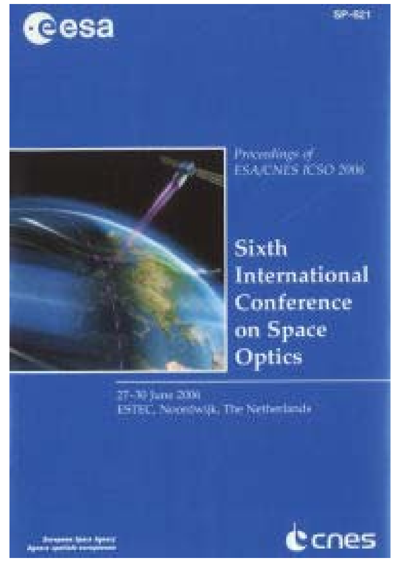
International Conference on Space Optics—ICSO 2006

Noordwijk, Netherlands

27–30 June 2006

Edited by Errico Armandillo, Josiane Costeraste, and Nikos Karafolas



Mixed garnet laser for a water vapour DIAL

Rainer Treichel, Stephan Strohmaier, Susanne Nikolov, Hans-Joachim Eichler, et al.

esa icso proceedings cnes

International Conference on Space Optics — ICSO 2006, edited by Errico Armandillo, Josiane Costeraste,
Nikos Karafolas, Proc. of SPIE Vol. 10567, 105671H · © 2006 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2308051

MIXED GARNET LASER FOR A WATER VAPOUR DIAL

Rainer Treichel[1] , Stephan Strohmaier[2], Susanne Nikolov[1], Hans-Joachim Eichler[2], Eamonn Murphy[3]

[1] EADS ASTRIUM GmbH, 88039 Friedrichshafen, Germany, E-mail: rainer.treichel@astrium.eads.net
[2] Technical University of Berlin, Straße des 17. Juni 135, 10623 Berlin , Germany, E-mail: eichler@physik.tu-berlin.de
[3] ESA, ESTEC, Keplerlaan , 2201 AZ Noordwijk ZH, The Netherlands, E-mail: eamonn.murphy@esa.int

ABSTRACT

For the water vapour DIAL "WALES" the wavelength regions around 935 nm, 942 nm and 944 nm have been identified as the most suitable wavelength ranges. These wavelengths can be obtained using optical-parametric-oscillators (OPOs), stimulated Raman shifters and the Ti-Sapphire laser but none of these systems could deliver all the needed parameters like beam quality, efficiency, pulse length and energy yet. Also these systems are comparably big and heavy making them less suitable for a satellite based application.
A fourth possibility to achieve these wavelength ranges is to shift the quasi-3-level laser lines (938 nm and 946 nm) of the Nd:YAG laser by replacing aluminium and yttrium by other rare earth elements. Changes of the host lattice characteristics lead to a shift of the upper and lower laser levels.
These modified crystals are summarized under the name of "Mixed Garnet" crystals. Only the Mixed Garnet lasers can be pumped directly with diode laser and use a direct approach to generate the required laser pulses without frequency conversion. Therefore no additional non-linear crystals or special pump lasers are needed and a higher electric to optical efficiency is expected as well as single frequency operation using spectral tuning elements like etalons.
In a first phase such mixed garnet crystals had been grown and characterised. The outcome was the selection of the gadolinium-scandium garnet for the most suitable laser crystal. During a second phase the complete laser system with output energy about 18 mJ in single 20 ns pulses and up to 8 mJ in free running mode with a combined pulse width of 250 µs at 942 nm have been demonstrated.
The results of the first laser operation and the achieved performance parameter are reported.

1. INTRODUCTION

The main objective of the WALES mission is to provide essential information on the distribution of atmospheric water vapour and aerosols in the troposphere and lower stratosphere (from 0 to 16 km altitude) for numerical weather prediction, climatology and atmospheric modelling. Absolute quantitative measurements of water vapour will be obtained over a large dynamic range (from 0.01 to 15 g/kg), with a high level of vertical resolution and accuracy not achievable by other systems. The spatial and temporal variation of water vapour will be directly sampled with global coverage, not only above and below optically thin clouds but also above cloud tops and in cloud gaps between dense clouds. The independent set of global water vapour profiles can be used to validate other measuring techniques such as operational passive infrared and microwave. Secondary information can also be derived such as cloud tops and base heights, optical thicknesses, planetary boundary layer height, and surface reflectance/albedo.
In the WALES Phase A study three wavelength regions each with a suitable subset of four wavelengths have each been identified. The reselection of these 3 times 4 wavelengths (see Table 1) is a result of a trade-off, which presents the best compromise between scientific requirements and technical reliability.

