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Development of atmospheric polarization LIDAR System

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Abstract LIDAR (**Li**ght **D**etection **A**nd **R**anging) system sensitive to the polarization of the backscattered signal is being developed in Yerevan Physics Institute. The system is designed primarily for remote sensing of the atmospheric electric fields. At present, the system is being tuned for measuring vertical atmospheric backscatter profiles of aerosols and hydrometeors, analyze the depolarization ratio of elastic backscattered laser beams and investigate the influence of external factors on the beam polarization [1]. In this paper, we describe the complete LIDAR system – the laser transmitter, receiving telescope and the polarization separator. The data acquisition and processing techniques are also described.

1. INTRODUCTION

Intensive studies in fields of high-energy phenomena in the atmosphere revealed electron acceleration and the bremsstrahlung photons generation caused by the electric field emerging in the thunderclouds [2]. Further studies demand knowledge of electrical field distribution inside clouds [3]. We are suggesting a measurement technique of the electrical field inside the clouds based on the continuous observations by a LIDAR (**Li**ght **D**etection **A**nd **R**anging) system. This technique is based on precise measurement of the backscattered laser radiation polarization changes in the clouds [4].

The real time measurements of the spatial and temporal distribution of the electric field in and around thunderclouds is important for understanding of the thundercloud formation mechanisms, for the prediction of lightning strokes initiation and for understanding of the processes of acceleration of cosmic ray electrons and generation of bremsstrahlung photons caused by the electric field of clouds.

The electric field meters, currently used for this purpose, are set on the Earth's surface or on board of balloons. These techniques are limited as electrostatic field on the Earth's surface significantly differs from that in the clouds; and balloons typically provide a single sample at discrete altitudes at one time. LIDAR systems are the main instrument which allows to realize real time remote measurement of the electric field strength and direction with high spatial and temporal resolution. LIDAR systems are based on the absorption and/or scattering of light by the gas, liquid or solids. The atomic and molecular spectra can be in a sensitive manner and very accurately measured by spectroscopy.

2. LIDAR SYSTEM OVERVIEW

LIDAR systems consist of three main parts: a Laser Emitter (LE), a Receiving System and a registration and control system.

The Laser Emitter of the polarized laser radiation is a solid state, flash-lamp pumped, Q-switched YAG: $Nd3^{+}$ laser with a second harmonic generator (SHG) and a beam expander. It generates linearly polarized 10 ns pulses with 1064 nm and/or 532 nm wavelengths and a repetition rate of 10-20 Hz.

The Laser oscillator was designed to have a positive branch confocal unstable resonator and a polarization output. Designing the laser oscillator resonator we adopt that the focal length of the thermal lens is induced in the active medium. With the help of a SHG the output laser oscillator beam with 1064 nm wavelength, after amplification, is converted into the second harmonic with 532 nm wavelength. The SHG was designed to have a nonlinear crystal KD*P with angular phase matching.

The laser construction is shown in Fig. 1. The Laser beam output is equipped with an additional polarizer (a Glan prism) to obtain a higher linear polarized output beam.

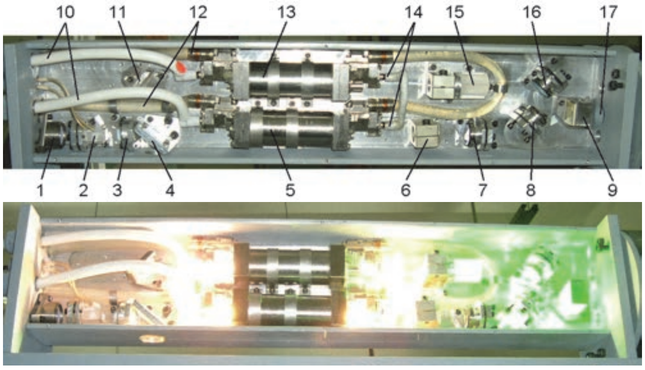

Figure 1. The Laser construction (left): 1 - Convex mirror, 2 – Electro optical Q-Switch, 3 – Diaphragm, 4 – Output polarizer, 5 – laser oscillator pump chamber, 6 – Quarter wave-plate, 7 – Concave mirror, 8 and 16 – Two wavelength mirrors, 9 – Glan prism, 10 – Flash-lamp driver cables, 11 – mirror, 12 – Cooling system pipes, 13 – Laser amplifier pump chamber, 14 – Flash-lamps, 15 – SHG, 17 – Hole for the output beam. The Laser in operation (right).

