del Corno,G,Gabetta,G.C.Reali,V.Kubecek,J.Marek:Optics Letters,vol.15, No.13 (1990) July 1,734

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Simultaneously Compression of the Passively Mode-Locked Pulsewidth and Pulse Train

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Abstract

Simultaneously compression of the passively mode-locked pulsewidth and pulse train have achieved by using a plano-convex unstable resonator hybrided by a nonlinear Sagnac ring interferometer. The >30mJ single pulse energy of alone oscillator and <10ps pulsewidth have obtained. Using this system, the LAGEOS and ETALON satellites laser ranging have been performed successfully.

Key words: Nonlinear Sagnac ring interfereometer,
Simultaneously compression of M-L pulsewidth and train

1. Introduction

In a variety of scientific research and technical applications, laser ranging included, the single mode-locked pulse is necessary. For this reason, the single pulse selector has to be need, and perhaps needs several stages amplifiers in order that achieving necessary energy. Moreover, in outfield applications, not only need smaller and lighter equipments, but need that, the equipment insensitive to mechanical and thermal perturbations, maintaining good aligament over days of operation. Recently years, our group in base on *investigations* of antiresonant ring hybrided unstable resonator, deeply into investigated the conditions and paramaters of simultaneously compression using an unstable resonator hybrided by nonlinear ring interferometer, and following results have been obtained:
the pulse train compressed to two cavity periods, the mode-locked pulsewidth

compressed to $\leqslant$10ps, the single pulse energy (alone oscillator) $>$30mJ (Nd:YAG) , the weight and size of the setup (not including power supply) 32Kg and $72\times30\times24Cm^3$ respectively.

