AD-A159 923 HIGH VOLTAGE PICOSECOND PULSE GENERATION UTILIZING LASERS(U) ROCHESTER UNIV N Y DEPT OF ELECTRICAL ENGINEERING R HEINTZ ET AL. 23 JUL 85 N00014-84-C-0179 1/1

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(12)

July 23, 1985

Dr. Richard G. Brandt
Office of Naval Research
1030 East Green Street
Pasadena, California 91106

Dear Dr. Brandt:

Enclosed please find the final report on N00014-84-C-0179. If you have any questions, please do not hesitate to contact me at 716-475-2143.

Sincerely yours,

Tapan K. Sarkar

Tapan K. Sarkar

TKS/src

Enclosures

HIGH VOLTAGE PICOSECOND PULSE GENERATION UTILIZING LASERS

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ABSTRACT:

A mode-locked Q-switched Nd:YAG laser is used to generate a train of light pulses of approximately 70 picoseconds duration. The energy in these laser pulses are of the order of 2 milli-joules. The train of pulses are then passed through a switchout so that a single pulse is selected. This single pulse then strikes a chromium doped GaAs semiconductor switch which then conducts. If a high voltage supply is connected to one end of the switch and a load is connected to the other end, then the load will observe an electrical pulse which is half the amplitude of the d.c. voltage and of the order of 100-200 picosecond duration. The width of the electrical pulse is determined by the width of the laser pulse and of the characteristics of the transmission line over which the GaAs is mounted.

I. INTRODUCTION

In many electromagnetic applications, it is necessary to require waveforms of high amplitudes and of picoseconds duration. The present state of the art commercial equipments is capable of delivering pulses of ± 4V in amplitudes and 100 picoseconds duration. These equipments are made by Picoseconds Pulse Labs. In this report, we present a way to produce pulses which are a kilovolt in amplitude and 100-200 picoseconds duration. The new technology which is capable of producing such high amplitude narrow pulses is derived from the laser research.

Historically, high power electrical pulses of picosecond duration were first produced by laser-induced photoconductivity in high resistivity semiconductors. Even though it was first demonstrated by Auston [1], several other researchers have produced similar results [2-4]. In this report we present the method as developed by earlier researchers for the development of this novel device capable of generating kilovolt pulses of picoseconds duration.

In Section 1, we present a brief description of the principles of operation of Nd:YAG laser, the concepts of mode locking and Q-switching. In Section 2, a description of the entire system is given. Typical waveforms are presented in Section 3.

2. PRINCIPLES OF LASER OPERATION

2. 1 Principles of Operation of Neodymium Lasers

Neodymium lasers are the most popular type of solid state laser. The laser medium is a crystal of $Y_3Al_5O_{12}$ (commonly called YAG, an acronym for yttrium aluminium garnet) in which some of the Y^{3+} ions are replaced by Nd^{3+} ions. Neodymium lasers can oscillate on several lines; the strongest and thus the most commonly used one being at λ = 1.06 μm.

A simplified energy level scheme for Nd:YAG is shown (p. 203, Yariv; p. 204, Orazio). The λ = 1.06 μm laser transition is the strongest of the $^4F_{3/2} \rightarrow {}^4I_{11/12}$ transitions. The two main pump bands occur at 0.73 and 0.8 μm, respectively. These bands are coupled by a fast non-radiative decay to the $^4F_{3/2}$ level, while the lower $^4I_{11/12}$ level is also coupled by a fast non-radiative decay to the $^4I_{9/2}$ ground level. Furthermore, the energy difference between the $^6I_{11/12}$ and $^4I_{9/2}$ levels is almost an order of magnitude larger than kT. Thus it follows that the Nd^{+3} laser works on the four-level scheme. Even though one of the drawbacks of the Nd laser is the lack of broad absorption bands to capture the photons emitted by the flashlamp, since it is a four-level laser system, it requires less pumping to achieve a population inversion (i.e. produce more electrons at the excited stage so that they can decay to the ground state remitting the characteristic radiation at frequency ν, where hν is the energy gap and h is the Planck's constant.)

