LASER-INDUCED FLUORESCENCE (LIF) LIDAR FOR PLANT MONITORING

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ABSTRACT

This paper introduces laser-induced fluorescence (LIF) lidars developed at Shinshu University for monitoring living status of plant.
1) Plant LIF spectrum monitoring lidar: LIF spectrum of poplar tree leaves 40 m away from the lidar was monitored. Broad LIF spectrum 400 nm to 800 nm gave information about pigments inside the leaves.
2) Plant LIF imaging lidar: A gated ICCD camera was used to make a distribution pattern of LIF intensity of a tree. Chlorophyll concentration of gingko tree leaves 65 m away from the lidar was remotely estimated and its distribution image of the whole tree was made.
3) Plant LIF lifetime measurement lidar: A 40 ps YAG laser and a 180 ps rise-time gated MCP-PMT made possible the leaf's LIF lifetime measurement in the daytime. The lifetime of plane tree leaves 18 m away from the lidar showed that it was longer from night to early morning and shorter in the daytime.

1. INTRODUCTION

Expansion of global warming area, increase of ultra violet rays, deposition of acid rain, spread of artificial pollutants in everywhere, and others are reported. They surely effect on growth of plants and cause a change of vegetation distribution on the earth. Consideration to important roles of plants, especially generation of oxygen and production of organic matter through photosynthesis which have been supporting our life and society, makes us reaffirm necessity of monitoring plant growth and understanding the status, which they are in the face of such undesirable environmental changes. This should be one of the highest priority researches.

It is known that plant leaves can emit fluorescence in response to laser irradiation which is called laser-induced fluorescence (LIF). The LIF spectrum varies its shape depending on molecule species and concentration containing in the leaves. So LIF will be a good indicator to monitor plant status.

When we attempt to obtain plant information, it is important to consider that plants are living system, and the monitoring should be done outside where plants are growing. Lidar as an optical method can be supposed to be suitable for this purpose because it is a non-invasive technique for remote sensing.

These considerations suggest that lidars based on LIF spectroscopy will be a powerful apparatus for plant monitoring.

2. LIF LIDAR FOR PLANT MONITORING

A basic structure of the plant monitoring lidars is the same as traditional ones. Detection structure and manner are improved according to the specific purpose.

2.1 PLANT LIF SPECTRUM MONITORING

A Q-switched Nd-YAG laser (355 nm, 6 ns, 3.2 mJ/pulse, and 10 Hz) was combined with a Schmidt-Cassegrainian telescope (25.4 cm in diameter). A bandle fiber, whose inlet shape was a circle and the outlet shape was a rectangle, was set at the focal point of the telescope and delivered fluorescence to a spectrometer. The connection of the telescope and the spectrometer using the fiber made the system handling easy. Detection was done by a multi channel plate (MCP) type intensified (I) CCD array in which the MCP was an electron amplifier. A photocathode of the MCP was electronically gated for 200 ns and the gate opening time was delayed to coincide with the fluorescence arrival time onto the detector. This synchronized detection in short time period effectively reduced the solar intensity so effectively that weak plant fluorescence could be detected from long distance even in the daytime. This synchronized detection method was also attempted in other LIF lidar systems.

The target was a poplar tree 40 m away from the system. An example of the LIF spectrum of a poplar's green leaf is shown in Fig. 1. A representative LIF spectrum with two peaks at 685 nm and 740 nm and small ones at 460 nm and 530 nm are observed. Origin of the former wavelengths is chlorophyll *a* and those of the latter ones are secondary metabolites [1], which involve living plant information.

