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Development and Comparison of Two Experimental Setups to Measure the Depolarization Ratio of Mineral Dust in the Lab

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Abstract: In this paper we discuss about the design, construction and working of two different experimental setups to measure the depolarization ratio of natural mineral dust samples in the laboratory in the exact back-scattering direction. The first setup involves a 50:50 beam splitter and the second setup involves a Faraday rotator to achieve the 180˚ backscattering angle. Both the experimental setups will be first tested at 532 nm wavelength. Later, the setup with better results will be extended to cover the full triple-wavelength (355, 532 and 1064 nm) capabilities for linear polarization and circular polarization, enabling ellipsometry measurements of mineral dust particles.

1. Introduction

Earth's atmosphere consists of a diverse range of aerosol particles originating from natural and human-made sources, influencing the climate dynamics, air quality, human health, and ecosystem health. Mineral dust is one of the significant contributors to the atmospheric aerosol loading and plays an important role in atmospheric processes [1].

The detection and characterization of the aerosol particles have been successfully done by active remote sensing with atmospheric lidars. The depolarization ratio, which measures the degree to which incident linearly polarized light becomes depolarized upon scattering by aerosol particles, is one of the most important optical property used for aerosol classification [2,3]. The integration of polarization sensitive measurements has enhanced the lidar's capability to retrieve additional information about the particles' shape, size, composition, and orientation. For non-spherical aerosol particles, the depolarization ratio has high values, whereas for spherical aerosol particles it is nearly zero.

Because of the irregular shape of mineral dust particles, it is easy to distinguish them from other aerosols. However, the irregular shape makes it difficult to retrieve the microphysical properties such as effective radius or number concentration from optical measurements [4]. Several optical models have been developed [5,6], in the past decades, to retrieve the microphysical properties from optical measurements. However, the optical models lack a good dataset for validation and constraints, especially with regard to its spectral behavior.

To get a comprehensive dataset of the scattering properties at 180˚ of mineral dust particles, a new scattering laboratory is under development in the framework of the project OLALA (Optical Lab for Lidar Applications) at the Leibniz Institute for Tropospheric Research. The detailed description of OLALA project is given in the ILRC contribution [7]. The laboratory studies of the depolarization ratio of mineral dust will complement field measurements by providing controlled environments for detailed investigations, validating remote sensing techniques, advancing fundamental understanding, and enhancing modeling capabilities, ultimately contributing to a more comprehensive understanding of aerosol behavior and its implications for the Earth's atmosphere and climate.

2. Previous Lab Studies and OLALA Setup

First laboratory studies of backscatter measurements were done by [8,9]. Sakai et al [9], measured the depolarization ratio of dust particles separated into fine and coarse-mode. However, the study was limited to a single wavelength (532 nm) and a maximum backscatter angle of 179.6˚. Järvinen et al [10], presented laboratory measurements of linear and circular near-backscattering (178°) depolarization ratios of over 200 dust samples measured at 488 and 552 nm wavelengths. The most promising laboratory approach up to now was developed by David et al [11], which was later modified by Miffre et al [12], to measure the depolarization of mineral dust at exactly 180˚ at two wavelengths (355 and 532 nm).

With our OLALA setup, we plan to measure depolarization of size-selected natural dust samples at exact 180˚ backscatter angle at typical lidar wavelengths of 355, 532 and 1064 nm. The previous studies [8-12] could not achieve all of these goals all together. The important aspect that makes our approach a worldwide unique effort is the use of better size-resolved natural mineral dust samples, which will improve our understanding of the size related information presented in the spectral slope of particle depolarization. Table 1 shows a comparison between OLALA setup and different lab studies done so far.

Table 1. laboratory setup for depolarization measurements (PL – pulsed laser, CW – continuous wave laser)

Ref.	Dust Sample	λ (nm)	θ	Laser
[9]	Asian dust Saharan dust	532	178.8 – 179.6°	PL
[12]	Arizona Test Dust	355 532	180° ± 0.2°	PL
[10]	Mineral dust	488 552	178°	CW
Our Setup	Natural Dust Samples (Size segregated)	355 532 1064	180° ± 0.2°	CW

3. Experimental Setup

There are two major challenges that need to be overcome while designing the optical setup. The first one is measuring at exactly 180˚ backscattering angle and the second challenge is to suppress the background stray light. To solve the first problem, we are going to use two different experimental setups with precise alignment and positioning of the optical components, calculated using advance ray-tracing software (Zemax). Suppression of background stray light is done by using a lock-in amplifier, which uses phase-sensitive detection to extract a weak signal from a noisy background.

