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Development of a Three-Wavelengths Switchable Ti:Sapphire Laser

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Introduction

Airborne and spaceborne water vapor differential absorption lidars (DIAL's) are very useful for understanding the global hydrological cycle. From the scientific requirements, an output wavelength of high accuracy, multi-wavelength and a high repetition rate operation are required to obtain both good measurement accuracy and high spatial resolution [1]. To fulfill these demands we have developed a high repetition rate, three wavelength switching Ti:Sapphire laser system by means of a three wavelength switching injection seeder and a rapid cavity tuning corresponding to the seeding wavelength [2]. Figure 1 shows the block diagram of the laser system. The frequency-doubled output of the conductive-cooled Q-switched Nd:YLF laser [3] was used as a pump light of the gain-switched Ti:sapphire laser. The wavelength of the Ti:sapphire laser is tuned and switched by the injection seeders whose output wavelengths are locked to the water vapor absorption lines with photo-acoustic cells.

Conductive-cooled Nd:YLF MOPA system

The configuration of the conductive-cooled Q-switched Nd:YLF MOPA system is presented in Fig. 2. A side-pumping scheme with Kaleidoscopic cavity [4], which works as a pump beam confinement cavity as well as a heat spreader for the Nd:YLF rod, was implemented in every conductive-cooling pumping module. The oscillator is a traveling-wave type resonator that was folded by two-crossed roof prisms: thus the laser beam pass four times through the prisms. This solution assures the required mechanical compactness and

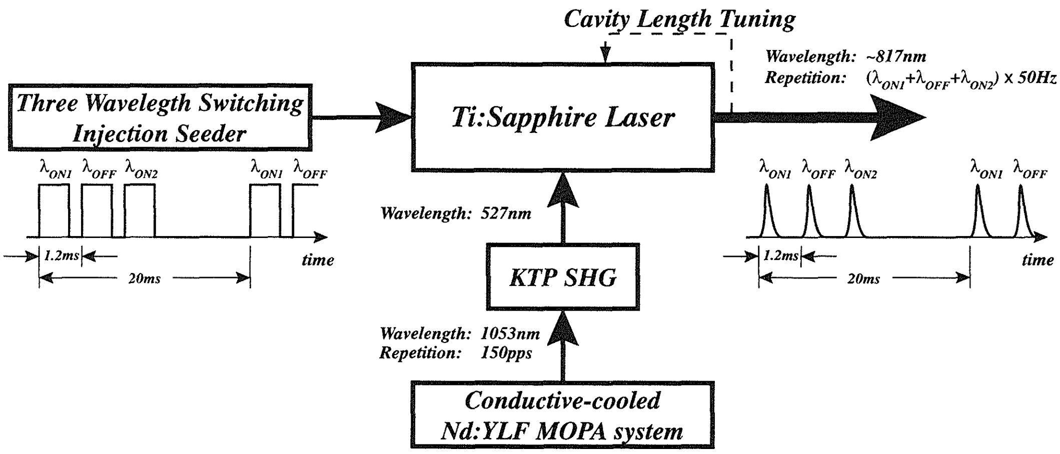


Fig. 1 Block diagram of the developed Ti:Sapphire laser system

provides a low sensitivity of the oscillator at the prisms misalignment. The $LiNbO_3$ Pockels cell and the polarizer P1 work together as an EO Q-switch and, at the same time, determine the oscillator coupling-ratio. Six special QCW 5-bar stacked arrays (SDL-32-S96D5), which operated at 3.75% duty cycle and 35°C temperature of the heat sink, were used for pumping. The repetition rate and the pump pulse duration are 150-pps and 250-μs, respectively. Under these conditions the oscillator delivers a maximum average output power of 7.2-W with an optical efficiency of 14%. The slope efficiency was 20%.

