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Nd:YAG Laser-Pumped Raman-Shifted Methane Laser as an Eye-safe Laser Rangefinder

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ABSTRACT

In this article, a feasibility study of the design and performance of a laser rangefinder emitting at an eye-safe wavelength of 1.54 micron, is reported. It is a Raman-shifted laser where an *Nd:YAG* laser emitting at a wavelength of 1.06 micron is used as pumping source that is incident on a Raman cell containing methane gas at a very high pressure, resulting in the Stokes radiation at 1.54 micron. Conversion efficiencies as high as 40 per cent have been reported so far by some workers and continued efforts are on to increase this value close to the theoretical limits. A comparative performance of this laser, proposed as a futuristic military rangefinder, is studied vis-a-vis commonly used *Nd:YAG* lasers as well as more recent rangefinders using CO_2 lasers. A comparison of this laser emitting at 1.54 micron, with *Er*: glass laser emitting at the same wavelength, is also discussed.

1. INTRODUCTION

Leaving the weapon lasers aside, the maximum use of lasers in the military is in rangefinding, target-designation, beam-riding and battlefield simulation. Advanced military technology using sophisticated weapon systems can no longer do without the laser devices for precise and ultra-quick rangefinding. The rangefinding schemes include (a) direct detection of received pulse, (b) radio frequency modulation of the continuous wave radiation, and (c) a coherent laser radar using heterodyne detection via a local oscillator (or homodyning); out of which we shall consider the first scheme only. In this paper, the range is measured by transmitting a pulse and measuring the time-of-flight of the return echo. This process is usually performed by sampling a portion of the transmitted beam with a photodetector of suitable spectral response.

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The sampled pulse initiates a counter circuit of relatively high frequency (generally between 15 and 30 MHz) that is stopped by the threshold crossing of the return pulse which is reflected from the sought target. The counter then presents the range of the target in a format suitable for the operator interface.

2. *Nd:YAG* LASER RANGEFINDERS

The rangefinding in the military is normally performed by a Q-switched *Nd:YAG* laser which emits pulses at 1.06 micron wavelength. But this wavelength is not safe for the human eye because of the high transmittance of the occular media and the appreciable retinal absorption[1]. Moreover, at 1.06 micron, the focussing power of the eye lens is quite good; meaning that the laser radiation is well focussed onto the retina where the produced hotspot can cause permanent eye damage. An observer has to keep a specified safety distance, NOHD (nominal occular hazard distance)*, when a laser is used which is hazardous to view. If, for example, when a typical *Nd:YAG* laser rangefinder is used in a tank-control system, the NOHD for intrabeam viewing must be approximately one kilometer; or even several kilomerers if the observer uses magnifying optics (binoculars)[2].

The US Army has recently purchased 100,000 pairs of laser protective spectacles, each costing US $ 30, to protect their troops from the radiation of *Nd:YAG* laser rangefinders and target designators[3]. But, for tactical reasons, many other countries have dropped this idea of equipping all the soldiers on the battlefield with laser goggles[2].

For the US Army's AN/GVS-5 *Nd:YAG* handheld laser rangefinder, two neutral filters are provided to reduce the output by factors of 3 and 6, respectively for the purpose of training of troops[4]. With this attenuation, the nominal 15 mJ output of the laser is reduced. This allows someone to look back into the beam from a distance of 1000 and 2200 meters, respectively, and be within an eye-safe output level. However, if one uses any optical viewing instrument with magnification, the safe viewing distance is extended accordingly. But, with this reduction in the output energy of the laser, the maximum range at which the unit will work, is also reduced. Hence the normal range of AN/GVS-5 is reduced from 10 km to about 2 km or less when the safety filters are installed[4]. Table 1 gives the quantitative values of ranges with this laser with and without neutral density filters.

