Wavefront Formation of Propagating Beam in Cloud-modeled Random Media

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Abstract

In this study, we examined the propagation characteristics of the annular beam through the scattering media regarded as cloud. Low fat milk (milkfat:1.8%, 1.0μmϕ) was used as the scattering medium. We confirmed that there was measurable forward scattering light in detected signal, and the coherence of the annular beam propagating in the scattering media was maintained enough to generate a non-diffractive beam even if the transmission was quite low**.** These results suggest that merits of the non-diffractive beam; high spatial resolution and tolerance to the atmospheric fluctuation, are applicable to the lidar observation.

1. Introduction

Optical sensing is used in various field; medical, industries, military and so on. In random (high scattering) media such as cloud and living tissue, propagating light is attenuated strongly by scattering effect, and thus the propagating distance is shortened. It is difficult to get information from the deeper area. Our purpose is to propagate the controlled beam in the deeper area of the random media. We examined the characteristics of the propagating beam through the random media of cloud model.

We utilized a non-diffractive beam. The non-diffractive beam is formed by diffraction effect from the annular beam[1]. It is steady in the atmospheric fluctuation[2]. Spatial resolution is improved because of the small diameter of the non-diffractive beam. But the propagating beam is scattered in the random media. Are the above merits of the non-diffractive beam available in the random media too? It is necessary to understand the propagation characteristics of the annular beam through the random media. In this study, we examined the change of the wavefront of the annular beam propagating through the cloud-modeled random media.

2. Experimental setup

The light source was a laser diode (LD) of wavelength of 657nm. We used a single-mode optical fiber to circularize the elliptical beam pattern emitted from LD. The beam emitted from the optical fiber was enlarged to 5mmϕ by an expander. This Gaussian beam was converted into the annular beam of 14mmϕ by a pair of Axicon prisms. The power of the annular beam entering the random media was 13mW.

The Gaussian beam distribution g(r) is expressed by

$$g(r) = \exp[-(r/h)^2] \qquad (1)$$

where h is a half width at 1/e of maximum intensity. It is converted into the annular distribution a(r) expressed by

$$a(r) = \sqrt{R - r/r}\ \ g(R-r) \qquad (2)$$

where R is the external radius, which is determined by the interval between Axicon prisms(Fig.1). The annular beam gathers its intensity in the center gradually through the propagation. As a result, it forms the non-diffractive beam.

The beam passed through the random media was coupled with a single mode optical fiber to detect quasi-straight scattered light selectively. The receiver's field of view (FOV) was 1.5mrad or less. We used diluted milk as the random media. The milk contained 1.8% milk fat (particle size 1μmϕ). The milk concentration was adjusted to attenuate the intensity of the incident beam up to about 10^{-7}%. When the beam of wavelength of 1μm propagates at the distance of 1.2km in the C1-cloud, the

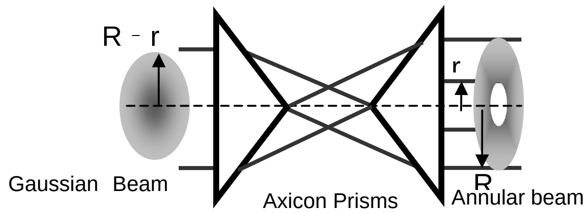
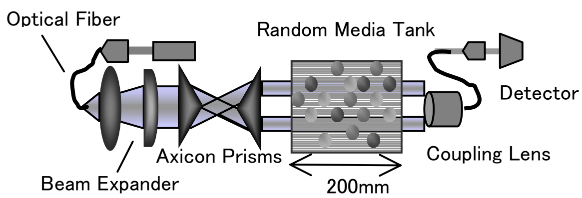
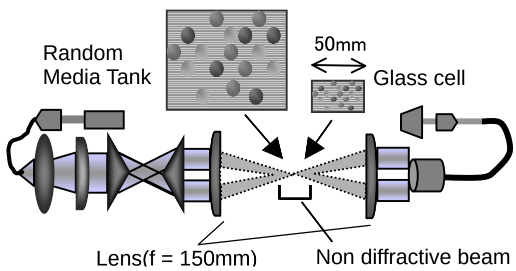


Fig.1. Transformation from the Gaussian beam to the annular beam.



(a)Collimated annular beam



(b) Focused annular beam (Non-diffractive beam)

Fig.2. Two experimental setups. (a)Collimated annular beam as incident light. (b)Non-diffractive beam formed by focusing annular beam. Then both water tank and glass cell are used.

light intensity is attenuated up to 10^{-7}%. The water tanks of 200×200×200mm and the glass cell of 50×20×30mm were used for containers of the random media.

We conducted two kinds of beam propagation experiments. One was the experiment that the collimated annular beam was used for the incident beam (Fig.2(a)). The other was that the non-diffractive beam formed by focusing annular beam was used (Fig.2(b)).

