LA-UR- 98-460

Title: GENERATION OF 1.54 μm RADIATION WITH APPLICATION TO AN EYE-SAFE LASER LIDAR

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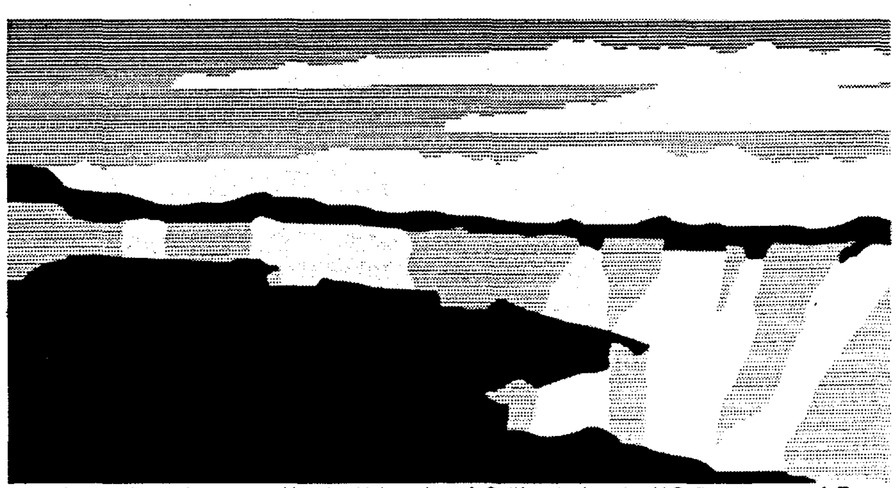
Submitted to: **Proceedings of the International Conf. on LASERS '97**
New Orleans, LA
December 15-19, 1997



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Abstract

Energies in excess of 250 mJ at 1.54 μm have been generated by Raman scattering of a Nd:YAG laser in methane and tested on an eyesafe laser lidar system.

Introduction

We report on the 50% photon-conversion-efficiency generation of 250 mJ of 1.54 μm radiation by Raman scattering for use on an airborne lidar system. The "eye-safe" region around 1.54 μm has been utilized for a number of lidar systems in the past because of the relatively high damage threshold of the eye, 1 J/cm^2, in this region.[1,2] Raman scattering of Nd:YAG radiation in methane has frequently been utilized to reach this wavelength,[3-7] but has generally been limited in power output for a number of reasons. Focusing into a methane cell can result in optical breakdown or multiphoton ionization that produces carbon deposits. Some of the input energy may also be reflected by Brillouin scattering, or may undergo backward Raman scattering. The latter is sometimes used as the Raman output because it can compete effectively with the forward scattering under some circumstances and can be of relatively good spatial quality because of partial phase conjugation.[6] One must be careful, however, to protect the laser from backward Brillouin scattering that may produce laser damage in addition to robbing energy.[4] Generation of higher-order Raman Stokes and anti-Stokes waves also presents a limitation on conversion efficiency to the first Stokes, as does saturation of the molecules in a small focal volume.

Raman Configuration and Results

In order to avoid some of these limitations, we have constructed a system that uses forward scattering of a nearly-collimated beam that does not have a tight focus in the cell. In addition to eliminating optical breakdown, this prevents backward Brillouin and Raman scattering because the gain pathlength is much longer than the coherence length of the multi-longitudinal mode Nd:YAG laser, and is in fact greater than the pulselength. Because of space limitations, the propagation path is folded as shown in Fig. 1. This also presents a way to attenuate the buildup of 2nd Stokes radiation at 2.8 μm by having mirrors coated for high reflectivity at the pump and 1st Stokes, but low reflectivity at the 2nd Stokes. Initial energy balance results indicated that there might be some conversion to 2nd Stokes because both 1st Stokes and pump decreased at high gain, but this could not be confirmed because the fused silica output window did not transmit at 2.8 μm. We have since replaced this output window with a larger aperture (14 mm) Infrasil window that transmits this wavelength and do not observe any 2.8 μm output. The decrease in energy at higher gains is attributed primarily to vignetting on the output window, which still occurs, but to a smaller extent, with the present

