Nd:GSAG Laser Amplifier at 942 nm Wavelength

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Abstract: The 943 nm wavelength region is interesting for water vapor detection with a differential absorption LIDAR. In this paper the measurement of the gain cross section in a Nd:GSAG laser crystal from 941-944 nm is presented. A peak gain cross section of $4.0\cdot10^{-20}$ cm^2 at 942.7 nm and a FWHM of 1.5 nm was measured. In addition first results with a diode pumped Nd:GSAG amplifier are presented.

OCIS codes: (280.1910) DIAL, differential absorption lidar; (140.3600) Lasers, tunable

Introduction

Water vapor is a very important content of the atmosphere with strong influence on climate and weather. There is a strong demand for improving the knowledge on water vapor distribution in the upper troposphere and lower stratosphere. A DIAL system can measure water vapor profiles simultaneously with high resolution and accuracy. For a space born DIAL system the wavelength regions of about 935 nm, 942 nm and 944 nm have been identified as the most suitable [1]. The more or less well established technologies such as the OPO and the Titanium Sapphire laser suffer from low over all conversion efficiencies to the desired wavelength range [2]. These frequency converter technologies use a Nd^{3+} laser as pump source and two further frequency converters.

For an efficient laser transmitter a laser material that can be pumped directly with laser diodes is necessary. The laser lines of the Nd:YAG laser (938 nm and 946 nm) which result from $^4F_{3/2} - {}^4I_{9/2}$ transitions are in the desired wavelength region but do not match exactly the required water absorption wavelengths. By manipulation of the host lattice the upper and lower laser levels can be shifted to achieve the desired wavelengths. As suggested by G. Huber and K. Petermann from Hamburg University [1] laser materials like Nd:YGG and Nd:GSAG emitting at 935/936 nm and 942/943 nm as well as other garnets can be used for water vapor detection.

A Titanium:Sapphire (TISA) laser with diffraction limited beam quality was used as pump source for the measurement of the stimulated emission cross-section of Nd:GSAG in dependence of wavelength. First results with a diode pumped Nd:GSAG amplifier are also presented. The measured gain in an Nd:GSAG amplifier at 943 nm is comparable with that in Nd:YAG at 946 nm. With Nd:YAG q-switched laser energies >75 mJ [3] and small signal gains >2.7 in amplifiers [4] have been reported.

Measurement of gain cross section

The experiment was conducted at room temperature with the Nd:GSAG crystal (length 13 mm, diameter 5.5 mm) mounted in copper heat sink without active cooling. Both faces of the crystal were coated with a broadband antireflection coating from 800 nm to 1300 nm. The nominal Nd^{3+} concentration in the GSAG rod was 0.6%. A schematic of the experimental set-up for double pass gain measurements is shown in Fig. 1. The Nd:GSAG laser crystal is pumped longitudinally with a gain switched TISA laser emitting at a wavelength of 808.5 nm with pulses of about 30 ns. The laser was collimated by a telescope to 1.3 mm beam diameter with energies of up to 20 mJ. The pulse energy incident on the Nd:GSAG crystal was controlled by a polariser half-wave plate combination.

In order to determine the stimulated emission cross section in Nd:GSAG the amplification of a probe laser was measured. A diode laser with an external cavity in Littrow configuration supplying single longitudinal mode operation was used as probe laser. The wavelength of the output was measured using a wavemeter and could be tuned from 930 nm to 950 nm. With a lens of 0.75 m focal length the probe beam was focused to ~0.9 mm beam diameter to the end face of the Nd:GSAG crystal. Due to the long focal length the change of the beam diameter from the entrance face to the end face of the crystal was negligible. The probe beam was made almost collinear (angle < 1°) to the pump beam by a dichroitic mirror with a high reflectivity at 943 nm and low reflectivity at 808 nm, the pump wavelength. Because of the low gain of the amplifier also a double pass configuration was used to improve the accuracy of the measurement. The intensity of the amplified probe beam was measured with a fast photo diode and recorded with a digital oscilloscope. To reduce the influence of the stray light from the pump pulse the detector was placed behind a spatial filter. Probe laser powers up to 10 mW were used. Additionally the polarisation of the probe laser as well as the pump laser was changed. But no polarisation dependent effects to the absorption of the pump light and the amplification of the probe beam were observed.

