POLARIZATION EFFECTS INDUCED BY A TWO-MIRROR LIDAR BEAM STEERING UNIT

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ABSTRACT

Experimental data on the polarization effects induced by a two-mirror beam scanner (or *beam steering unit*) are presented. We discuss the change in polarization resulting from two different coatings and for any combination of azimuth and elevation angle. A method to cancel the effect of the scanner's mirrors so that the transmit polarization remains linear independent of the coating parameters and the pointing direction is suggested.

INTRODUCTION

Polarization lidars typically project a linearly polarized laser beam into the atmosphere in order to measure the linear depolarization ratio of the backscattered radiation by atmospheric hydrometeors and aerosol particles [1]. The depolarization measurements may be used for example to distinguish water droplets from ice crystals in clouds [2], to discriminate types of aerosols [3-6], to study polar stratosheric clouds [7], and to track honey bees for locating landmines [8].

To apply the linear depolarization lidar technique one must assure that the transmitted beam is linearly polarized. This presents a challenge for scanning lidars that use a one- or two-mirror scanner (beam steering unit, BSU). The reason is that the state of polarization (SOP) of the laser beam incident on the BSU is transformed upon reflection by each mirror [9-11]. An alternative to using a BSU is to scan the beam by moving the entire transceiver [12] which is not practical for large lidar systems. Furthermore, two-mirror BSUs offer more pointing agility.

Garisson et al. [10] developed the theoretical framework to describe the change in SOP by reflection from a pair of mirrors. The solutions are strongly dependent on knowledge of the precise coating parameters. Therefore, we are studying this problem experimentally for particular sets of mirrors. We built a miniature BSU in the lab and use a polarimeter to measure the SOP as a function of coating, azimuth and elevation angle. We will present results for two types of coatings: enhanced aluminum and protected gold. In addition, we devised a method that allows us to alter the incident polarization so that the transmit polarization through the BSU remains linear. The method works for all combinations of azimuth and elevation angle.

Aerosol depolarization measurements can also be performed with a circularly polarized laser beam [1, 13, 14]. Hu et al. [15] suggest this approach for optically thick media because, compared to linear polarization, circular polarization is less sensitive to multiple scattering. If the lidar employs a beam scanner, the effect of the mirrors must still be understood and corrected for. We plan to perform tests with circular polarization in order to quantify and minimize the change of SOP due to the BSU mirrors.

We acknowledge that a similar issue exists for the backscattered radiation. Here, we treat the transmitted beam and plan to address the backscattered signal in the future.

EXPERIMENT

This work is inspired by the Raman-shifted Eye-safe Aerosol Lidar (REAL) which is currently at California State University at Chico. REAL uses a two-mirror BSU [16]. The backscattered signal is separated by a polarizing beam splitter cube into two channels – parallel and perpendicular linear polarization defined with respect to the plane of polarization of the transmit beam [3]. Mayor and Spuler [3] show backscatter depolarization ratio from horizontal scans through low-altitude aerosol plumes. For a horizontal scan, the SOP of the beam transmitted into the atmosphere remains linear, but for all other elevation angles it is elliptical.

We built a mini-BSU to study the effect of the BSU on the polarization state. The experimental setup is shown in Fig. 1. The laser is a cw laser at 1.54 μm, the same as the REAL Raman-cell injection-seeder. However, the laser can be easily exchanged to test the polarization characteristics at other lidar wavelengths of interest.

The mini-BSU is assembled from a cage system, two rotary stages, and two right-angle mirror mounts (Fig. 2). The angle of incidence on each mirror is always 45°. A polarimeter is attached to the exit aperture of the mini-BSU to detect the SOP for all pointing directions. Initially we tested mirrors coated with enhanced aluminum. These mirrors are witness samples of the large BSU mirrors currently (winter 2011-2012) installed in REAL [17]. Now we are testing off-the-shelf protected gold coated mirrors from Thorlabs. We are interested in finding a coating with minimum sensitivity to changes of the SOP induced by the BSU mirrors.