Nd:YAG lasers can operate either cw or pulsed. For both cases, linear lamps in single ellipse, close coupling or multiple ellipse are commonly used. Medium pressure (500-1500 Torr) Xe lamps and high pressure (4-6 atm) Ar lamps are used for the pulsed and cw cases, respectively. Typical rod diameters range from 5 and 10 mm with a length between 5 and 20 cm. These types of lasers yield very high peak output power (~10-300 Terawatts) when pulsed or Q-switched.

2.2 Principles of Laser Oscillation

An optical passive confocal resonator is formed by two mirror surfaces forming a cavity of length L. Each resonator has infinite set of modes. The first few lower-order modes are the TEM_{00}, TEM_{01}, TEM_{02} and TEM_{13}. The fundamental mode TEM_{00} has a Gaussian radial (p. 125, Orazi) profile both along x and y directions. In this case the mode pattern corresponds to a circular luminous spot on the mirror. The next higher order mode TEM_{01} has a different pattern. In our case, we want the laser to operate on the TEM_{00} mode. This is achieved by inserting a diaphragm with a suitable aperture size on the axis of the resonator. As the radius of the aperture decreases, the difference in loss between the TEM_{00} mode the higher-order mode increases. So, by an appropriate choice of the aperture, we can obtain oscillation of the TEM_{00} mode alone. This mode-selecting scheme inevitably introduces some loss of the TEM_{00} mode itself.

Even when a laser is oscillating on a single transverse mode (i.e. TEM_{00}), it can still oscillate on several longitudinal modes (i.e. modes differing in their value of the longitudinal mode index). These modes are separated in frequency by $\Delta\nu_n = c/2L$. To isolate a single longitudinal mode, it is sometimes possible to use a very short cavity. However, in that case, L is small and so is the volume of the active material and this results in a low output power. Hence, we utilize the Fabry-Perot transmission etalon in the laser cavity to select the longitudinal modes. The Fabry-Perot etalon consists of two mirrors, one of which is partially transmitting, that form a cavity. This cavity is resonant when the round-trip phase shift of the light that is inside the two mirrors is an integral multiple of 2π radians. Then the resonant frequency is given by $\nu = q\frac{c}{2L}$ where q is an integer. So the output from a Fabry-Perot etalon is a number of TEM_{00} modes which differ in frequency ν.

2.3 Principles of Mode-locking

The technique of mode locking allows the generation of laser pulses in which the harmonically spaced TEM_{00} resonator modes have a coherent phase relationship leading to a repetitively pulsed output whose pulse width is determined by the laser bandwidth and whose repetition rate is determined by the intermode frequency spacing.

If we consider a laser resonator of optical length L with a periodic loss modulation located adjacent to one mirror. If the period of the loss modulation is exactly equal to the round-trip transit time of a photon in the resonator, then a small pulse which traverses the modulator during the low-loss state on one pass will, after amplification in the laser medium, traverse the modulator during the low-loss state on every succeeding pass. As a result, the amplitude of such a pulse can grow to a stable value. On the other hand, any pulse traversing the modulator during the high-loss state will be attenuated on each pass and thus will not grow in amplitude. The principle of loss modulation is discussed in 2.4.

The actual shape of the loss modulation is sinusoidal and thus the oscillation comprises a laser pulse travelling back and forth in the resonator and traversing the modulator twice each cycle at zero crossings (when the loss is minimum). The output consists of repetitive pulses spaced at the round-trip transit time, generated by partial transmission through the output reflector each time the pulse is reflected from this mirror.