Table 1. AN/GVS-5 *Nd:YAG* laser rangefinder : performance with attenuating filters[4]

Rangefinder using	Maximum range (m)	Minimum unaided distance (m)	Minimum safe-viewing distance with 7 × 50 binoculars (m)
No filter	10,000	1100	8000
Red filter (19 dB)	5,000	120	840
Yellow filter (29 dB)	1,900	20	140

* The distance from the laser system at which the level of optical radiation falls below a level of being dangerous (particularly to the human eye) is termed as NOHD. When the person at risk is using optically aided viewing devices, say binoculars, the NOHD of the laser system significantly increases[1].

3. NEED FOR EYE-SAFE LASER RANGEFINDERS

The military forces continue to be confronted with the problem that during laser operation, without using attenuation filters, the observer is required to keep specified NOHD for both aided and unaided viewing. To overcome the difficulties connected with these restricted conditions, a requirement has been established by many countries that all laser rangefinders to be developed in the future will have to be eye-safe, that is, they have to be lasers with NOHD equal to zero[2].

Eye-safe lasers are important in the military rangefinders mainly because they can be used in the training of troops, in which eye safety is a key requirement[5]. Eye safety also becomes important when the rangefinder is to be used where unprotected individuals can become exposed to the laser radiation[6]. In a battlefield situation, one might assume that the user of laser rangefinder will not really be concerned if the eyes, which the laser damages, are those of the enemy. That is true, but there are cases, when the laser presents a problem. One is in training in any sort of force-on-force simulation, when the force standing opposite to you are really your own troops. Another situation is where a forward observer wants to use his rangefinder toward his own lines to determine how far he is from a particular point[4]. Rangefinders using *Nd:YAG* laser cannot be used in a populated area[7] or areas where civilian population is living (to combat terrorism, for example), for the same eye safety considerations. Besides these uses, eye-safe lasers also find applications in civil uses like surveying.

These were the grounds for starting the development of the second generation of laser rangefinders with eye-safe characteristics. The Armed Forces of Italy[5,6], West Germany[2], USA[8] and many other countries are already engaged in incorporating these eye-safe lasers as the next generation rangefinders into their Army and Air Force.

4. CARBON DIOXIDE LASER RANGEFINDERS

Carbon dioxide laser wavelength (10.6 micron) is far beyond the range of transmission of the human eye to the retina. Hence a high level of laser light can be tolerated before the damage of eyes occurs. This is one of the reasons that currently many countries are replacing or planning to replace their existing *Nd:YAG* laser rangefinders by the CO_2 laser rangefinders.

But the CO_2 laser rangefinders, requiring the peak powers for the maximum range of 10 km or so, are also dangerous to the eyes because they cause permanent damage on the surface of the cornea. The human eye, in fact, is not transparent to the CO_2 laser radiation and so the optical power is absorbed in a very thin layer (epithelium), thus causing local surface burns on the cornea[5]. Another difficulty in using a CO_2 laser rangefinder is that it requires a sensitive receiver; at 10.6 micron, the detector must be cryogenically cooled to develop adequate sensitivity[4]. In addition, the refractive optics for this wavelength must be germaniun, zinc selenide, zinc sulphide or other infrared transmitting materials. This greatly increases the system costs. Another limiting factor is that, in order to get long range performance, the output level of the laser may have to be above the eye-safe limits, making the unit no longer eye-safe.

5. ADVANTAGES OF EYE-SAFE LASERS EMITTING AT 1.54 MICRON WAVELENGTH

Eye-safe radiations are those whose wavelengths are not well transmitted within the occular media and are poorly absorbed by the retina. Furthermore, the focussing power of the eye lens should be very low. Wavelengths between 1.4 and 2 micron satisfy these requirements. One such wavelength of interest, which is the one under discussion in this article, is 1.54 micron. This wavelength has very poor transmission through the human eye compared to that of 1.06 micron wavelength. Similarly, the focussing power of the eye lens for 1.54 micron wavelength onto the retina is extremely poor compared to that of 1.06 micron wavelength. Therefore, this wavelength is far safer to the human eye compared to 1.06 micron. Now, comparing the performance of 1.54 micron wavelength with the one emitted by a CO_2 laser (10.6 micron), we note that whereas 10.6 micron radiation is strongly absorbed by cornea causing its damage, the 1.54 micron radiation, instead of getting totally absorbed by the cornea, gets strongly absorbed in the aqueous of the human eye[9] (a much larger volume), thereby causing less damage to the eye. To understand the potentiality of a laser emitting at this wavelength for eye-safety considerations, we define a term known as, maximum permissible exposure (MPE), a limit above which the radiation from a light source (laser or other) will be dangerous to the person getting exposed to it. Values of MPE for a given person are different for the eye and the skin. Similarly, for the same person, the MPE value for the eye is lower when that person views the beam directly, letting the beam fall into his/her eyes (intra-beam viewing) than the case when the radiation is falling into the eye after getting reflected from a diffuse surface. The value of MPE for the same person's eyes or skin will depend, among other parameters, on the wavelength of the laser.