With this set-up we can experimentally test the depolarizing effect of any coating. Thus, the application of such experimental data sets may reach beyond polarization lidars. For example, optical engineers can use the data to select the appropriate coating for optical components that

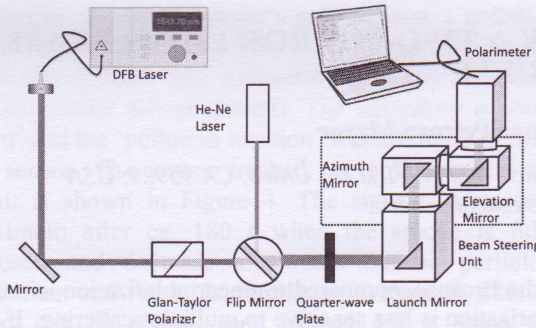

Figure 1: Experimental set-up. Glan-Taylor polarizer sets the incident polarization to linear (in the reference frame of the polarimeter); the quarter-wave plate can be used to alter the incident polarization so that the effect of the BSU is diminished; the He:Ne laser is used to align the launch and BSU mirrors; the handedness of elliptical polarization is determined by the polarimeter—right is for rotation of the electric field vector $\vec{E}$ in counterclockwise direction in a right-handed coordinate system ($\vec{E}_x \times \vec{E}_y = \vec{k}$, where $\vec{k}$ is for the propagation direction).

need to be installed in polarization sensitive instruments. Coating designers can use the data as an experimental validation of the theoretical model they use to predict the performance (in terms of polarization) of a coating.

RESULTS

To define azimuth angle, we will use a horizontal scan (0° elevation angle). Here, 0° azimuth angle refers to pointing the laser beam parallel to the incident beam on the launch mirror back toward the laser. When the azimuth angle is 90° the beam points perpendicular to the path used to inject the beam in the BSU.

Linear polarization incident on the BSU

Fig. 3 shows polarization plots from vertical scans (from 0° to 180°) for three azimuth angles 0°, 30°, and 60° and two different coatings. These would be analogous to vertical scans (also known as range height indicator or RHI) in the lidar. The incident polarization is vertical. For non-zero elevation angle the ellipticity strongly depends on the type of coating and pointing direction. The experiments confirmed that for a horizontal scan the SOP is preserved but rotates as a function of azimuth angle [3]. The ellipticity caused by the gold coated mirrors is almost twice as large as the ellipticity of the aluminum coated mirrors when compared for the same set of azimuth and elevation angle. It must be noted, however, that both mirrors have protective dielectric coatings that are most likely different and therefore we cannot attribute the observed depolarization to the metallic coating alone. The orientation of the ellipses (angle between the major axis and the x axis) is slightly different for both types of coatings which shows that it is a function mainly of the

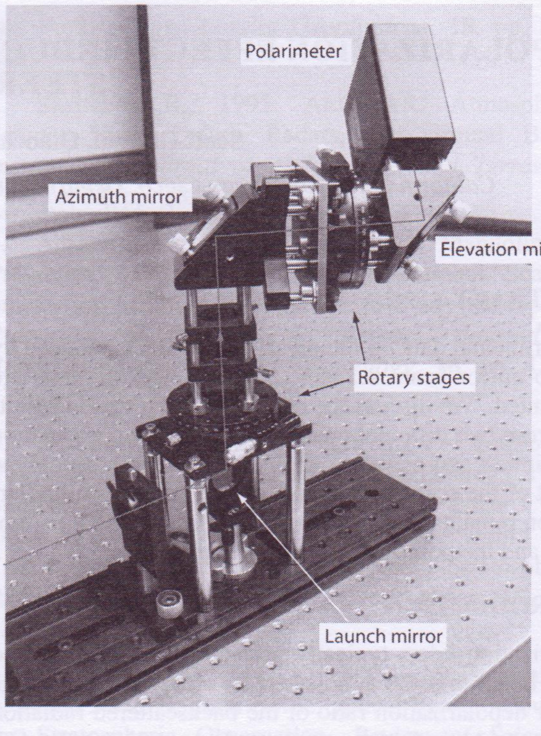

Figure 2: Photograph of the miniature BSU in the lab.

azimuth-elevation angles and is probably less affected by the type of coating.

By mapping the SOP for full RHI and PPI (plan position indicator or horizontal) scans, we found that the SOP repeats every 180° in azimuth and elevation. When comparing horizontal to vertical polarization, we found that the corresponding ellipses have the same ellipticity but their orientations are at 90° angles with respect to each other. In other words, the relative orientation of the ellipses follows the same relation as the incident polarization directions.

Correction of the induced polarization effects of the BSU

For a given coating, the induced change in polarization by the BSU mirrors is a function of azimuth and elevation angles. We apply a correction for each scan direction by means of manually setting the incident polarization with a quarter-wave plate so that the transmitted beam is always linearly polarized (Fig. 1). However, if the polarization characteristics of the mirrors are well known, the rotation of the wave plate could be controlled electronically and linked to the BSU control system.