The proper modulation frequency, f_o, is thus one-half the inverse of the round-trip transit time, T. Note that this is also one-half the spacing between axial modes of the resonator, Δf.

$$f_o = \frac{1}{2T} = \frac{\Delta f}{2} = \frac{c}{4L}$$

If the modulation frequency is not properly adjusted, the optical pulse circulating in the resonator rapidly shifts out of phase with the loss modulation and thus experiences attenuation; and hence, the need for close adjustment of the modulation frequency to one-half the resonator mode spacing.

The width of the output pulses, τ, is determined by the number of resonator modes, N, which are phase coherent (locked), or equivalently, the bandwidth of the oscillation, Δν,

$$\tau = \frac{2L}{CN} = \frac{1}{\Delta\nu}$$

Thus it is important to permit oscillation over the largest possible bandwidth to obtain the narrowest pulses. In the case of Nd:YAG, the maximum bandwidth, determined by the gain line-width, is 40 GHz, leading to the possibility of 25 picosecond pulsewidths. However, depending on system gain and etaloning, the effective bandwidth may be less resulting in somewhat longer pulsewidths.

2.4 Theory of Acousto-Optic Loss Modulation

The interaction between optical and acoustical waves can be employed to modulate the optical beam. The acoustical wave produces a periodic variation in the index ellipsoid via the photoelastic effect, resulting in scattering of an incident optical beam. If the angle between the normal to the acoustic beam and optical beam direction is adjusted to the Bragg angle θ_B, given by

$$\sin \theta_B = \frac{\lambda_o}{2\lambda_s}$$

where λ_o and λ_s are the optical and acoustical wavelengths, respectively, then the intensity of the scattered beam and thus the loss to the incident beam is maximized.

The elastic wave is generated within a fused quartz prism by an acoustic transducer driven by an RF signal. In order to eliminate acoustic resonances of the prism and thus permit a wise frequency range of operation, the transducer is carefully matched. It is important to point out that the acousto-optic interaction is polarization dependent.

2.5 Theory of Q-Switching

Q-switching of a laser oscillator refers to a process whereby the usual long pulse or cw oscillation of the laser is modulated to provide very short, high peak power pulses of radiation. Inherent in the operation is the concept of energy storage in the laser medium during the interpulse interval.

Q-switching is accomplished by temporarily reducing the Q (quality factor) of the laser resonator by the addition of loss. Because of the low Q, the laser is prohibited from oscillating. However, pumping continues allowing energy to be stored in the upper laser energy level for approximately the lifetime of that level (250 μsec in the case of Nd:YAG). When the Q is increased again, the loop gain is substantially greater than unity and the field in the resonator grows rapidly utilizing the energy stored in the laser medium. The result is the generation of a short pulse with peak power substantially greater than the average power.

In our case, Q-switching is effected by an acousto-optic device. The theory of acousto-optic modulation is described in Section 2.4.

In the principle of Q-switching, an RF signal is applied to an acoustic transducer, generating an elastic wave in the fused quartz prism, a fraction of the incident optical beam is scattered, resulting in a loss within the laser resonator. A modulation signal is applied to the RF driver to periodically turn off the RF, thus removing the loss and allowing a Q-switched pulse to develop.

The sequence of operations can be described as follows: A modulation signal is applied to the RF to provide pulses of RF. This signal drives the acoustic transducer resulting in an elastic wave propagating in the quartz block with the same temporal characteristics. Because of the loss when the elastic wave is present, the laser cannot oscillate the the gain increases. When the RF is turned off, the laser gain is well above that required for oscillation and a pulse builds up rapidly. The gain decreases approximately to zero. The RF is then switched back on, allowing the process to repeat itself.

It is well known that the fused quartz photoelastic coefficient p_{12} is larger than p_{11}, resulting in a 5-times greater Q-switch deflection efficiency for light polarized at 90° to the direction of ultrasonic propagation. While an intracavity Brewster plate can function effectively to polarize the TEM_{00} mode in this high-loss direction, a Brewster plate introduces unacceptable laser power loss and mode distortion for all higher order modes--a result of the thermal stress birefringence induced in the Nd:YAG rod. Without a polarizing plate in the cavity, the laser can and always will choose to oscillate in the polarization that experiences minimum loss, thus avoiding the high-loss polarization when the Q-switch is turned on.