The LE Beam Expander is an extra cavity Cassegrain telescope with 14^{X} magnification, which allows to expand the 8 mm across laser output beam to 112mm diameter and reduce the laser beam divergence down to < 0.1 mrad.

The Laser with the beam expander mounted on the receiving telescope (RT) is shown in Fig.2.

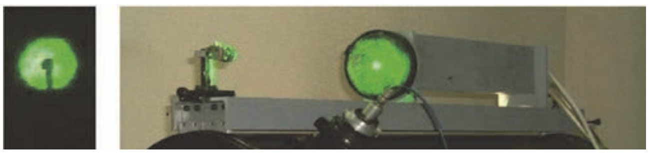

Figure 2. The Laser Emitter, including the beam expander in operation mounted on the RT (in the right) and the Laser Emitter output beam-spot on the distance of 2 meters (in the left).

Receiving System of backscattered radiation contains 250mm aperture Receiving Telescope (RT) and polarization separator (PS).

The PS is placed on the output of the receiving telescope and its function is to separate the orthogonal to each other polarization components of the back scattered signals. To reduce an additional depolarization of the signal in the optics, the PS was designed with minimum optical components before polarization separation. Calculations shows the possibility of polarization separation without using collimation optics in the RT and overcome the difference between the working angles of the Glan prism and the RT concave mirror.

For polarization separation is used a Calcite prism and two prisms with different refractive indexes (to reduce the abberations in the calcite prism). For this configuration the beams with orthogonal to each other polarization have been refracted under different angles and separated from each other in space for more than 8 mm. The separated beams are channeled into two optical fiber bundles with 4 mm apperture and transported to photo receivers.

Designed and assembled PS is presented on the Figure 3. The PS mount has two angular and two parallel (in crossed directions perpendicular to RT optical axis) alignment capabilities and also can be aligned parallel to RT optical axis (RT focus finder). The polarization separation angle against LE beam polarization can be controlled by means of stepper motor and play free gear system.

The PS was aligned on the optical table for checking the calculations as well, as to design the procedure of alignment for its integration into RT. The points are the separated cross-polarized 532 nm diode laser beams (Figure 3).

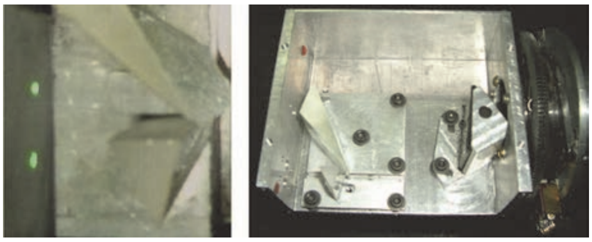

Figure 3. The Polarization Separator

Signal Detection and Processing System registers the orthogonal to each other polarized components of the backscattered radiation by means of photomultipliers (PMT). It allows reducing the optical background noise by means of filters to separate the signal according to wavelength as well as changing the field of view of the receiving telescope.

3. THE LIDAR SYSTEM

The developed LIDAR system is presented on three photos below.

By means of the RT mirror the backscattered radiation is directed and focused on the inputs of the fiber bundles. On its way the radiation is passing through PS which separates orthogonal to each other polarized components of the backscattered radiation. Two fiber bundles transport the separated optical signals to PMT boxes. After optical filtering, signals enter into PMTs, which amplifies and converts them into electrical signals.