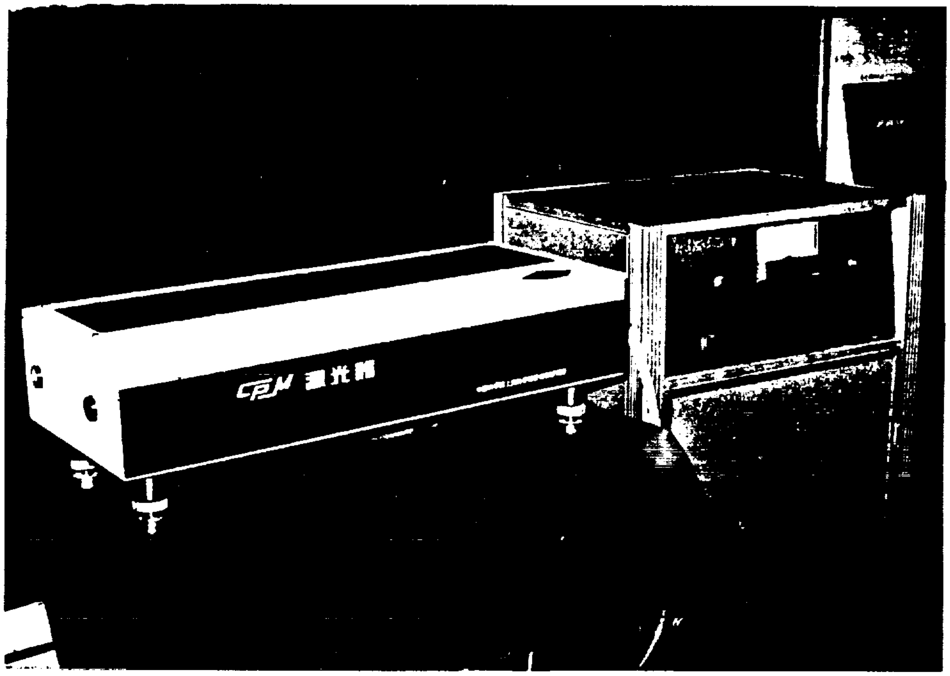

Fig.1 Photograph of the setup

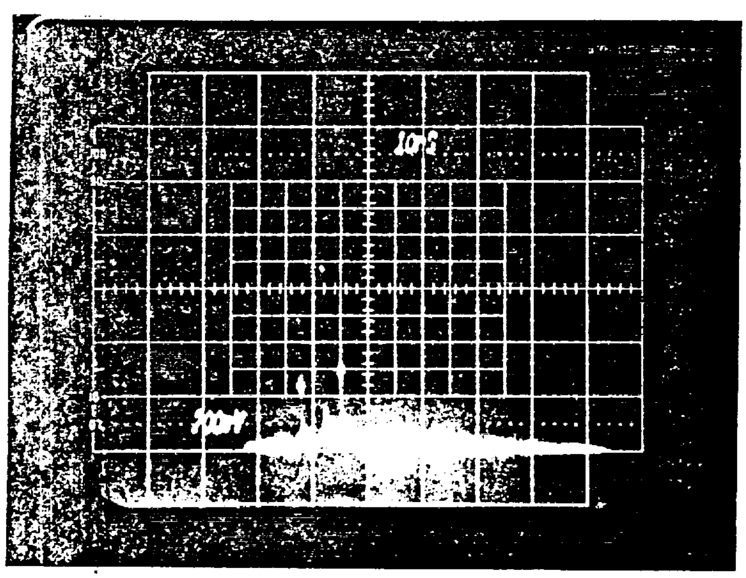

Fig.2 Oscillogram of the M-L pulse train

2. Theroy

Our experiment results exhibit that the mode-locked pulse train and pulse width have achieved compression simultaneously. This can't been explained fully by previous passively mode-locked theroy[1],[2]. Our study believe that true reasons for simultaneously compression should be altributed to the collision interference of the nonlinear ring interferometer, which formed a temporally modulated grating and stationary in space. Therefore, this grating is free from the deleterious atomic motionally induced or frequency-induced "washout" effect. Then, counterpropagation two beams, suffer strongly saturable absorption modulation, and at splitter mirror, again interference, resulting beams, which through a high inversion gain medium, the pulse signal obtain enhanced and compressed by cross-phase modulation. The necessary conditions of the doubly compression by using nonlinear ring interferometer, are Y1 parameter enough large, as that has to be at least one order of magnitude larger than R of [1]. $Y1 \sim |\ln \delta\Omega|$ is the initial amplitude of the stimulated emission, $\delta\Omega$ is solid angle, in which the laser radiation are concentrated. In according to [3], we deduced

$$Y1=\left(\frac{\delta n}{n}\right)^{2}\frac{TV(X1+\mu_{a})}{2\zeta}$$

here ζ is the relative excess pump power above the threshold for a closed shutter, $(\delta n/n)$ is the relative excess inversion population, T, cavity period time for mode-locked operation, $(X1+\mu_a)$, X1 is the linear losses per unit optical path, μ_a is absorption coefficient of the mode-locking dye. μ_a must be enough large, as that has to be at least one order of magnitude larger than corresponding value of optimum transmittance of [2]. In proper conditions, sufficient large Y1 can be depleted the δn, and initiated the nonlinear ring interferometer, an overshoot pulse after switching[4], return to a high inversion gain medium, then the pulse signal enhanced and compressed by cross-phase modulation, simultaneously compression of the mode-locked pulses achieved quickly, and a single gaint pulse is obtained.

3. Experiment setup

Experiment setup used in this work is different to [4] slightly. The main difference are addition of interferometer's function.

The nonlinear ring interferometer is composed of a P-polarization 50/50 splitter 1, two totally reflective turning mirrors 2 and 3, and a dye cell 4, which located at the colliding center, fulling pentamethine cyanine dissolve in 1,2-dichloroethane. Two polarizers 5 and 10 used for enhance the polarization purity of the gain medium Nd:YAG, 6, 90mm in length and 6.0mm in diameter, the ends of the rod were angled at 87.5° to the normal of the rod axis. The rear reflector, 11 is a convex mirror, turning mirrors 7 and 8, an aperture 9, output coupled mirror 12 and recollimated lens 13.