Our experimental setup is divided into two parts: Microphysical setup and Optical setup which are described in the following section.

3.1. Microphysical Setup

Parts of the Leipzig Aerosol Cloud Interaction Simulator (LACIS) [13], will be used as an aerosol chamber for OLALA. The aerosol chamber will be a 1 m long tube with the inner diameter of 1.5 cm. The tube is painted black from the inside to avoid stray light scattered by the wall. Generated aerosols of mineral dust particles will be size selected using either a Differential Mobility Analyzer (DMA, d< 850 nm) or an Aerodynamic Aerosol Classifier (AAC, d< 5µm) and then fed into the flow tube. At the end of the flow tube, an Optical Particle Sizer (OPS) is placed to measure the size distribution.

3.2. Optical Setup

The optical setup is very similar to that of a polarization lidar and consists of an emitter, receiver and data acquisition system. For emitter, we are using a diode pumped fiber pigtailed continuous wave (cw) laser at 532 nm (Cobolt, Huebner Photonics). For our setup we decided to go with a cw laser as it provides a constant and stable output over time which leads to a higher signal-to-noise ratio, providing better sensitivity for detecting weak signals from scattered light. The laser fiber output is connected with FC/APC fiber collimator of numerical aperture 0.51 and focal length 7.86 mm (F240APC-532, Thorlabs).

The receiver part consists of a polarizing beam splitter cube (PBS251/M, Thorlabs) which collects the backscattered light and separates it into two orthogonal components with respect to the polarization plane of emitted laser. A plano-convex lens of focal length 150 mm (LA4874-A, Thorlabs) along with an interference filter of central wavelength 532 nm and full width at half maximum of 4 nm (FLH532-4, Thorlabs) is placed in front of the Silicon detector having a diameter of 1 mm and rise time of 1 ns

(DET10A2, Thorlabs). The interference filter, the lens and the Si detector are all placed inside a black tube to protect the optics from getting dirty and avoid any disturbances from the outside environment. The detector is connected with the lock-in amplifier (SE1022D, Saluki Technology, Taiwan) to record the final output values. The characterization of the two channels will be performed by using the Δ90 approach [14], widely used for atmospheric lidar systems. In front of the receiver unit, a micrometer pinhole will be placed to collect the scattering angles from the very-near backward direction.

We plan to test two experimental setups for 532 nm wavelength. The simple setup uses a 50:50 beam splitter similar to [15], and the advanced method involves a Faraday rotator.

3.3. 50:50 Beam Splitter Setup

The laser emits a linearly polarized light wave which falls on the 50:50 beam splitter (Fig. 1). 50% of light reflected by the beam splitter goes to the aerosol chamber and the remaining 50% of light transmitted by the beam splitter is absorbed by the beam dump. The light backscattered from the aerosol chamber then falls again on the 50:50 beam splitter. The transmitted part is directed to a polarizing beam splitter cube which further separates the parallel and perpendicular components of light. This setup is currently being developed in the laboratory .

3.4. Faraday Rotator Setup

Linearly polarized light from the laser passes through the polarizing beam splitter and then through the Faraday rotator. The Faraday rotator shifts the polarization of the light by an angle of 45° as shown in the block diagram in Fig. 2. This wave then passes through another polarizing beam splitter cube, which separates the parallel and perpendicular components of light. The perpendicular component goes to the beam dump and the parallel component is directed inside the aerosol chamber by a dichroic mirror. On the way back, the backscattered light from the aerosol chamber is directed by the dichroic mirror to the polarizing beam splitter (Fig. 2b). The PBS cube separates the parallel and perpendicular component of light, which is detected by the respective detectors at the end.

