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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.

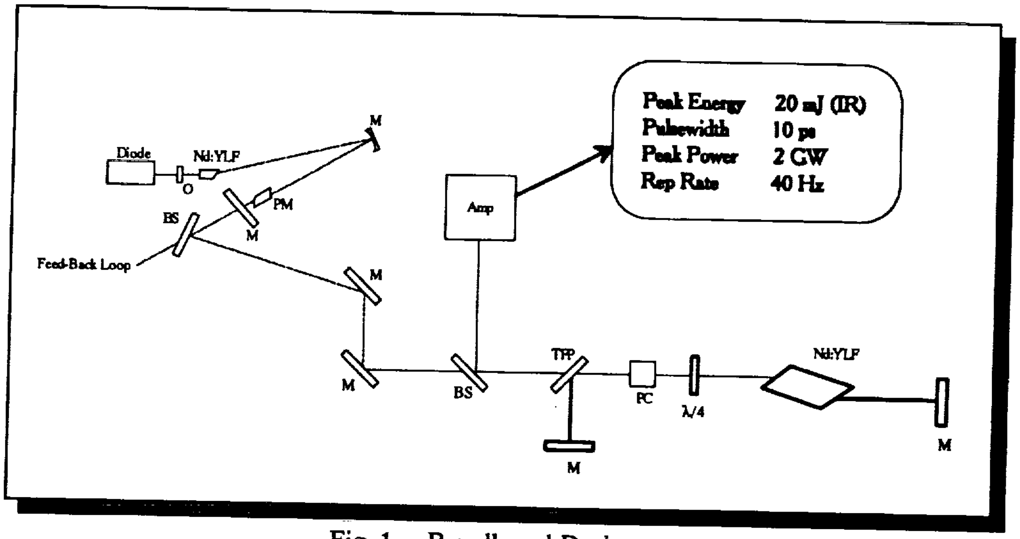

Fig. 1. Breadboard Design

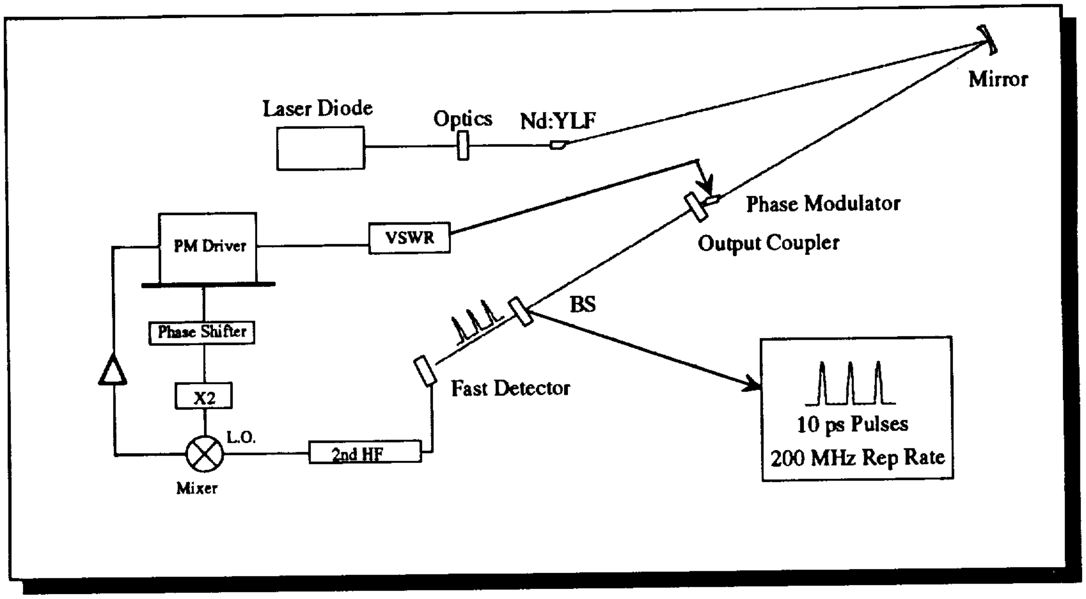

Fig. 2. FM Mode-Locked Laser and Feed-Back Loop

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.).