To illustrate the significance of a laser emitting at 1.54 wavelength for eye safety, Table 2 compares the values of MPE of this wavelength with the wavelengths (1.06 and 10.6 microns) emitted by other commonly known lasers (*Nd:YAG* and CO_2 lasers, respectively) used in military rangefinders. The MPE values are for the case of intrabeam viewing. From Table 2, we clearly see that the MPE at 1.54 micron, far exceeds those at 1.06 and 10.6 micron wavelengths, which is the major reason for choosing a 1.54 micron laser as an eye-safe rangefinder.

The 1.54 micron wavelength is not the only one possible, but is perhaps the most convenient from the rangefinding point of view alongwith eye-safety requirements. This wavelength can be generated easily and it has got good transmittance through

Table 2. Maximum permissible exposure limits at different wavelengths of radiation (assuming pulse repetition rate to be 1 Hz or less) for intrabeam viewing[1,5]

Wavelength (micron)	Exposure duration (s)	MPE (J/cm^2)
1.06	10^{-9} to 10^{-7}	5×10^{-6}
10.6	10^{-9} to 10^{-7}	10^{-2}
1.54	10^{-9} to 10^{-7}	

the atmosphere. For example, for 10 km clear visibility, the typical values of the atmospheric extinction coefficients for 1.06, 10.6 and 1.54 micron wavelength lasers are 0.27×10^{-5} cm^{-1}, 0.19×10^{-5} cm^{-1} and 0.22×10^{-5} cm^{-1}, respectively[2]. This value for 1.54 micron wavelength is a little less than that for 1.06 micron and a little more than that for 10.6 micron wavelength, which are known to have very good transmission through the atmosphere. This wavelength (1.54 micron) also exhibits reduced scattering loss in the atmosphere over the smaller wavelength (1.06 micron) of *Nd:YAG* laser. The 1.54 micron wavelength also offers very good sensitivity for both germanium (*Ge*) and Indium-Gallium-Arsenide (*InGaAs*) detectors[10]. It may be noted that tne detection range varies inversely with the fourth root of the noise equivalent power (NEP) of the detectors. Detectors with low NEP are commercially available these days for 1.54 micron wavelength. Table 3 lists some of commonly used detectors and their typical performance characteristics. Besides these, quaternary Indium-Gallium-Arsenide-Phosphide (*InGaAsP*) PIN field effect transistor detectors have also been used with excellent results[7]. The typical sensitivity of commercially available[9] photovoltaic *InGaAs* detectors at 1.54 micron wavelength is 5×10^{-19} J/cm^2, which is reasonably good for a detection of range of about 10 km. Besides the use of such lasers (at 1.54 micron) toward eye safety, which is being discussed in this article, there are other important applications of this wavelength in the field of optical fibre communication, because at 1.54 micron wavelength the attenuation of radiation through optical fibres is extremely low.