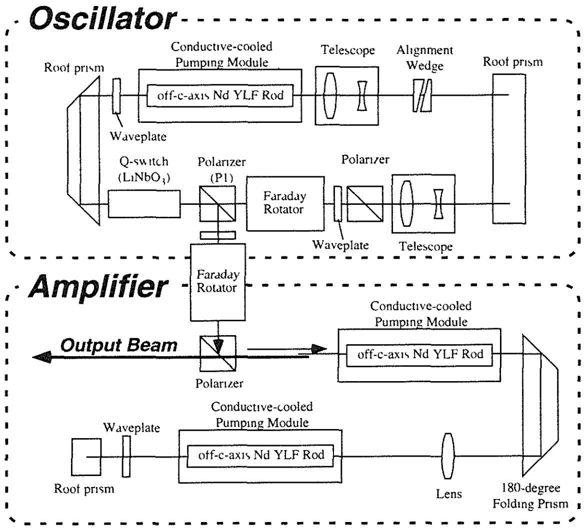


Fig. 2 The conductive-cooled Q-switched Nd:YLF MOPA system.

The double pass amplifier contains two pumping modules with a 180-degree folding prism and a lens, which optimized the beam size in media, placed between them. The first-pass amplified beam is rotated upside-down by a reflection roof-prism, thus improving the characteristics of the second-pass amplification. Each pumping-module used 18 special QCW 5-bar stacked arrays (SDL-32-S96D5).

The amplifier output power as a function of oscillator beam power is shown in Fig. 3. The diode average pump-power per every module of the amplifier was 141-W. To describe the double-pass characteristics a theoretical model, which consider the temporal overlap between the forward- and the backward-traveling waves in the amplifier, was developed. Thereby a good agreement with the experimental resulted. The amplifier delivered a maximum average output power of 50-W (333-mJ energy per pulse) with an optical efficiency of 15%. Next, the 1053-nm output was frequency doubled by a KTP crystal. Thus a maximum SHG output average power of 30-W (200-mJ energy per pulse) and a conversion efficiency of 60% resulted.

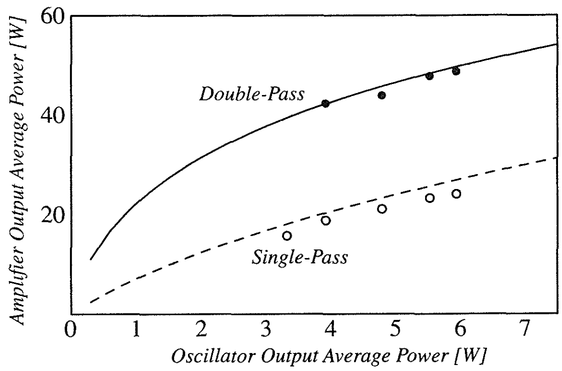


Fig. 3 The amplifier output average power as a function of the oscillator average power (experimental data by signs and a theoretical results by lines).

Three wavelength switching injection seeder

Figure 4 shows the switching injection seeder. Three AlGaAs Fabry-Perot type laser diodes (LD's) were used. Two LD's were tuned to the weak (ON1:

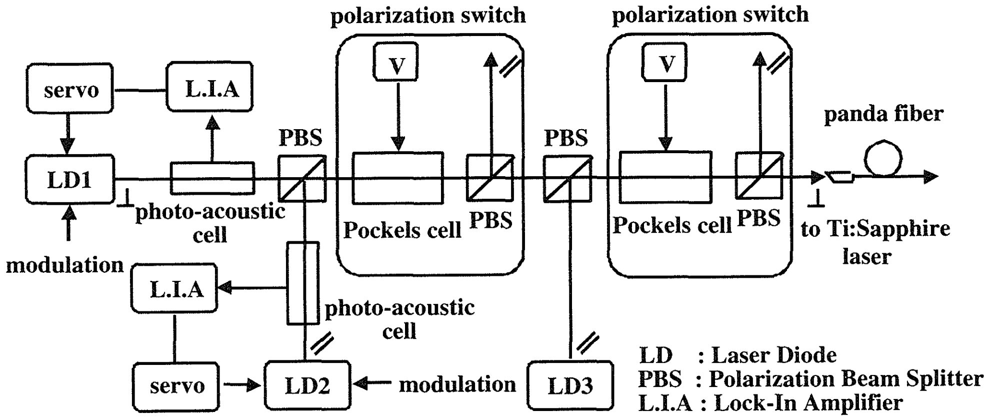


Fig. 4 Diagram of the injection seeder.