The electrical signals from PMTs passed to the signal registration system. The signal observations are realized by means of 500 MHz oscilloscope. The triggering of the registration system is organized by means of photodiode system optically communicated with outgoing laser pulse.

The angle of the PS can be controlled by means of stepper motor and play-free gear allowing orient the polarization separation angle perpendicular to LE beam polarization plane as well, as to any angle to it.

In the LIDAR Registration and Control System the CAMAC crate is used as a framework for custom made blocs and as a power supply for different subsystems and modules. The NI USB DAQ system, custom made BNC module for DAQ inputs and outputs, PMT power supplies, custom made power supplies for system electronics, etc. are installed into CAMAC crate (Figure5).

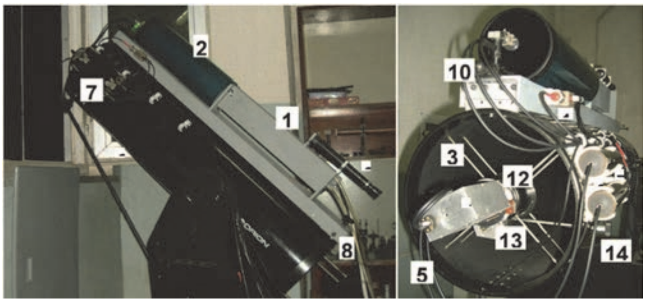

Figure 4. The LIDAR system. 1 - The Laser; 2 – Laser Beam Expander; 3 - RT; 4 - PS; 5 - Signal optical fiber bundles; 6 - Optical filter boxes; 7 - PMTs; 8 - LE alignment platform; 9 - Aiming optics; 10 - Triggering and output energy control optical fiber bundles; 11 - Triggering photodiode; 12 - PS alignment mount; 13 - Stepper motor with Play-free Gear; 14 - RT mirror focus finder.

The system is used for the digitizing observed signals and to control the LIDAR system, including:

- LE beam 1064nm output energy.
- LE beam 532nm output energy.
- LE beam repetition rate.
- LE Q-Switch driver pulse delay.
- LE beam polarization finder.
- PS – LE beam polarization angle.
- Registration delay, etc.

Figure 5. The LIDAR Registration and Control System.

1 - Stepper Motor Driver;

2 - PD and PMT Amplifier Power Supplies;

3 - NI DAQ BNC Inputs and Outputs;

4 - NI USB DAQ;

5 - PMT Power Supplies;

6 - Oscilloscope 500MHz.

The main specifications of the LIDAR system are listed in the Table 1.

Table 1. LIDAR System Specifications.

Laser Emitter	
Laser source	YAG:Nd3+ Custom made
Wavelength	1064 nm 532 nm
Pulse energy	300 – 500 mJ (@ 1064nm) 100 – 200 mJ (@ 532nm)
Beam Expander	14x
Beam divergence	<10-4 rad (after beam expander)
Pulse width	10 ns

Laser Emitter	
Repetition rate	10 – 20 Hz
Polarization linearity	<10-3
Receiving Telescope	
Diameter	250 mm
Field of view	2 x10-4 rad
Polarization Separator	Custom made
Optical fiber bundle aperture	4 mm
PMT	FEU-100 and FEU-83 (Russia)
Range	0.1 – 15 km
Spatial resolution	5 m
Signal and data processing	
Oscilloscope	HMO 3054 (Hameg)
Oscilloscope	PicoScope 5444B
DAQ	NI USB DAQ
Software interface	NI LabVIEW

4. THE FIRST OBSERVATIONS OF THE BACKSCATTERED SIGNALS

Fig. 6a and b present the first observations of the signals scattered from the clear atmosphere and the clouds. It highlights the backscattered signal amplitude above the noise level for the distance of ~7.5 km. The oscillograms are the direct output signals from the PMTs (without amplification and processing) received from the atmosphere per one laser shot/each. The triggering signals are at the beginning of the oscillograms.