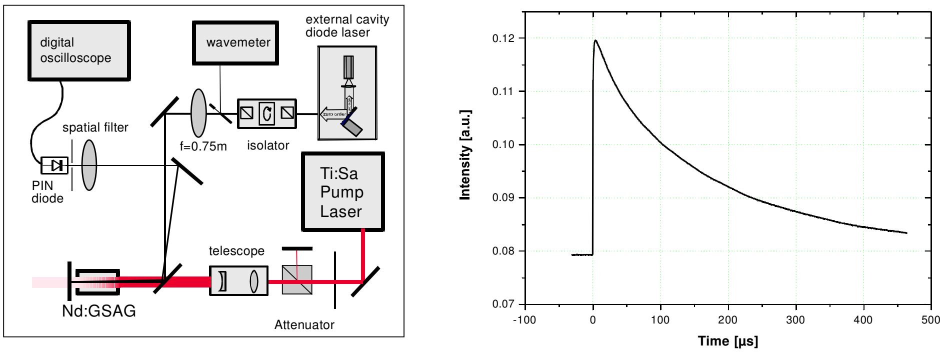

Fig. 1: Left, experimental set-up for gain measurement. Right, typical temporal profile of a gain measurement.

A typical oscilloscope track of a gain measurement is shown on the right side of Fig. 1. The graph shows the time dependence of the probe beam intensity on the photo detector for an incident pump pulse area density of 2 J/cm^2. At t=0 the pump pulse excites the Nd^3+ ions from the $^4I_{9/2}$ ground state to the $^4F_{5/2}$ pump band which has a fast decay to the upper laser level $^4F_{3/2}$. On the time scale of Fig. 1 the temporal width of the pump pulse can be ignored coinciding with a rapid raise in signal intensity at t=0. With the end of the pump pulse the intensity decays to the unamplified probe beam intensity. The single pass small signal power gain is given by equation (1). where I_{in} and I_{out} are the input and output probe laser intensities, g_0 is the small signal power gain coefficient averaged over the length L of the amplifier. With the knowledge of g_0 and the inversion density ΔN the stimulated emission cross-section σ can be calculated. In equation (2) $h\cdot\nu_p$ is the pump photon energy and E_p is the absorbed pump energy area density.

$$G_0 = \frac{I_{\mathrm{out}}}{I_{\mathrm{in}}} = \exp(g_0 \cdot L) \qquad (1) \qquad\qquad \sigma = \frac{g_0}{\Delta N} = \left(\frac{h\cdot\nu_p}{E_p}\right)\cdot g_0 \cdot L \qquad (2)$$

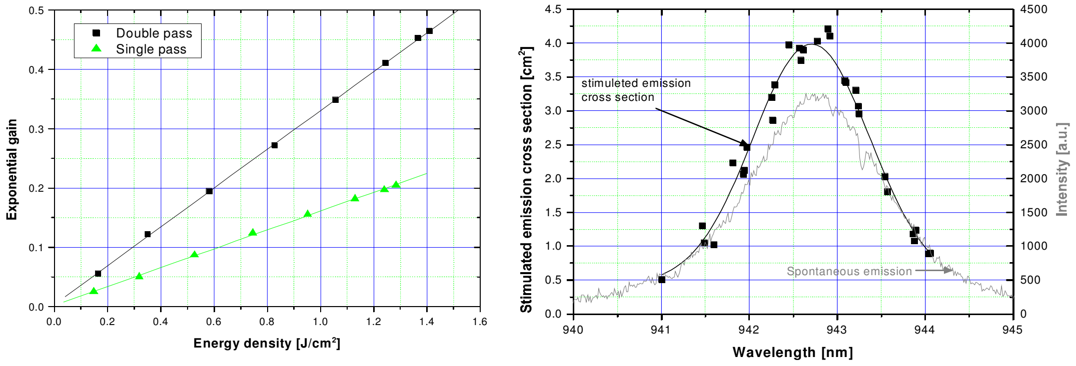

Fig. 2: Left, measurement of the gain exponent $g_0{\cdot}L$ at 942.9 nm for single and double pass through the amplifier in dependence of pump energy density. Right, stimulated emission cross section in dependence of wavelength calculated from measured exponential gain and spontaneous emission spectrum measured by optical grating spectrometer.