Table 3. Performance characteristics of some of common quantum detectors at 1.54 micron wavelength[11]

Detector type	Spectral response (micron)	Responsivity (A/W)	NEP W/√Hz	Damage threshold (W/cm^2)	Size (mm)	Operating temperature (°C)	Frequency response (3dB points)
Ge, avalanche	0.8–1.8	0.2	1×10^{-10}		0.1	–	Upto 2 GHz
InGaAs, PIN	1–1.7	0.6–0.9	1×10^{-14}	100	0.03–3	–40 to +80	DC–1.2 GHz
InGaAs, avalanche	0.9–1.7	0.8	2×10^{-13}		1–3	–40 to +80	DC–1 GHz

6. LASERS AT 1.54 MICRON WAVELENGTH AND THEIR COMPARATIVE PERFORMANCE

There are two lasers known to emit at 1.54 micron wavelength – erbium : glass (*Er*:glass) laser and *Nd:YAG*–pumped Raman-shifted methane laser. The technology of *Er*:glass laser is similar to that of *Nd*:glass or *Nd:YAG* laser. It is pumped by a linear flash-lamp. In the second type of laser emitting at 1.54 micron, and the central topic in the present article, a Q-switched *Nd:YAG* laser beam emitting at 1.06 micron wavelength falls on a Raman cell containing methane gas at a very high pressure (40-70 atmospheres). A methane molecule has got one of the vibrational energy levels at 2915 cm^{1}. The input radiation of 1.06 micron wavelength interacts with the third-order nonlinear susceptibility of methane gas molecules through the process of stimulated Raman scattering (SRS) to upshift this wavelength to 1.54 micron, emitted as the output Stokes radiation, according to the energy level diagram

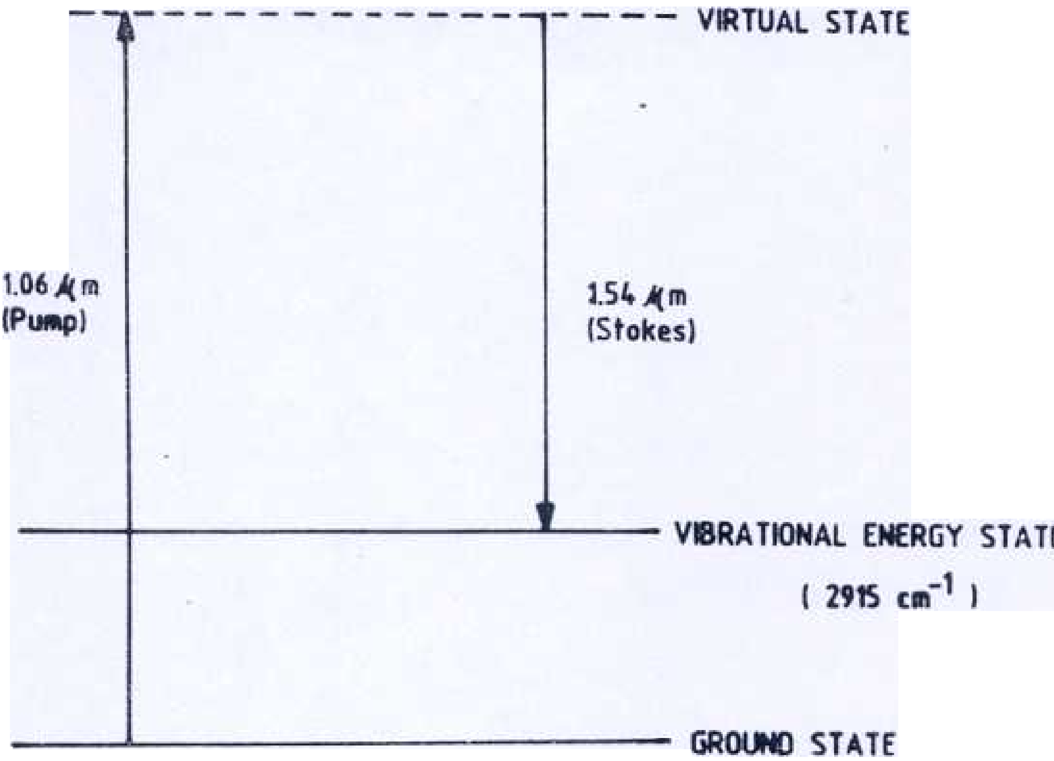

Figure 1. Energy-level diagram of a methane molecule representing the process of stimulated Raman scattering in which an input laser beam at 1.06 micron is upshifted to output laser beam at 1.54 micron.