816.757-nm) and the strong (ON2: 816.459-nm) water vapor absorption lines, respectively, by means of the photo acoustic spectroscopy method. This method was chosen because, compared to the optical spectroscopy using multi-pass cell, is insensitive to various optical misalignments. The third LD was tuned to the wavelength range where no absorption line exists (OFF: 816.56-nm) by means of stabilizing both the injection current (< 0.01-mA) and the temperature (< 0.01 degrees). The fast derivative signal and the wavelength stability for ON2 are presented in Fig. 5. Wavelength stabilization accuracies of ±0.017-pm for ON1, ±0.0017-pm for ON2 and less than ±0.5-pm for OFF-line were measured. In order to switch the output wavelength we used polarization switches. In this scheme, a polarization beam splitter (PBS) combines two LD's outputs, a $LiNbO_3$ Pockels cell rotates the polarization and, finally, another PBS selects the LD's output as the seeder. This output was coupled to a polarization-maintaining single mode fiber and transferred to the Ti:sapphire laser. The switching time is less than 600-μs. As an example, Fig. 6 presents the output spectrum of the seeder after the polarization switch. More than -30-dB suppression of the other two output powers was achieved.

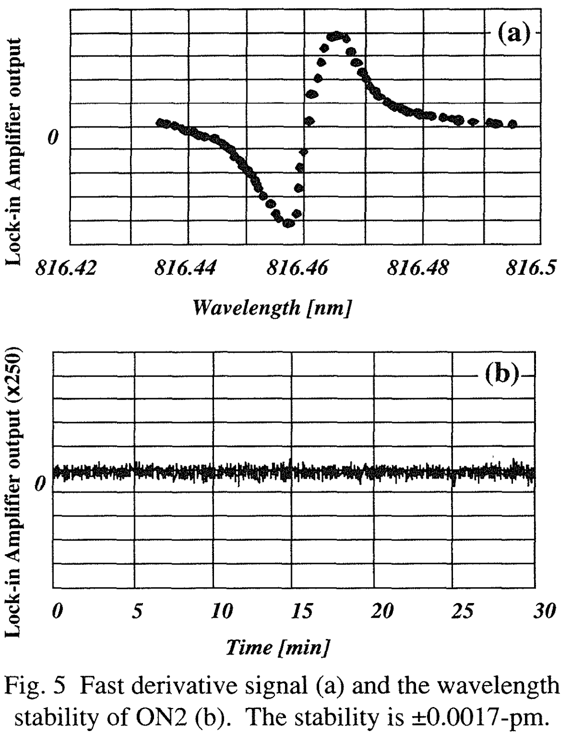


Fig. 5 Fast derivative signal (a) and the wavelength stability of ON2 (b). The stability is ±0.0017-pm.

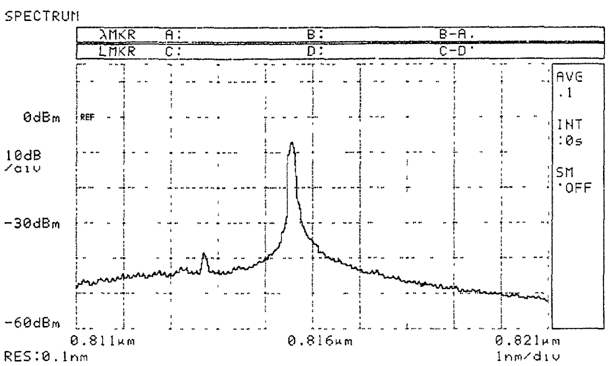


Fig. 6 Output spectrum of the ON2 with the polarization switch. More than -30dB suppression of the ON1 power and the OFF power was obtained.

