Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp255-256

F-1-02

A potable bioactive monitoring device for observing water transport in plants with a non-invasive technique

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Abstract

We have developed a portable bioactive monitoring device for observing growth conditions of domesticated plants to contribute to the efficiency of farm work. The small device with a CMOS image sensor is attached to a leaf surface and observes time-dependent change of stomatal transpiration without invasiveness. It can reveal water transport mechanism in vivo.

1. Introduction

Currently, growing management of agricultural plants is carried out based on the plants' outward information such as the size of plants and the leaf development. However, these methods have not obtained real time information from the plants. There is a problem that it is difficult to respond promptly because of delay from the information. In order to respond quickly, methods for monitoring physiological activities such as water transport of plants in real time are studied. Focusing on water transport measurement, it is possible to measure in a non-invasive method without dye and obtain the relationship between the water transport and the growth of the plants. At present water transport researches in plants are actually measured using the magnetic resonance imaging [1] or the positron emission tomography [2]. However these methods need a large-scale devices. It is difficult to observe the water transport in the field such as a farm. If the water transportation of plants can be measured noninvasively in real time at the farm, a more efficient cultivation strategy can be achieved.

In this research, we have developed a small optical imaging device that has a compact shape and a versatile system for measuring water transport by using CMOS integrated circuit technology [3].

2. Potable monitoring device

In order to observe water transport in plants, we have developed a potable monitoring device with small shape and lightweight structure (Fig. 1a). This device includes a CMOS image sensor, a fiber optic plate (FOP) and LEDs that are placed on a small printed-circuit board (Fig. 1b). The sensor specification is shown in Table I. For protect the sensor from scuffs and moisture, the FOP is placed on the sensor's surface.

The device has two LEDs with different color for illumination, which are transmitted to plant tissue for detecting water transport of the leaf. Green LED with an emission wavelength of 525 nm is located on opposite side of the sensor as light sources for observing the surface of the leaf. This wavelength is absorbed little by the chloroplast [4]. The device enables to acquire fine images of the leaf (Fig 1c). Infrared LED with an emission wavelength of 940 nm is used for observing the water transport. This wavelength is high absorption spectral of the water and has little influence on plants. We can observe the water transport in plants. In this experiment, observe the movement of the pores and the stomatal transpiration.

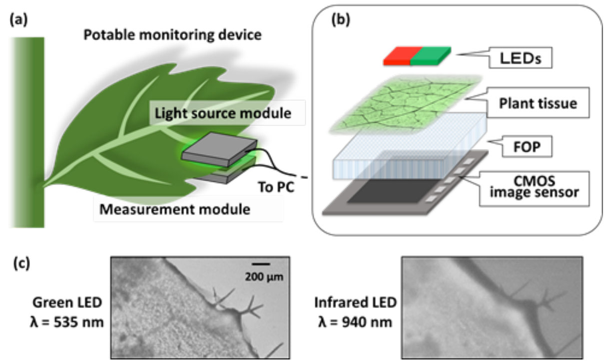

Fig. 1 A potable monitoring device for observing water transport in plants (a) Overview of the device. (b) Structure of the device. This device has two color LEDs for observing two functions. (c) It shows transmission images of the leaf. Left image was captured with a green LED light source. Right image was captured with an infrared LED light source.

Table I. Specification of the CMOS imaging device

CMOS image sensor	Technology	0.35-µm 2-poly 4-metal standard CMOS Process
	Operating voltage	3.3 V
	Chip size	1048.6 µm×2700 µm
	Pixel array size	900 µm × 1920 µm
	Pixel size	7.5 µm × 7.5 µm
	Pixel count	33768
LED	Wavelength	535 nm, 940 nm

Our proposed device is so small that it can be attached to a leaf in a plant for optical imaging as shown in Fig. 1. Thus, it does not need any bulky optics such as an objective lens. These small and light features enable observation of water transport with minimizing the effects of stress to the plants.