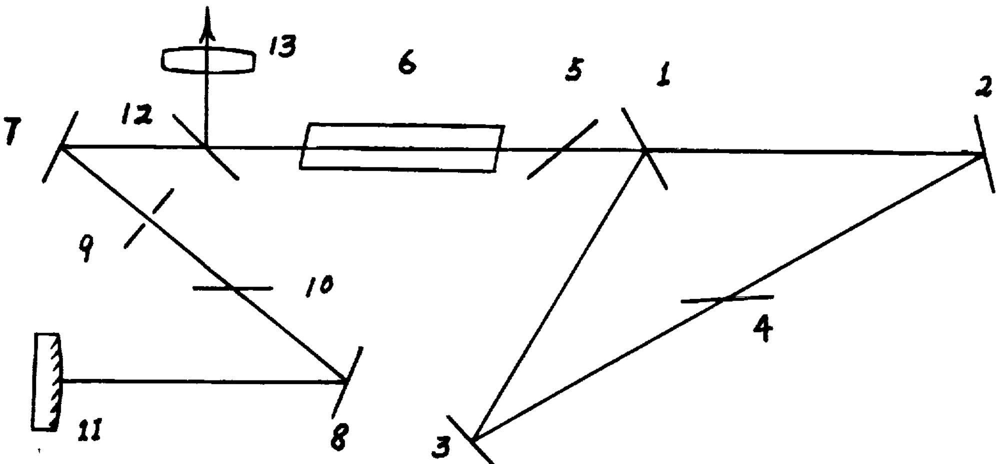

Fig.3 Optical layout of a nonlinear Sagnac ring interferometer.

Since the distance from the splitter mirror to colliding center is equal optical path, for all longitudinal modes $\omega_0 \pm m\Delta\omega$, that into oscillated, can be formed interference fringes, stabilzed in space, and these fringes are insensitive to mechanical and thermal perturbation. Due to the high angle selectivity of this system, so that it may be maintaining good aligenement over days of operation. In this system do not need single pulse selector and A-O modulator, without any amplify, the output energy of oscillator can be achieved >30mJ, pulsewidth <10ps. These performances are sufficient for many applications. For as LAGEOS and ETALON (20,000KM) satellite laser ranging, only need addition to one amplifier and a frequency doupler. More recently, the facts of successful laser ranging of LAGEOS and ETALON in Shanghai Observatory, have showed this point.

4. Conclusions

We have reported the results of a nonlinear Sagnac ring interferometer hybried unstable resonator. The results demonstate that the multiple interference effect quicken the mode-locking process, and the simultaneously compression of the mode-locked pulsewidth and pulse train have been achieved, and a GW level single pulse was obtained. This system have many advantages as that lighter weight, smaller size and insensitive to mechanical and thermal perturbations, particularly applied to outfield utilizations, such as mobile satellite laser ranging, and have great potentialities for heighten precision and distance of laser satellite ranging.

The damage problem of the optical components and improvement of the ratio of the first-second peak of the mode-locked train are currently in the progress.

Reference

[1] G.H.C. New, PIEEE, Vol.67, No.3, PP.380-396, Mar. (1979)
[2] A.L. Max, etal, IEEE JQE., Vol.QE-19, No.4, PP.562-566, Apr. (1983)
[3] A.M. Ratner "Spectral, Spatial and Temporal Properties of Lasers" PP.190-191, Plenum Press, New York-London, (1972)
[4] T. Bischifberger and Y.R. Shen, Physical Review A, Vol.19, No.3, PP.1169-1176, (1979)
[5] Sun Zhan'ao, etal, "Chinese Journal of Lasers", Vol.16, No.5, PP.302-304, (1989)

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An improved light source for laser ranging

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Summary

The development of a new laser material, Cr-doped LiSAF makes possible the development of a laser source for satellite ranging systems that is superior in performance capabilities than current Nd:YAG-based laser sources. This new material offers the potential of shorter pulses and more preferrable wavelengths (850nm and 425nm) than multi-wavelength Nd:YAG systems, leading to superior ranging resolution and greater detection sensitivity.

We are embarking on a feasibility study of a two-wavelength , mode-locked laser system based on Cr:LiSAF, providing shorter pulses for improved ranging resolution.