Table 1: Absorption wavelength sets for Water Vapour Dial

Set	Line	λ_o
935 nm group	Strong	935.684 nm
	Medium	935.561 nm
	Low	935.906 nm
	Offline	935.4 nm
942 nm group	Strong	943.0822 nm
	Medium	942.441 nm
	Low	943.247 nm
	Offline	940.0 nm (942.7 nm TBC)
944 nm group	Strong	944.367 nm
	Medium	944.858 nm
	Low	945.235 nm
	Offline	945.0 nm

The nadir-pointing DIAL instrument performs differential measurements of absorption at four closely separated wavelengths, three of which are 'online' measurements at molecular absorption lines of water, and one 'off-line' measurement, where absorption is significantly reduced. In this way, the different sub-intervals of the dynamic absorption range are addressed by dedicated on-line wavelengths. The

Proc. '6th Internat. Conf. on Space Optics', ESTEC, Noordwijk, The Netherlands, 27-30 June 2006 (ESA SP-621, June 2006)

different on-line wavelengths possess different penetration depths, thus allowing measurements over different altitude intervals. The strongly absorbing water vapour lines are used for higher altitudes (low water vapour concentration) and the weakly absorbing lines are used for lower altitudes (high water vapour concentration). The on-line measurements and the separate off-line measurements are used in a cascaded way, i.e. for each on-line measurement, the measurement on the next weaker line serves as its off-line measurement.
For the development of global climate simulation models the available data about the three-dimensional distribution of water vapor in the atmosphere plays a fundamental role to determine the quality of their parameterization. Only with sufficient and reliable data it will be possible to receive results that describe the real climatic situation.
Therefore the knowledge on water vapor distribution in the upper troposphere and lower stratosphere is of high relevance. In various publications it was shown that a differential absorption LIDAR or DIAL system can measure water vapor profiles simultaneously with high resolution and accuracy. The performance of the DIAL system is mainly determined by the parameters of the laser transmitter. The requirements for the laser transmitter are summarized in Table 2.

Table 2: Laser transmitter requirements for a water vapor DIAL

Parameters	Value
Wavelength range	942/943 nm
Laser linewidth	< 160 MHz
Laser frequency stability	< 60 MHz
Laser spectral purity	> 99.9 %
Laser pulse energy	> 70 mJ

The stability and energy requirements for a space borne laser transmitter lead to three different technologies that are currently under development:

- Raman laser converters based on a nonlinear optical material for frequency conversion of a pump laser by stimulated Raman scattering. The choice of the Raman material and therefore its Raman shift determines the emission wavelength.
- Titanium sapphire laser (TISA) pumped by a frequency-doubled Neodymium-YAG laser and tunable to emit in the demanded wavelength region around 935/936 nm.
- The new Neodymium doped garnet laser materials which can produce the desired wavelength directly.

In all concepts the exact wavelength match is achieved by injection seeding or amplification of a master laser.

2. ND:YGG AND ND:GSAG GARNET LASER

Diode pumped laser materials like Nd:YGG and Nd:GSAG emitting at 935/936 nm and 942/943 nm as suggested by G. Huber and K. Petermann from Hamburg University as well as other garnets can be used for water vapor detection. Both water vapor absorption lines packages can be addressed with garnet lasers as shown in Fig. 1. The wavelength group around 936 nm using Nd:YGG as laser material and the 942 nm wavelength group using Nd:GSAG.