In Fig.6.1, the (a) curve is the backscattered signal parallel to the laser emitter beam polarization component and the (b) curve is the crossed one (depolarization channel). The laser emitter output beam is at the beginning of the oscillogram. Taking into account the light velocity in the air, the full scale of oscillogram indicates approximately 7.5 km distance (50 usec - laser pulse time of flight). The signal from depolarization channel shows, that the LIDAR receiving system birefringence is negligibly small.

The oscillograms are obtained with one 100-mJ laser emitter pulse (without averaging or special processing). The PMT supply Voltage 2 kV also is not on maximum and the output signals of the PMTs are without amplification.

The estimations show that the reserve of the system is enough to realize elastic backscattering measurements from not less than 15 km distances.

The second oscillogram (Fig.6.2.) indicates the backscattered signal with the same laser emitter beam and with reduced PMT supply voltages allowing observing the amplitude of the backscattered from the clouds signals (about 6 km far from the system). On the oscillogram one can notice that the laser radiation in the clouds is depolarized ((b) one), which is an indication of the existence of ice droplets in the cloud. From the oscillogram can be easily calculated the heights, the thickness and distribution of the cloud by measuring the attenuation of the laser radiation in the clouds, and so on.

These first observations of the backscattered signals from the atmosphere and clouds by means of the designed LIDAR system show that its completion with a signal digitizing system and a signal processing PC program will allow to use it in the numerous applications of atmospheric research for distances not less than 15 km.

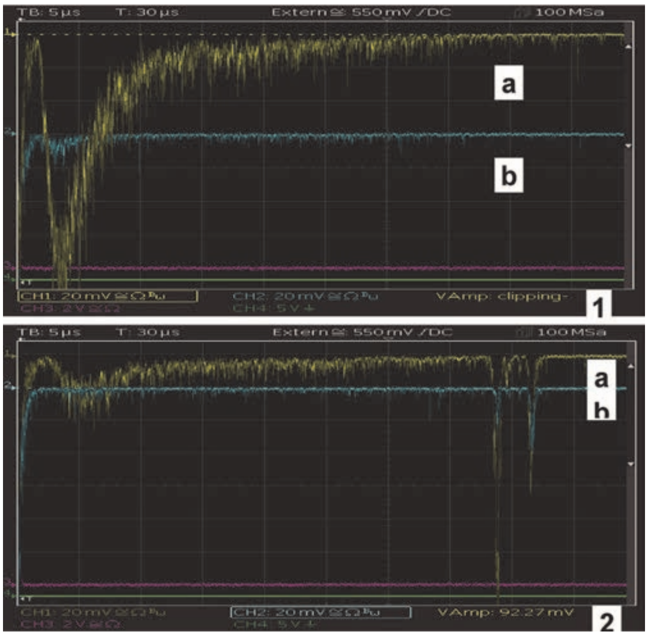

Figure 6. The Scattering from Atmosphere and Clouds received signal oscillograms. a – parallel with laser beam polarization channel, b – crossed with laser beam polarization channel (Horizontal - 5us/div; Vertical -20mV/div).

5. SUMMARY AND FUTURE PERSPECTIVES

A LIDAR system for remote sensing of the atmosphere was designed at the Yerevan Physics Institute and current plans are to use the system for backscatter measurements from aerosols and hydrometeors. It is directed to investigate the influence of the external factors on the backscatter signals including influence of the atmospheric electric fields. It is planned also to add a nitrogen and water Raman channels into the receiver to investigate the cloud and aerosol backscatter and extinction, as well, as the influence of the external factors (including the el A LIDAR system for remote sensing of the atmosphere was designed at the Yerevan Physics Institute and current plans are to use the system for backscatter measurements from aerosols and hydrometeors. It is directed to investigate the influence of the external factors on the backscatter signals including influence of the atmospheric electric fields. It is planned also to add nitrogen and water Raman channels into the receiver to investigate the cloud and aerosol backscatter and extinction as well as the influence of the external factors (including the electric fields) on the deformation of the spectral bands.

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