represented in Fig.1. The characteristics of the output pulses at 1.54 micron have been found to be identical to those of the pulses at 1.06 micron[5], except that the pulse duration at 1.54 micron is slightly less than that at 1.06 micron. For example, in a typical system, the pulsewidth of 22 ns at 1.06 micron had been seen to shorten to 17 ns at 1.54 micron wavelength[8]. This is because for the Raman conversion, the output pulse does not begin until the threshold is reached, after which time the pump pulse is slightly depleted. Theoretical quantum conversion efficiency (from 1.06 micron to 1.54 micron) is about 69 per cent. Quantum conversion efficiencies as high as 40 per cent have so far been made realisable[7], and continued efforts are on to improve the design of methane Raman cell to achieve higher conversion efficiencies.

6.1 Comparative Performance of the Lasers Emitting at 1.54 Micron

Out of these two lasers emitting at 1.54 micron, *Er*:glass laser has got certain drawbacks. Firstly, it is a three-level laser and thus needs strong optical pumping. Typically 50 J of electrical energy is necessary to obtain 25 mJ of Q-switched optical output, giving the efficiency equal to 0.05 per cent, which is very low[5]. Secondly, the Q-switched operation in *Er*:glass laser is quite difficult since (a) the 1.54 micron-saturable absorbers for passive dye Q-switching are rarely available, (b) mechanical switches (rotating prisms, for example) are still to be used, and (c) a Pockels cell for electro-optical Q-switching at 1.54 micron is quite cumbersome and expensive. Unlike *Er*:glass laser, the Q-switching is very easy and well-matured in

Nd:YAG laser used as a pump source in the Raman laser. Even after the decrease in energy of the 1.54 micron beam from the pump beam, the overall efficiency of the Raman-shifted laser is found to be much higher than that of *Er*:glass laser. For these reasons, we have preferred to opt for the Raman-shifted methane laser over *Er* : glass laser to be used as an eye-safe laser rangefinder. Such a laser rangefinder has been designed and fabricated, for example, by Hughes Aircraft Company, and has been accepted for incorporation in the US Army[8]. In 1983, the US Government decided to develop and procure 40,000 such eye-safe laser rangefinders for its Army[7].

Besides the above listed advantages, these eye-safe lasers can also be used as air-to-ground simulators to enable training with several laser target designator systems. Yet another application of such a laser is that it has been used in a transreceiver system to measure the height of clouds[4]; and such an application is currently under development by the Air Forces of various countries to be used at military airports.

7. STIMULATED RAMAN SCATTERING AND OTHER NON-LINEAR EFFECTS IN METHANE CELL

When an intense beam of laser light (*Nd:YAG* laser in the present case) traverses a suitable medium (methane gas, here), the weak spontaneous scattered light is amplified by several orders of magnitude due to the high incoming photon flux. This process is known as the stimulated Raman scattering. From the physical point of view, the SRS is a non-linear process in which the energy of the incident photon is shared between a phonon (the first vibrational excited state of methane molecule, in the present case) and a lower energy photon (longer wavelength). This stimulated process occurs only if the pump intensity is higher than a certain threshold value. The intensities necessary for ready observation of stimulated scattering processes are approximately[12]

$$10^6 < I_L < 10^9 \ (\mathrm{W/cm^2})$$

For very high intensities ($I_L > 10^{12}$ W/cm^2), all substances become rapidly ionized forming hot and dense plasmas.

We observe two first-order Raman lines for each molecular vibration. The Stokes and anti-Stokes radiations are connected with transitions from the ground to the first excited state (at 2915 cm^{-1} in methane melecule, for example) and vice versa. Since the excited states are populated only slightly at room temperatures, the anti-Stokes lines are weak compared to the Stokes transitions. Frequently, weaker, higher-order Stokes lines are also observed which correspond to transitions to higher excited states. The generation of stimulated Raman light is accompanied by intense molecular or lattice vibrations, which have a high degree of temporal and spatial coherence. These molecular vibrations modulate the incoming light beam generating corresponding side bands. In this way, higher order Stokes and anti-Stokes lines are generated, all of which with the same frequency separation. Raman Stokes radiation occurs predominantly in the forward and backward directions. The anti-Stokes (and part of the Stokes) emission is observed in cones with angles of several degrees. Spectral line narrowing is expected for stimulated emission since the gain is the largest near the centre of the spontaneous line. In the SRS, the steady-state SRS takes place mainly in the forward direction (relevant in the present case), whereas if the pulse duration of the pump pulse is too short (<< 1 ns), the transient SRS takes place mainly in the backward direction (not applicable in the present case, because the pulse width of Q-switched *Nd:YAG* laser will be a few nanoseconds).