Background

Current satellite multi-wavelength laser-ranging systems operating with Nd:YAG based systems are capable of resolving earth-satellite distances to within a centimeter. The latter limitation is primary set by the minimum pulse-duration available from current field-usable mode-locked Nd:YAG laser systems having diffraction-limited beam divergence. Recent developments in ultrashort laser pulse technology with a new laser material perfected at CREOL in the last two years, now offers the possibility of an improved multi-wavelength laser-ranging system. The principal advantages this new material will offer is in shorter laser pulse durations, down to a few picoseconds, thereby improving ranging accuracy to the millimeter level, and in the use of shorter laser wavelengths permitting detection in a region of higher photocathode sensitivity, thereby improving overall sensitivity.

The new laser material Cr-doped LiSAF[1] has already been extensively studied[2,3], and reliable mode-locked operation has been demonstrated[4]. At the present time most of the technology of Cr-doped LiSAF is resident at CREOL. This has occured as consequence of it's crystal growth development at CREOL, and in a concerted effort being made by CREOL scientists to determine it's optical and physical properties. As a consequence, many laboratories are examining potential applications of this exciting new laser material.

Technical Details

We wish to take advantage of the possibilities offered by Cr:LiSAF in developing a fieldable laser for satellite ranging providing the general properties referred to above. A modelocked Cr:LiSAF laser can be built under this program that would have the principal components shown in fig.1.

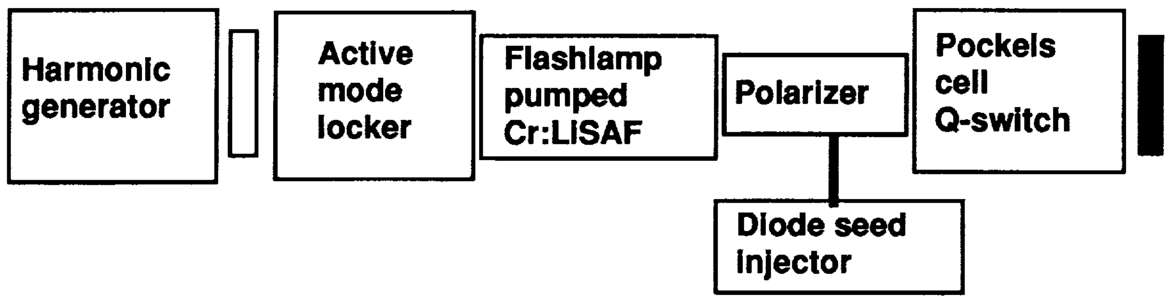

Fig.1. Schematic of an actively modelocked multifrequency Cr:LiSAF laser for satellite ranging

A cw single mode diode laser operating at ~845nm can be used to seed the Cr:LiSAF laser with a specific frequency. This will both control the frequency of the laser, and it's harmonic, and ensure that the modelocked laser has single mode output itself, ensuring diffraction-limited beam divergence. Short pulses wouldbe formed within the laser with the aid of conventional modelocking and Q-switching techniques. With the laser locked to a specific output frequency, efficient, stable, phase-matched second harmonic conversion will be guaranteed. The output performance of the laser will have the following parameters

Energy per pulse-train	500mJ	Wavelength	850nm
Number of pulses	10	Energy per pulse	50mJ
Pulse-duration	30ps	Pulse separation	10ns
Second Harmonic Conv. Eff.	25%	En. @ 425nm	12.5mJ

References

1. S.A. Payne, L.L. Chase, L.K. Smith, W.L. Kway, and H.W. Newkirk, "Laser performance of $LiSrAlF_6:Cr^{3+}$," J. Appl. Phys. **66**, 1051, 1989.
2. P. Beaud, Y-F. Chen, B. Chai, and M. Richardson, "Small-signal gain properties of $LiSrAlF_6:Cr^{3+}$", submitted to Optics Letters.
3. Y. F. Chen, P. Beaud, B. H. T. Chai & M. Richardson, "Small signal gain measurements of Cr-doped LiSAF and LiCAF" Proc. Conf. on Advanced Solid State Lasers Santa Fe (Optical Society of America 1992) to be published.
4. P. Beaud, E. Miesak, Y-F. Chen, B. H. T. Chen and M. Richardson, "A flashlamp-pumped Cr:LiSAF regenerative amplifier" Proc . Conf. on Advanced Solid State Lasers Santa Fe (Optical Society of America 1992) to be published.