3. Experimental setup

For observing the water transport in a plant's leaf, we attached the device to a leaf of a poplar as shown in Fig. 2. First, the device was attached to the leaf directly (Fig. 2b). Next, we put the two types of LED light sources mounted on the other side of the leaf.

After setting up the device, the LEDs were turned on (Fig. 2c). In this experiment, we covered the sensor with aluminum foil for shading (Fig. 2d). There was small stress to the plants from the device.

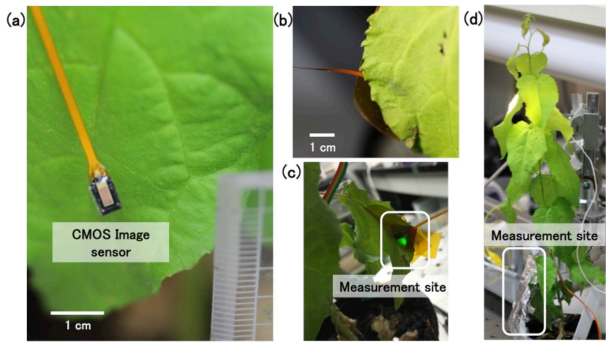

Fig. 2 Photos of the potable monitoring device with the poplar. (a) The CMOS image sensor. (b) The sensor attached on the leaf surface. (c) The green LED light source. (d) Experimental set up of the potable monitoring device for measurements.

4. Observation of stomatal transpiration

The water transport in the plant is correlated closely with transmission images. It is important to observe the stomatal transpiration for understanding plant growth. We performed optical imaging using our CMOS imaging device. The illumination light at 940 nm is effectively absorbed plant surface by the water. Thus, transpiration changes in the leaf can be imaged our device. In this experiment, we measured the stomatal transpiration of the leaf. We obtained sequential images at a frame rate of 40 fps.

We observed the leaf with the infrared LED light source as shown in Fig. 3a. Leaf veins can be seen in this figure. The five squares in the figure indicate regions of interest. Figure 3b shows the results of the imaging. The intensity changes of the leaf surface were observed after 500 seconds (Figure 3c). These intensity changes indicate the stomatal transpirations of the leaf surface. Our device can observe the stomatal transpiration *in vivo* experiments.

Conclusions

We have developed a portable bioactive monitoring de-vice for observing growth conditions. We successfully obtained fine images of the leaf. Moreover, we observed the stomatal transpiration of the leaf by using our device. In the next work, we will try to observe of stomatal transpiration related to the movement of the pores with the green LED light source at the same area of the leaf.

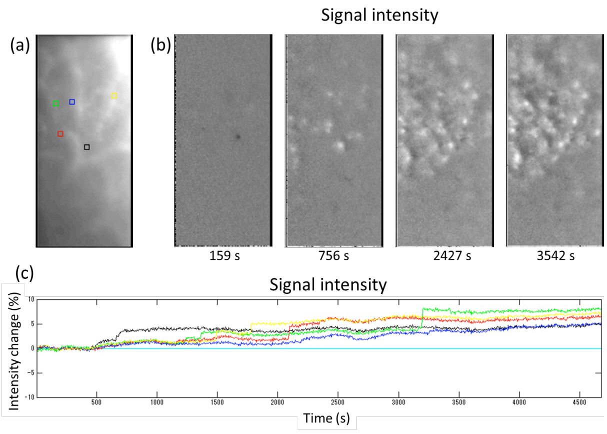

Fig. 3 Results of stomatal transpiration measurement with infrared LED light source. (a) Transmission image of the leaf with regions of interests. (b) The continuous images of intensity changes of the leaf. The stomatal transpirations occurred during the experiments. (c) The signal intensity changes of the regions of interests of Fig. 3a. The timing of the stomatal transpirations occurrence can be observed.

Acknowledgements

This work is supported by Japan Science and Technology Agency, Core Research for Evolutional Science and Technology (JST-CREST), and VLSI Design and Education Center (VDEC), The University of Tokyo with the collaboration with Cadence Corporation and Mentor Graphics Corporation.

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