In addition to these scattering processes, several others can also take place simultaneously depending upon the intensity, pulse duration and pulse repetition frequency of the pump pulse. One such non-linear scattering process is known as the stimulated Brillouin scattering (SBS). Brillouin light originates from the scattering of incident light by the propagating acoustic phonons, where the creation and annihilation of one phonon gives rise to the Stokes and anti-Stokes Brillouin lines, respectively[12]. The value of wavelength shift in SBS is very very small compared to that in SRS. In SBS, one observes two lines very close to the incident frequency. SBS process predominates if the pulse duration of the pumping laser is large compared to 1 nanosecond, (as is the case with our Q-switched *Nd: YAG* laser) and its effect will be the largest in the backward direction and zero in the forward direction[12]

These non-linear processes such as SBS, anti-Stokes SRS and some others are responsible for the reduction of conversion efficiency and gain of steady states SRS Stokes radiation (which is sought in the present case) and care must be taken to account for these effects and, as far as possible, try to minimise these.

The amplification of the spontaneous scattered light in SRS depends exponentially on the intensity I_p of pump laser, the interaction length L in the Raman cell, and the spontaneous scattering cross-section, $d\sigma/d\Omega$ among other parameters[5]. The first-order Stokes intensity, I_s (L), at a distance L of the Raman cell, is given by[5]

$$I_s(L) = I_s(0) \exp(g I_p L - aL) \qquad)$$

Here $I_s(0)$ is the spontaneous scattered light; g is the differential Raman gain coefficient and a is the loss (absorption) coefficient. The threshold intensity of the pump laser is equal to a/g. In Eqn. (1), g is proportional to the spontaneous Raman cross section $d\sigma/d\Omega$, inversely proportional to the Raman linewidth $\delta\nu_R$, and proportional to the number density of Raman medium[7]. One of the methods to increase the value of g is, therefore, to increase the number density of the Raman medium by increasing the pressure (of methane gas, for example) in the Raman cell. Some typical values of g observed by various workers are 1.4 cm/Gw at 10 atmospheric pressure of methane gas with Q-switched *Nd:YAG* laser as a pump source[6], 0.47 cm/Gw at 50 atmospheric pressure of methane gas in a shorter (4 cm long) Raman cell with a few nanoseconds pulsed *Nd : YAG* laser as a pump source[7], and 0.33 cm/Gw at 30 atmospheric pressure of methane gas when the pump source was a mode-locked *Nd:YAG* oscillator-amplifier laser[13]

8. DESIGN CONSIDERATIONS OF RAMAN-SHIFTED METHANE LASER

The schematic diagram of *Nd:YAG* laser-pumped Raman-shifted methane laser rangefinder is drawn in Fig. 2. The key to the figure explains about the components of this system. Before proceeding further, it may be mentioned that Fig. 2 represents only one of the possible designs proposed to be undertaken by us. There are likely to be many changes in this, depending upon the availability of components and ease and optimization of the design and fabrication of the remaining components. For example, in Fig. 2, only a raw beam at 1.06 micron is shown to be incident on the