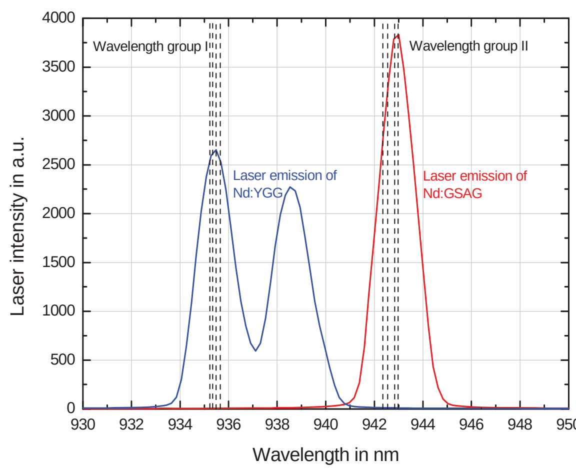


Fig. 1: Spectra of Nd:YGG and Nd:GSAG laser emission covering water vapor absorption lines

Best efficiencies and beam quality can be achieved in a longitudinal pump configuration. The setup shown in Fig. 2 consists of a diode pump laser with 1 kW peak pump power at 808 nm wavelength that is coupled into the resonator longitudinally through the HR mirror. The garnet crystal is mounted in a copper holder with indium between the garnet crystal and the copper holder to improve the thermal contact. The heat removal from the copper holder can be accomplished using either water or Peltier cooling. Q-switching was accomplished by placing a polarizer, a quarter-wave plate and a Pockels cell into the resonator.

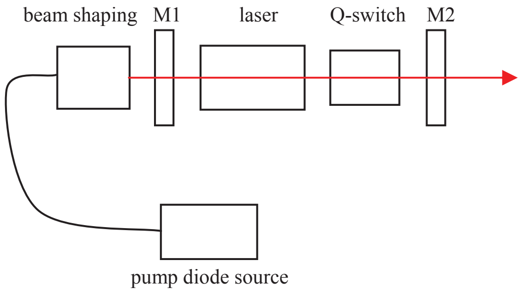


Fig. 2: Laser setup longitudinally pumped from one side with up to 300 mJ pump energy in 300 µs pulses at 1 kW peak pump power

The presented results apply to measurements with Nd:GSAG. In first experiments without Q-switch a pulse energy of 86 mJ with a conversion efficiency of 33 % at 10 Hz was achieved. That is to our knowledge the highest pulse energy obtained from a Nd:GSAG laser in the 942 nm wavelength region. For Q-switch operation a change of the resonator length from 3 cm to 30 cm was necessary and resulted in Q-switched pulses with 25 ns duration and pulse energies of 18 mJ compared to 30 mJ for the same setup but in free running mode without active Q-switch. The optimum pump pulse duration was 300 µs. With output energies of 1-10 mJ at 942 nm wavelength the beam quality was in the range of $M^2 = 1.5$.
The Q-switched pulse energy is presently limited by laser-induced damage of the optical components, which can be overcome by advanced resonator design.
In addition, frequency stabilisation of the Nd:GSAG-laser has to be developed to meet the spectral properties as given in table 2.

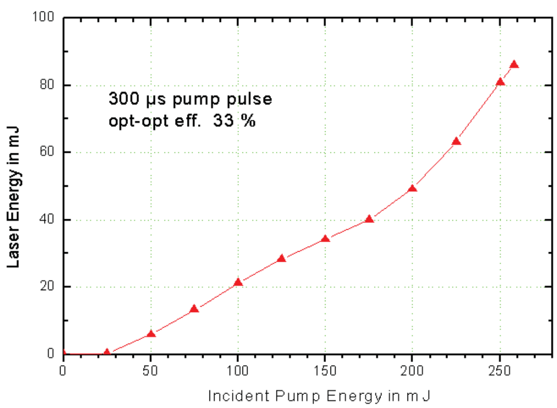


Fig. 3: Performance of the longitudinally pumped laser at 942 nm wavelength: Output versus input energy of Nd:GSAG

3. CONCLUSION

An optical efficiency of 20 % with a compact design should be possible with a Garnet laser. This transmitter technology is however presently only usable for water vapor DIAL but additional wavelength regions can be accessed in the future by using other garnet materials.
The properties of the garnet laser, especially the high overall conversion efficiency, make it the most suitable concept for DIAL measurements of water vapor concentrations.

4. ACKNOWLEDGEMENT
This work is being done under the ESA contract no. 17160/03/NL/JA.