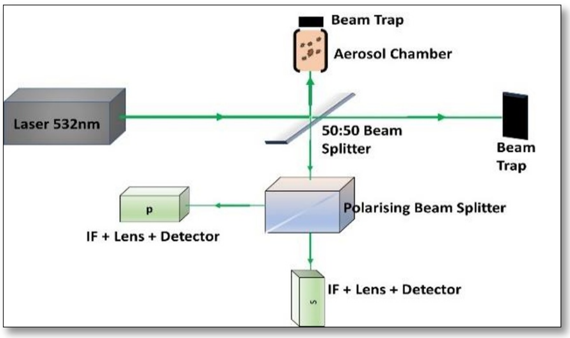

Figure 1. Optical setup with 50:50 beam splitter

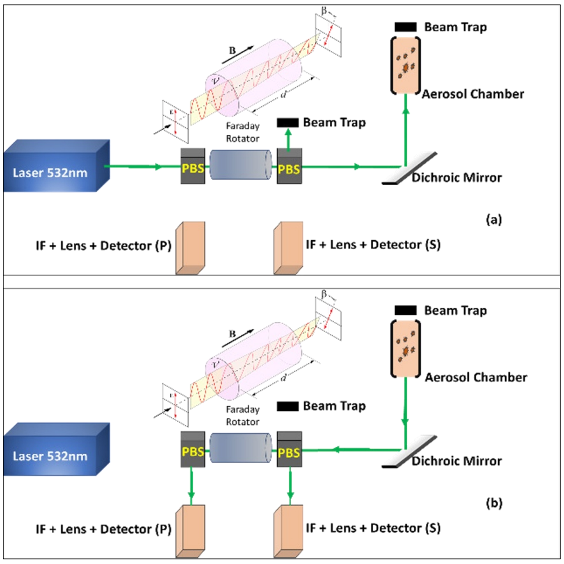

Figure 2. Optical setup with a Faraday rotator. (a) shows the path followed by incident beam. (b) shows the path followed by scattered beam from aerosol chamber.

4. Preliminary Results

First test measurement with the 50:50 beam splitter setup was done at the end of April with ammonium sulphate particles. The cw laser was modulated by a sine wave of frequency of 30 Hz and amplitude $0.4V_{PP}$. A background measurement was done before introducing the aerosol particles into the aerosol chamber. The concentration and particle size were not measured for the preliminary test measurements.

The data recorded in parallel and perpendicular channels for background measurement and with ammonium sulphate is shown in Fig. 3. A noticeable change in the backscattered signal in both the channels can be seen after introducing the aerosols in the chamber.

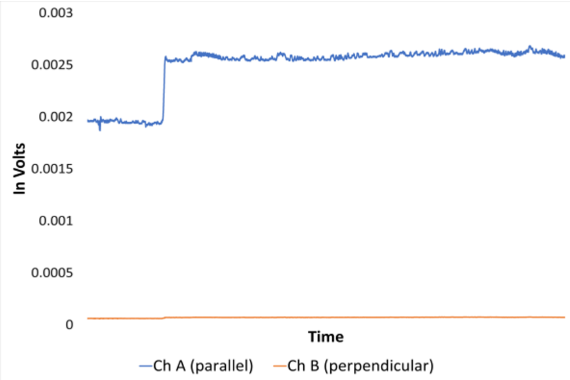

Figure 3. Change in parallel and perpendicular channel on introducing aerosol

The data was recorded for 20 minutes. The mean value of parallel and perpendicular channel for background and with ammonium sulphate particles is given in Table 2.

Table 2: Mean value for background and with ammonium sulphate

	Parallel	Perpendicular
Background	1951.947µV	62.0889µV
Ammonium Sulphate	2547.706µV	71.7255µV

The mean value of parallel and perpendicular channels after subtracting the background measurement is 595.759µV and 9.6366µV. This leads to a particle depolarization ratio of 1.6%. This value is not calibrated yet.

5. Outlook

After getting promising results from the test measurements, we are planning to do next measurements with size resolved aerosol particles. By the month of June, we plan to implement the single wavelength setup with Faraday rotator and 50:50 beam splitter. Based on the experience from the single wavelength setup, the setup with better results will be extended to include all three wavelengths (355, 532 and 1064 nm).

6. Acknowledgments

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