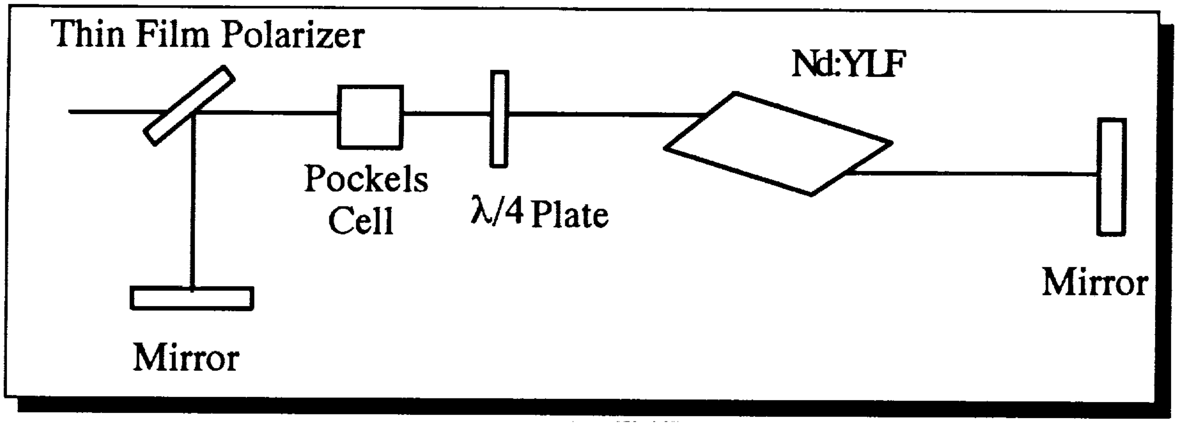

Fig. 3. Regenerative Amplifier

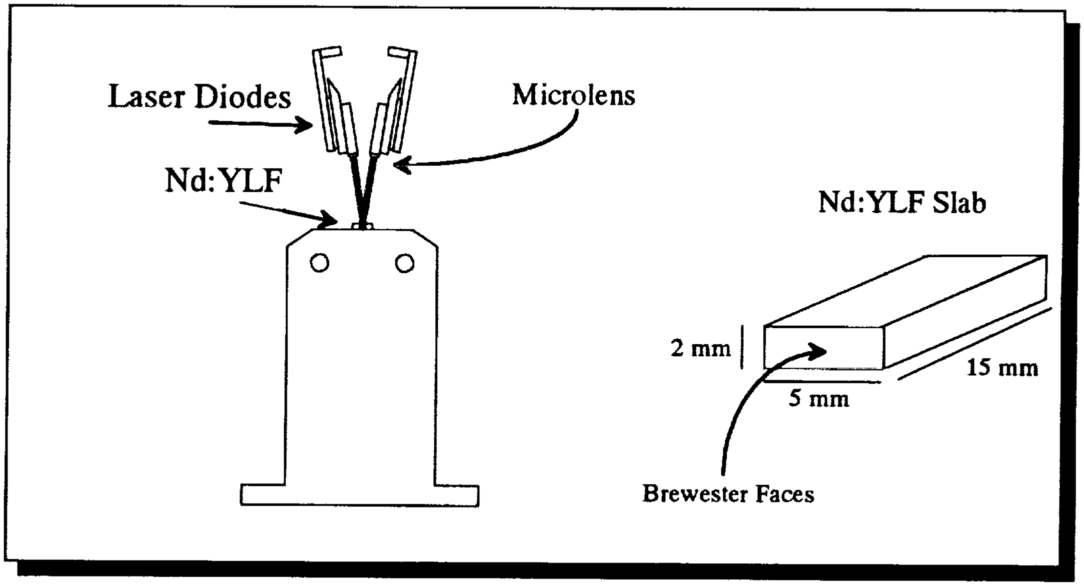

Fig. 4. Diode Collimation and Pump Scheme

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.