For each wavelength the gain was measured in dependence of the absorbed pump energy density and from a linear fit the stimulated emission cross-section can be obtained (Fig. 2). With this method the peak stimulated emission cross-section was determined to $\sigma = 4.0 \cdot 10^{-20}$ cm^2 at 942.7 nm. This is similar to the emission cross section of Nd:YAG at 946 nm. In Fig. 2 also the spectrum of the spontaneous emission is shown. The line shapes of the spontaneous emission and the emission cross-section agree quite well. A FWHM linewidth of 1.5 nm was measured.

Diode pumped Nd:GSAG amplifier

In previous experiments the TISA laser was mainly used as pump source because of the good beam quality that makes the determination of the applied energy density much easier. For further experiments laser diodes are used to provide a better efficiency. The diode pump module is coupled into a 1.0 mm fiber and provides 300 µs pulses with 10 Hz repartition rate and up to 280 mJ pulse energy. The end face of the fiber is imaged to the Nd:GSAG crystal by a telescope with a magnification of 1.5 for the amplifier and 1.0 for the oscillator. The experimental set-up and first results are shown in Fig. 3.

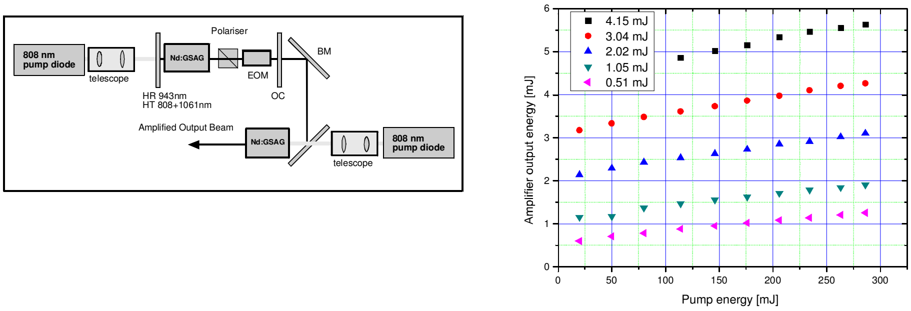

Fig. 3: Left, diode pumped Nd:GSAG oscillator-amplifier set-up. A q-switched diode pumped Nd:GSAG oscillator is amplified by a second diode pumped Nd:GSAG rod. Right, experimental results. For 5 oscillator pulse energies the amplifier output in dependence of amplifier pump energy is shown.

Output q-switched pulse energies up to 5.5 mJ were achieved with the oscillator and a gain > 2.5 with 0.5 mJ probe pulse energy has been shown.

Conclusion

In this paper the measurement of the wavelength dependence of the stimulated emission cross-section of Nd:GSAG in the 942 nm region is presented for the first time. The lineshape of σ was estimated to be Lorentzian (homogeneous line) with a FWHM of 1.5 nm. For all three water vapor absorption wavelengths needed for DIAL in this wavelength region $\sigma > 3.0 \cdot 10^{-20}$ cm^2 and therewith quite near the gain peak. The peak cross-section is with $4.0 \cdot 10^{-20}$ cm^2 at 942.7 nm similar to the cross-section in Nd:YAG at 946 nm and the same performance can be expected. Since Nd:GSAG is a new material the crystal quality is a critical point and has to be further improved.

Using laser diodes as pump source, q-switched Nd:GSAG pulse energies > 5.5 mJ at 943 nm were achieved limited by the damage threshold of optical components. In first amplifier experiments a gain > 2.5 with 0.5 mJ probe pulse energy has been shown. For further experiments the oscillator has to be improved by the magnification of the mode diameter to overcome the damage problems and it is planed to increase the gain by increasing the number of paths through the amplifier.

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