So far we applied this method for the mirrors with enhanced aluminum. We found that we can rotate the quarter-wave plate continuously over a 20° range and obtain linear polarization after the BSU for the entire map of full (360°) horizontal and vertical scans.

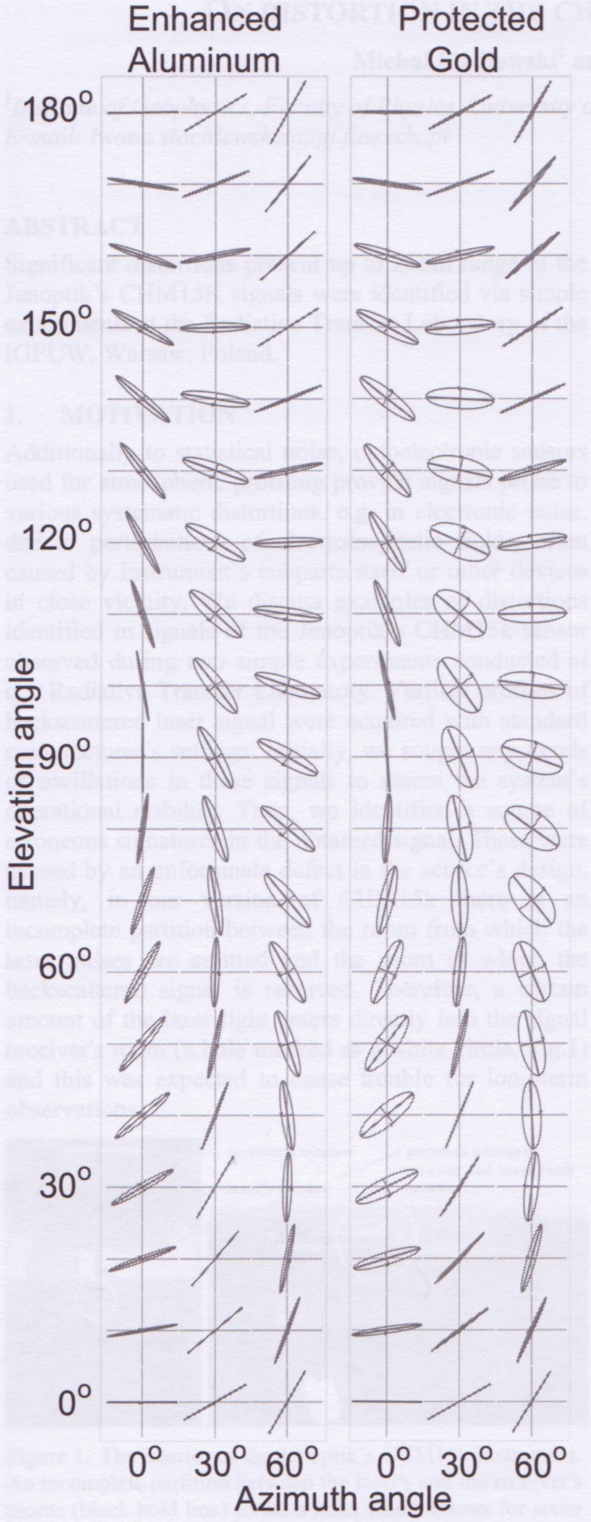

Figure 3: Polarization plots from vertical scans for three azimuth angles. The incident polarization is vertical. Two different coatings are compared.

Circular polarization

When circular polarization is incident on the BSU, the polarization of the transmit beam becomes elliptical for most of the combinations of azimuth-elevation angles. To correct for this, we plan to apply the same method as described in the previous subsection. Results will be presented at the conference.

CONCLUSIONS

In a two-mirror scanning lidar system the transmit polarization changes as a function of mirror coating parameters and azimuth and elevation angle. The induced ellipticity depends on the coating and the elevation angles. The orientation, on the other hand, is coating independent. It is determined by the pointing direction (azimuth angle) and the incident linear polarization (horizontal or vertical). In order to apply the polarization technique to scanning lidars, a correction of the induced depolarization of the BSU mirrors is required. We propose a method to continuously change the incident polarization using a quarter-wave plate to compensate for the effect of the BSU mirrors. This will require only the addition of a common optical element to the lidar system that will be electronically controlled and linked to the rotation of the BSU mirrors. We think that this method will also work if the choice is to transmit circular polarization rather than linear.

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