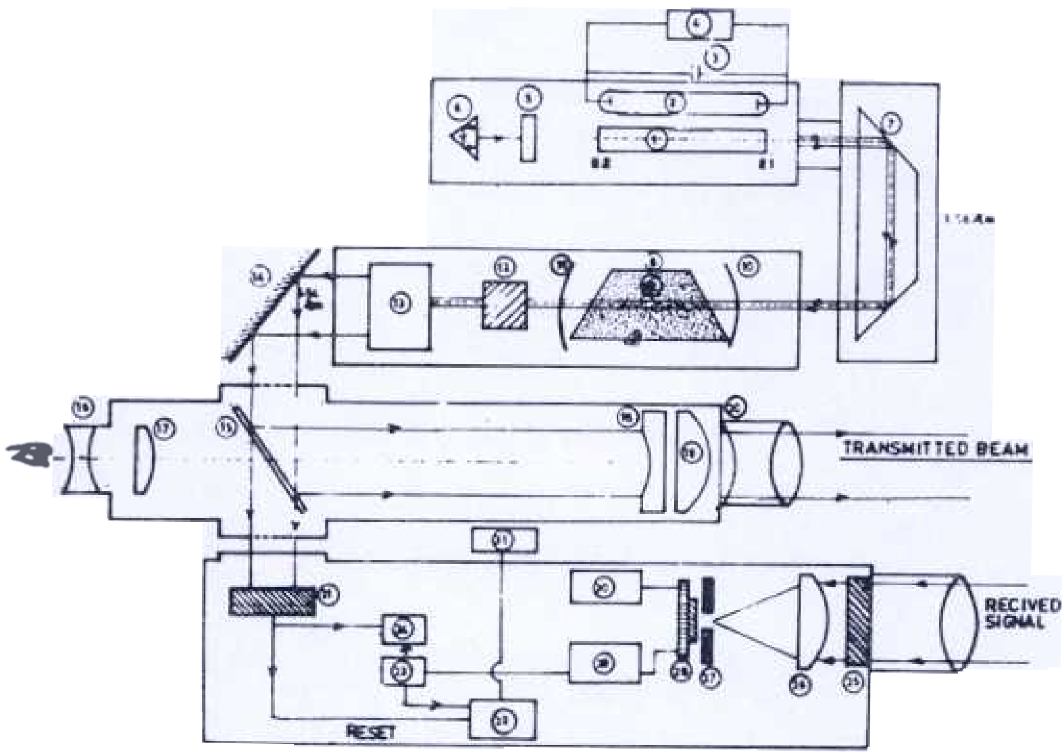

Figure 2. Schematic diagram of the eye-safe laser rangefinder

Key to the figure : (1) *Nd : YAG* laser rod, with end E2 AR-coated and the end El with 50% reflectivity, (2) linear flash lamp filled with xenon gas, (3) energy storage capacitor, (4) power supply for flash lamp, along with pulse-forming network and triggering circuit, (5) dye Q-switch for passive Q-switching of 1.06 μ m radiation, (6) Porro prism, (7) rhomboid prism (folding prism), (8) Raman cell with Brewster windows, (9) methane gas at a pressure between 50 and 70 atmospheres, (10) concave mirror with 90% transmissicn for 1.6 μ m radiation and about 100% reflectivity for 1.54 μ m wavelength, (11) concave mirror with about 100% reflectivity for 1.06 μ m wavelength and about 50% reflectivity for 1.54 μ m wavelength, (12), (25) interference filters allowing only 1.54 μ m radiation to pass through and blocking all other wavelengths, (13) beam expander (7×) for 1.54 μ m radiation, (14) plane mirror having 100% reflectivity for 1.54 μ m at 45°, (15) beam divider having 99% reflectivity and 1% transmission for 1.54 μ m at angle of 45°, (16), (17) Eye-lens group, (18), (19), (20) camera objective, (21), (28) photodectors sensitive at 1.54 μ m (*InGaAs*, PIN), (22) counter, (23) AND gate, (24) clock, (26) focussing lens, (27) field stop, (29) pre-amplifier and amplifier stages for the detector (28), (30) bias for the detector, (28), (31) range display

Raman cell. We may experiment with various types of focussing geometry and come to an optimum conclusion at that stage only.