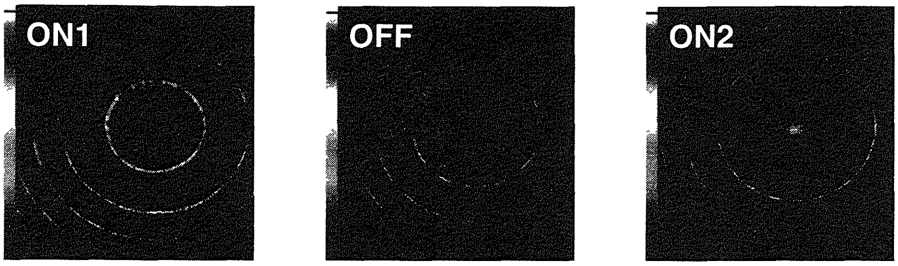
Ti:sapphire laser

A traveling-wave type resonator was used for the Ti:sapphire oscillator. The oscillator output coupler consists of a PBS and a half waveplate. The Ti:sapphire rod was cut at the Brewster angle. A Faraday isolator obtains the directional oscillation and a cavity length tuner was used in order to tune the wavelengths of longitudinal modes to the wavelengths of the injection seeding. The beam diameter at the rod position was optimized by an intra-cavity telescope and anamorphic prism pairs compensated the astigmatism of the pumped rod. Thereby, at the maximum pump-power of 30-W (527-nm), the Ti:sapphire laser outputs a single longitudinal mode with an average power of 6.8-W and 150-pps repetition rate.

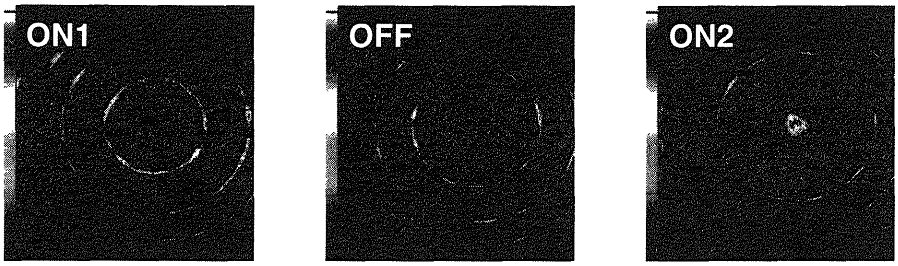
The pulsed output from the Ti:sapphire laser was monitored using single mode optical fiber. The beat signal between this laser output and the frequency shifted injected LD output was obtained by mixing them in Si photo diode. A frequency discriminator, which consists of a low pass filter and a high pass filter, obtained the error signal. Then, this signal was fed back to a PZT actuator in the cavity length tuner to let the beat frequency be constant.

Experimental results of the Ti:sapphire laser

The output spectrums of the seeder and of the Ti:sapphire laser, measured by a Fabry-Perot etalon, (FSR: 6-GHz, resolution: 88-MHz) are shown in Fig. 7. The pulsed output spectrums from the Ti:sapphire laser consists well with the spectrums of the seeder. The standard deviation of the frequency difference between the Ti:sapphire laser and the seeder outputs, which was



(a) Output spectrums of seeder.



(b)Output spectrums of Ti:Sapphire laser.

Fig. 7 Output spectrums of the seeders and the Ti:Sapphire laser.

measured from the FFT spectrum of the beat signal, was less than ±0.06-pm during 5 minutes of operation. This corresponds to 15000 shots for each wavelength. Finally, Table 1 summarizes the Ti:sapphire laser performances.

Table 1 Performances of the developed Ti:sapphire laser for the water vapor DIAL.

	Item	Result
Ti Sapphire laser	Wavelength	ON1 816 757nm ON2 816 459nm OFF 816 56nm
	Spectral width	±0 045pm
	Wavelength stability	±0 06pm
	Sidemode suppretion	> 26dB
	Average output power	6 8W
	Output pulse energy	45mJ
	Output energy stability	±4 9%
	Repetition rate	(ON1, ON2, OFF) x 50Hz
	Pulse width	23ns

Conclusions

A high power diode-pumped Nd:YLF laser and a Ti:sapphire laser were developed for an airborne water vapor DIAL system. The output energy of the Nd:YLF laser was 333-mJ with a repetition rate of 150-pps. The Ti:sapphire laser, which was pumped by the Nd:YLF laser, was tuned to a strong absorption line (ON1), a weak absorption line (ON2) of water vapors and an off line by an injection seeder that consists of three single longitudinal mode laser diodes. These three lines, which are separated each other by a 1.2-ms time duration, are simultaneously transmitted into the atmosphere at a 50-Hz repetition rate. The laser spectral width was ±0.045-pm with a wavelength stability of ±0.06-pm. The maximum output energy of each laser line was 45-mJ.

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