This has been accomplished by inserting a 1.06 μ quarter-wave plate between the Q-switch and the rear laser mirror oriented with its fast and slow axes at ± 45°, respectively, to the ultrasonic propagation direction. The polarization of the light incident on the Q-switch can be decomposed into high- and low-loss components. After passage through the Q-switch and $\lambda/4$ plate, reflection off the mirror and transmission back through the $\lambda/4$ plate, these high- and low-loss polarizations have effectively passed through a $\lambda/2$ plate at 45° to the fast and slow axes. This produces a 90° polarization rotation so that on the return trip through the Q-switch, the high- and low-loss polarizations have been reversed, allowing the Q-switch to operate with high efficiency on the larger fraction of light remaining in what had been the low-loss polarization. If we denote the single-pass fractional high and low losses by 5α and α, respectively, then the round-trip loss for all polarizations is 6α, an increase of three-fold over 2α, the loss which would result with the laser oscillating in the low-loss polarization.

Since a polarization rotation would adversely affect laser oscillation when the Q-switch is off, the effect of the $\lambda/4$ plate at position A must be nullified. By inserting another $\lambda/4$ plate at position B between the laser rod and Q-switch, oriented with fast and slow axes along the slow and fast axes of the A plate, a "no-wave" plate results and laser oscillation is unperturbed.

3. EXPERIMENTAL SET UP

The YAG laser head is situated between two mirrors. One of the mirrors is 100% reflecting and the other is 70% reflecting. The mirrors are situated approximately 55.5 inches apart. On one side of the YAG head is the Q-switcher and on the other side is the polarizer and pinhold and the mode locker. All the optical components have been set up on Invar bar using magnetic bases. For typical operation of the laser, 50 MHz RF power is necessary to time the various devices of the laser.

The heart of the RF power distribution is a 49.97 MHz stable oscillator. This stable oscillator has 3 outputs. One of the outputs is amplified through the amplifier and then through a matching Quantrix load box is fed to the mode locker. The mode locker needs about 4 watts of RF power to produce loss modulation through a periodic variation in the index of ellipsoid of a fused quartz prism. The principles of modulation have been described in Section 2.

Another output of the 50 MHz source is passed through a programmable delay generator to produce a delayed pulse. The width of the pulse is around 7 μsec, and the pulse remains off for about 1 millisecond. When this pulse is attenuated and applied to the Q-switch driver, the driver then shuts off the RF signal going to the laser head via an amplifier. The picosecond Q-Switch driver also gives a sync output. This sync output is fed to the switch out to switch a single pulse out of the pulse train. The switch out selects generally the largest pulse located at the center of the Q-switched pulse.

REFERENCES

1. Auston, D. H. (1975), Appl. Phys. Lett., 26, pp. 101-102

2, Antonetti, et al (1977), Opt. Comm., 23, p. 435

3. Lee, C. H. (1977), Appl. Phys. Lett., 30, p. 84.

4. Margulis, W. and Libbet, W. (1981), Ops. Commun. 37, p. 224

FUTURE WORK

Work is in progress to generate jitter-free stable electrical pulses of kilovolt in amplitude and rise times less than 100 picoseconds.