The cylindrical *Nd:YAG* rod has got one end AR-coated and another having about 50 per cent reflectivity. The rod is placed in a diffuse reflector close-coupled cavity alongwith an equally long linear flash lamp filled with xenon gas. Energy-storage capacitor, power supply for the flash lamp, pulse forming network (PFN) and triggering circuit are suitably connected to the two electrodes of the flash lamp. The totally reflecting mirror's role is being played by a Porro prism device[14]. It is known that it is extremely difficult to maintain the alignment of flat-mirror resonators in military rangefinders. For example, in military systems, recoil-induced vibrations may reach accelerations in excess of 100 g's. In order to operate under such severe conditions, porro prism end reflectors are used instead of mirrors. The result is a resonators that is less sensitive to misalignment than the one that uses conventional flat (or long radius), dielectric-coated end reflectors.

The *Nd:YAG* laser is passively Q-switched with the help of a dye solution (saturable absorber) which is a thin layer impregnated in a thin plastic sheet. Dye Q-switching has the advantage over the electro-optical Q-switching in the sense that it does not require an expensive and bulky electrical system for this purpose. The 1.06 micron laser radiation comes out of the partially reflecting end of the *Nd:YAG* rod. This beam is folded by a rhomboid prism. Before we proceed, we may mention one well-known advantage of prisms over mirrors. For the beams to get totally internally reflected by prisms, no reflective coating is required on their surfaces (unlike mirrors); therefore the prisms are protected against corrosion.

The 1.06 micron radiation is incident as such (or focussed onto the centre) in a Raman cell containing high-pressure methane gas. The pressure of the gas in the cell is between 50 and 70 atmospheres, its value can be optimized while studying the system experimentally. It has been found that at pressures of 80 atmospheres or above, the Raman gain does not increase any longer, contrary to what has been discussed earlier. It is because at such high pressures the vibrational line of methane molecules broadens (pressure broadening), which counterbalances the gain (due to increased pressure and hence increased number density of methane molecules)[5]. It has been found[8] that in methane gas, the stimulated Raman laser operation produces severely distorted output beams (when a simple high-pressure gas cell is used) at pulse repetition rates exceeding 5 Hz. This may be due to thermal blooming of light at these high repetition rates. The Brewster windows of the Raman cell are hard sealed using glass to metal sealing. For eye-safety maintenance mode, the system should be so designed such that the Raman cell and the beam expander are an integral assembly that cannot be separated[7]. The next generation Raman cells will have changes in their design that incorporate Raman oscillators and multiple pass (more than two) amplifiers[6]. Conversion efficiencies of about 50 per cent are expected to be achieved by the 1990s in a fieldable, fully qualified military unit. The methane gas inside the Raman cell should be of research-grade purity ($\geq$ 99.5 per cent pure), 0.20 micron or better pore filter[13]

At the output of the Raman cell, radiations of many wavelengths including the unused pump beam of 1.06 micron wavelength, first-order Stokes radiation at 1.54

micron, higher-order Stokes frequencies including the one at 2.8 micron, anti-Stokes frequencies at 0.83, 0.66, 0.55 and 0.48 microns, will be coming out. Out of these wavelengths, the maximum energies will be contained by 1.06 and 1.54 micron wavelengths, whereas the other radiations are very weak. In order to filter out only 1.54 micron wavelength and suppress the others, an interference filter is used. It is followed by a beam expander of magnification 5 to 10 X. The 1.54 micron radiation is then allowed to fall on a beam divider via a flat mirror. The beam divider reflects about 99 per cent of this energy as the transmitted beam of this rangefinder, and transmits about 1 per cent of this energy which falls on a photodetector (sensitive at 1.54 micron). This 1 per cent energy of the 1.54 micron pulse starts a clock. The clock is stopped by a return echo from the target and thus the range is determined by time-of-flight method. The receiver optics and electronics, described in Fig. 2, are similar to the one used in *Nd:YAG* laser rangefinders. The range is either displayed by light emitting diodes at the focus of the eye or suitably interfaced depending upon the particular requirement.

9. CONCLUSION

We have clearly seen the vital need of the laser rangefinders which are eye-safe and discussed the advantages of one such laser over others. This Raman-shifted laser rangefinder has then been analysed theoretically. The design of such a laser is proposed and it is planned to be fabricated and tested by us in future.

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