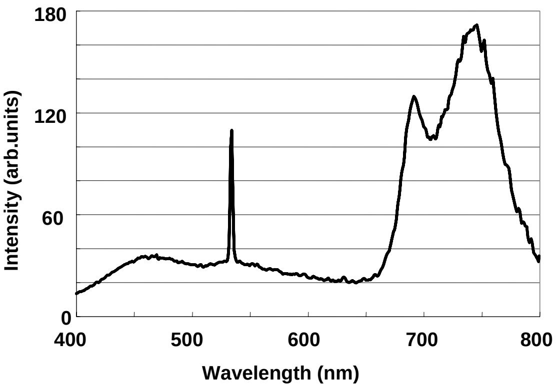

Fig. 1 LIF spectrum of a poplar's green leaf

2.2 Plant LIF imaging lidar

A LIF imaging lidar was developed to make a chlorophyll concentration distribution image of a whole tree. Chlorophyll is the main molecule for photosynthesis. A laser (532 nm, 10 mJ/pulse, 6 ns, 10 Hz) was magnified by a negative lens to cover the whole area of a tree. An ICCD camera with a 42 mm diameter lens was used as an imaging device. An interference filter centered at 685 nm and that at 740 nm were inserted alternately to obtain chlorophyll information. The chlorophyll concentration was calculated by taking the ratio of their intensities (740 nm intensity to 685 nm intensity) [2].

The second target was a gingko tree (5 m height x 4 m width) growing outside which was located about 65 m away from the system. Observations were made at nighttime and at least once a month from May to November. Figure 2 shows an example of chlorophyll concentration image of the gingko tree (image center) in August [2].

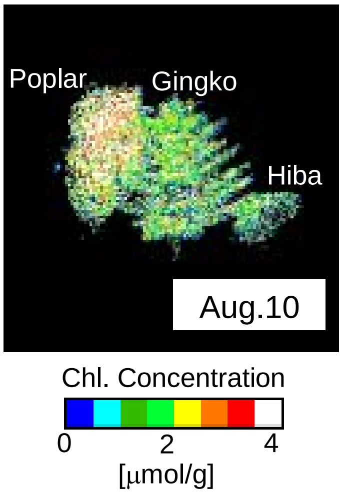

Fig. 2 Chlorophyll concentration distribution image of a gingko tree

2.3 Plant LIF lifetime measurement lidar

Mean chlorophyll LIF lifetime, which is derived from a time-dependent decay curve of LIF, is found to be almost proportional to fluorescence quantum yield [3]. The quantum yield provides a measure of the capability of photosynthesis activity that can be evaluated by measuring LIF lifetime.

A lifetime measurement lidar was constructed with a pico second Nd-YAG laser (532 nm, 40 ps, <500 μJ/pulse, 20 Hz), a 40 cm Fresnel lens type telescope, two MCP-PMTs with 185 ps of rise-time and a digital oscilloscope having 8 GHz of analogue band-width. The rise time of the detection system was calculated to be 223 ps. LIF over 650 nm and back scattering at 532 nm from the same leaf were separately detected by each of the MCP-PMTs. The lifetime was calculated by a de-convolution analytical method.

Target was a plane tree leaf which was 20 m away from the system. Variation of the measured LIF lifetime is shown in Fig. 3. The lifetime gradually decreased from 1.3 ns early in the morning before sunrise to 0.9 ns at noon and stayed low during the daytime, then increased to around 1.5 ns at night. This shows inverse relationship of the lifetime to the solar radiation intensity.

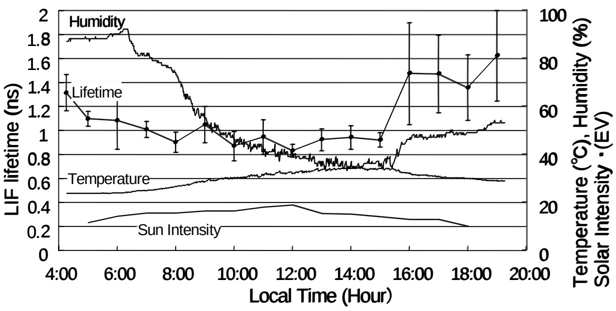

Fig. 3 Daily variation of LIF lifetime of a plane leaf

4. CONCLUSION

Three different type LIF lidars were developed. Results were sufficient to demonstrate the usefulness of the LIF lidar and the possibility of remote monitoring of living plants' status.

REFERENCES

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