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GOVERNMENT PROPERTY RECEIVED UNDER CONTRACT NO. N00014-84-C-0179

GP-01	Scientech M/N 36-0401 4" surface absorbing Disc Calorimeter, serial number 544. $895.00
GP-02	Scientech M/N 36-4002 Power & Energy Indicator for all 4" and 8" Disc Calorimeters. S/N 2095. $695.00
GP-03 GP-04	Karl Lambrecht Double Escape Q-Switch Polarizer M/N MGLQD-8 with multilayer VEE wating for 1-064 μm (2 items). $1,145.00 each = $2,290 total
GP-05 GP-06	Melles Griot High Energy Laser Mirror 45° incidence (fused silica substrate, 25 mm diam.) with wating for YAG laser, 1-064 μm, P/N 08 MLQ 003/426, 2 pieces. $135.00 each
GP-07A GP-07B GP-07C GP-07D	Newport Corporation M/N MM2-1A mirror & beamsplitter mount. $53.00 per piece = $212.00 total
GP-08A GP-08B GP-08C GP-08D	Newport Corporation M/N MM2 mirror & beamsplitter mount. $42.00 each = $168.00 total
GP-09A GP-09B GP-09C GP-09D	Newport Corporation M/N VLH-3 variable lens holder. $64.00 each = $256.00 total
GP-10A GP-10B GP-10C GP-10D GP-10E GP-10F	Newport Corporation M/N VPH-3 post holder 3". $20.00 each = $120.00 total
GP-11A GP-11B GP-11C GP-11D GP-11E GP-11F	Newport Corporation M/N VPH-4 post holder 4". $22.00 each = $122.00 total
GP-12A GP-12B GP-12C GP-12D GP-12E GP-12F	Newport Corporation M/N SP-3 support post 3". $11.00 each = $66.00 total

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GP-13A	Newport Corporation M/N SP-4 support post 4". $12.00 each =
GP-13B	$72.00 total
GP-13C	
GP-13D	
GP-13E	
GP-13F	
GP-14A	Newport Corporation M/N 10BR08 right angle prism 1".
GP-14B	$98.00 each = $490.00 total
GP-14C	
GP-14D	
GP-14E	
GP-15	Newport Corporation M/N 05BC16PC.9 polarizing beamsplitter cube. $191.00
GP-16	Newport Corporation M/N 460-XYZ micropositioning stage. $547.00
GP-17A	Newport Corporation M/N 816 photosensor (with 817 OD-3 filter),
GP-17B	2 pieces. $255.00 each = $510.00 total
GP-18	Melles Griot quartz retardation plate, first order, λ14 retardation, 10 mm diam., P/N 02 WRQ 003 @ 532 nm. (the GP-18 identifying no. was written on the plastic box, the plate is too small to write on.)
GP-19	Melles Griot, high energy laser beamsplitter (fused silica substrate, 25 mm diam.), with coating for YAG laser - 1.064μm, P/N 08 BSQ 003/626.
GP-20	Quantronix 116 / U of R laser system (see attached list). (This GP-20 has not been written on any of the parts of this system yet.)
GP-21A	Newport Corporation optical bench
GP-21B	(M/N KST 48 NH) & support system
GP-21C	(M/N NR-28)
GP-21D	(Bench, GP-21A; 3 legs, GP-21B, C, & D)
GP-22A	Glendale safety goggles for YAG laser
GP-22B	(M/N LGS-NDGA)
GP-22C	(These numbers are "etched" into each pair
GP-22D	of goggles)
GP-23	Hewlett Packard coaxial high power attenuator (M/N 8498A), option 030-30dB, with option 890 calibration data (identifying number was "etched" into item)
GP-24A	Narda coaxial attenuations with SMA connectors
GP-24B	
GP-24C	
GP-24D	Miniature fixed attenuators
GP-24E	M/N 4779-6dB; GP-24E, GP-24F
GP-24F	M/N 4779-20dB; GP-24G, GP-24H
GP-24G	Micro miniature medium power attenuators
GP-24H	M/N 4776-6dB; GP-24B, GP-24C M/N 4776-20dB; GP-24A, GP-24D

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GP-25	Tektronix 7B15 delaying time base
GP-26	Quantronix mode locker, M/N 352
GP-27	Tektronix 7A29 wideband vertical amp

July 18, 1985
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