3. Experimental results

Experiment (a) Figure 3(a) is the experimental result of Fig. 2(a) Collimated annular beam. It shows intensity distribution of the propagated beam. The forward-scattering light was contained in the detected light. It expanded the beam width. We confirmed that it was the same scattering intensity as the experiment in which the Gaussian beam was used.

Experiment (b) Figure 3(b) is the result of the experiment in which the large random media (water tank) was used in Fig.2(b). One can see that the forward scattering light had the same intensity as the former experiment (a). The intensity distribution of light propagated through the random media well remained its feature of the non-scattering beam passed through water (milk0%). This means that the non-diffractive beam was generated at neighborhood of the focus point though the random media. These results suggest that the annular beam propagating in the cloud maintains enough coherence to generate the non-diffractive beam. In addition, The forward scattering light at the center of the annular beam was more fluctuated than the former results. We considered that this phenomenon resulted from the fluctuation of the side-lobe of the non-diffraction beam.

Figure 3(c) is the result when the small random media of glass sell was used. The forward scattering light increased twice as large as the intensity of the former experiment. The intensity of scattered light should be equal to other experiments, because the transmittance in Fig.3(c) was almost equal to other experiments. When the propagating beam was scattered by the small random media at the focal point, it acted as a point light source. As a result, multiple scattered light was detected. This experiment is equivalent to the situation that the non-diffractive beam is incident in the measurement object (cloud) at the short distance in lidar observation. This result means that in such case, the enough narrow FOV is essential in lidar detection optics, because of the reduction of the multiple scattered light.

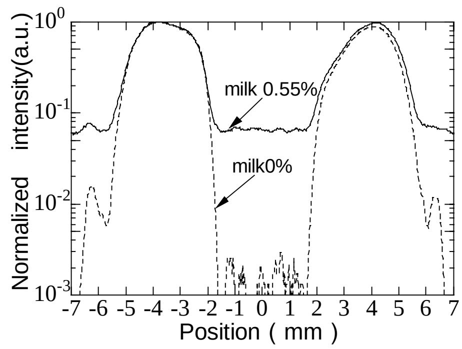
4. Conclusion

In this study, the characteristics of the propagating annular beam thorough the cloud-modeled random media were examined by the experiment. We confirmed that the annular beam propagating in the cloud maintained enough coherence to generate non-diffraction beam, while there was the forward-scattering light of about 6% intensity of the total. Those results suggest that the merit of the non-diffraction beam; high spatial resolution and tolerance to atmospheric fluctuation, are applicable in the lidar cloud observation. In the situation that the non-diffractive beam is incident in the object at the short distance, the narrow FOV is essential for detection optical system because the multiple scattering light is not able to be ignored. For the future study, we will verify the correlation between the coherence of the propagating beam and ratio of forward-scattered light intensity to the total in the concentrated random media, which is the model of living tissue. We explore the condition that the beam efficiently propagates in the deeper area of the media.

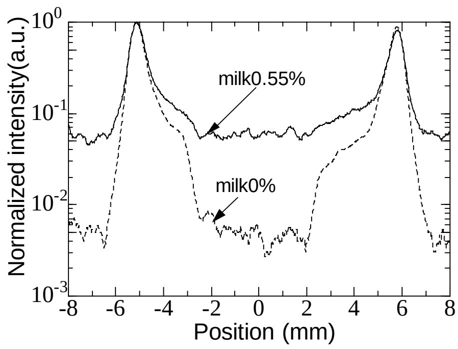
Reference

[1]T. Aruga, “Generation of long-range nondiffracting narrow light beams”, Appl.Opt., Vol.36, No.16, pp.3762-3768, 1997

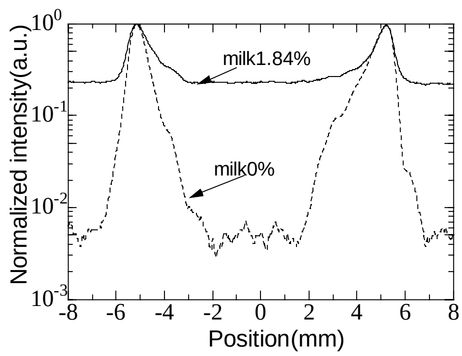
[2]T. shiina, M. Ito, and Y. Okamura, "Nearly Non-DiffractiveBeam for Lidar Application", Proceeding of SPIE Laser System Technology, Vol. 5087, pp.115-123, 2003



(a)Collimated annular beam though the large media



(b)Focused annular beam through the large media tank



(c)Focused annular beam through the small media cell

Fig.3 Beam intensity distribution through the random media at each experiment. In these graph, intensity was normalized.