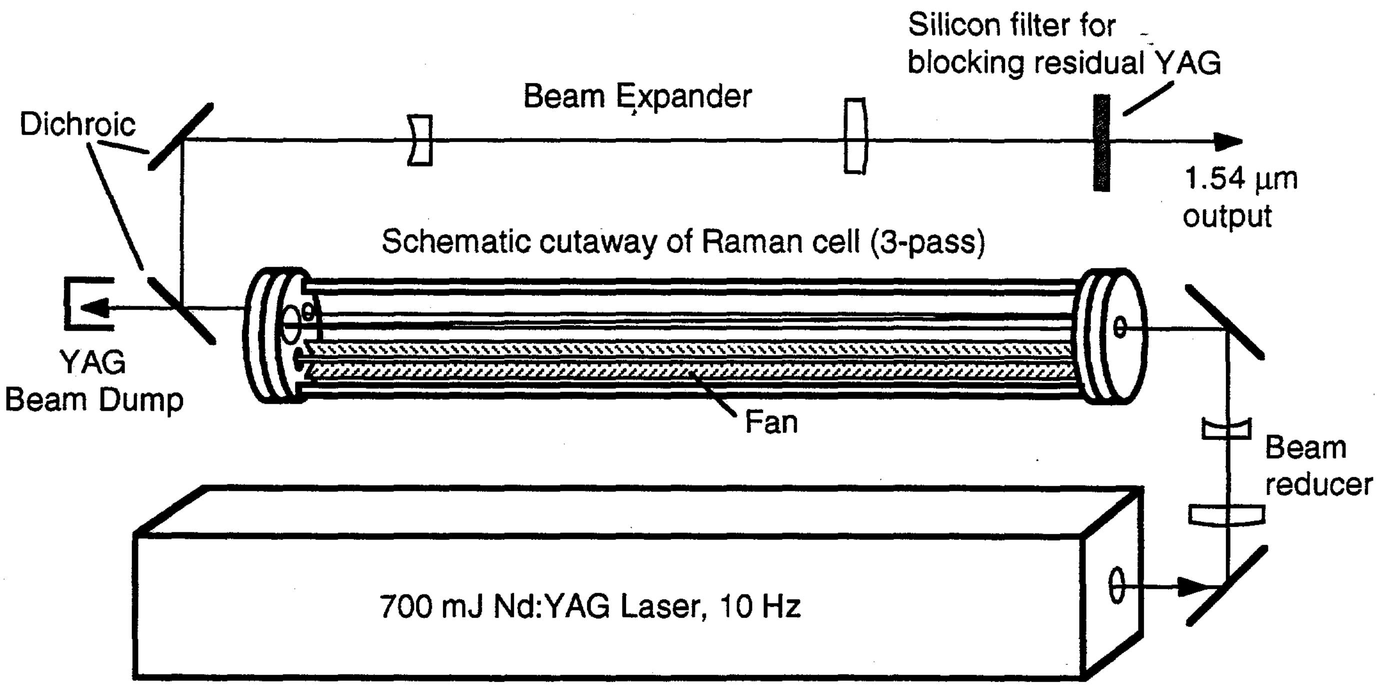

Fig. 1. Side view of methane Raman converter as mounted on helicopter pallet. Receiving telescope is mounted to the same scanable frame. Beam input is reduced to 6.5 mm dia and output is expanded to approximately 55 mm to reduce divergence to ~250 μrad. Gain can be adjusted by changing the pressure, the number of passes, or the input beam collimation.

aperture. Small amounts of off-axis red and green anti-Stokes radiation can sometimes be observed in the cell (particularly if the gas in the cell is not adequately stirred) but this is generally not seen in the output.

The cell can be operated in 3, 5, or 7-pass configuration by changing the angle of the cell relative to the beam, so that the beam bounces the appropriate number of times across flat mirrors (mounted 60 cm apart in the end flanges) and emerges parallel to the input beam. The input beam is down-collimated from 9 mm to 6.5 mm, and this collimator can be used to adjust the flux density along the path length to avoid damage on the folding mirrors. Fresnel peaking of the beam can in principle produce an intensity 3.77 times as high at a distance $L=a^2/\lambda$ downstream from a flat-top input, where a is the beam radius, but this has been measured as less than a factor of 2.5 for our beam. This must be taken into account in determining the design parameters, which were based on a Raman gain of 0.27 cm/GW at a pressure of 20 atm.[8,9] Best operation is obtained for 5 passes (3.0 m) at a pressure of ~17 atm, where 1.54 μm energies in excess of 250 mJ have been obtained with a 700-mJ 4-ns pump beam, with less than 10% energy fluctuation. This corresponds to better than 50% photon conversion efficiency. Almost comparable energies can be obtained for 3 passes (1.8 m) at a pressure of ~22 atm. Saturation of the medium should not occur because the number of molecules in the conversion region is several hundred times the number of photons in the pulse. However, we do often see slightly better conversion on the leading edge of the pulse than on the trailing edge. The use of a four-bladed fan internally driven by means of a stepper motor at ~800 rpm to stir the gas allows 10 Hz operation with little or no beam quality degradation. An output power of 2.4 W has been obtained under these conditions. The beam divergence of the Raman output is typically about three times that of the pump, and can be reduced to ~250 μrad by means of a 4x beam expansion telescope. Dichroic mirrors and a silicon filter reject any YAG or shorter wavelengths from the output beam path.

Lidar Application

This output has been utilized in initial ground tests on a flight-qualified Nd:YAG lidar system for use in a

Black Hawk helicopter. The down-looking nature of the atmospheric aerosol measurements necessitates the conversion of the airborne system to eyesafe wavelengths to enable Class 1 unrestricted laser operation. The limited space in the Black Hawk cargo compartment necessitates that the Raman conversion cell light path be folded to enable both vertical scanning and rotation to shoot out both the port and starboard doors.

Initial atmospheric measurements have shown that some characteristics of the 1.54 μm return are different from 1.06 μm. Clear air scatter is significantly lower than the expected scaling from 1.06 μm. The 1.54 μm sees through "dense" cumulus and displays the ice altostratus at 26 kft altitude. Some storm clouds are weak scatterers, others much stronger; the 3-D structure of a cumulonimbus cloud has been recorded at 32 km range. Forest smoke is weakly scattered, but forest pollen is easily seen. Although signal-to-noise is generally smaller than obtainable with a comparable amount of 1.06 μm radiation, the collection optics, detectors and ampliers are still being optimized. The 2.5-mm silicon avalanche photodector (APD) used for 1.06 μm has been replace with either a 0.2-mm InGaAs APD with a light funnel, or with somewhat better results, a 2-mm InGaAs PIN diode with an additional amplification stage. Hard-target ranging has been accomplished out to 83 km.

Acknowledgments

This work was performed under the auspices of the U.S. Department of Energy. We are grateful to the U.S. Army CBDCOM for support.

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