Proceedings Paper:

Singh, K, Bandyopadhyay, A, Bertling, K et al. (11 more authors) (2020) Monitoring Water Dynamics in Plants using Laser Feedback Interferometry. In: 14th Pacific Rim Conference on Lasers and Electro-Optics (CLEO PR 2020). 14th Pacific Rim Conference on Lasers and Electro-Optics (CLEO PR 2020), 03-05 Aug 2020, Sydney Australia. OSA . ISBN 9780646825045

https://doi.org/10.1364/cleopr.2020.c12b_4

Monitoring Water Dynamics in Plants using Laser Feedback Interferometry

Khushboo Singh[1,2], Aparajita Bandyopadhyay[2,3], Karl Bertling[4], Yah Leng Lim[4], Tim Gillespie[4,5], Ashley Robinson[5], Dragan Indjin[6], Yingjun Han[6], Lianhe Li[6], Edmund H. Linfield[6], A. Giles Davies[6], Paul Dean[6], Aleksandar D. Rakić[4] and Amartya Sengupta[1,2,4]

[1]Department of Physics, Indian Institute of Technology Delhi, New Delhi – 110016, India

[2]THz Imaging and Spectroscopy Laboratory, Indian Institute of Technology Delhi, New Delhi – 110016, India

[3]Joint Advanced Technology Center, Indian Institute of Technology Delhi, New Delhi – 110016, India

[4]School of Information Technology & Electrical Engineering, University of Queensland, St Lucia QLD 4067, Australia

[5]L3Harris Micreo, 7 Hi-Tech Court, Brisbane Technology Park, Eight Mile Plains, QLD 4113, Australia

[6]School of Electronic and Electrical Engineering, University of Leeds, Leeds LS2 9JT UK

Email: amartya@physics.iitd.ac.in

Abstract: In the present work, the drought response in Tiger grass (Thysanolaena latifolia) plants has been investigated by monitoring water status using THz QCL based Laser Feedback Interferometry imaging technique.

1. Introduction

Precise measurement of water status in plants is of critical importance in understanding the drought tolerance and adaptive response of the plants [1]. Terahertz (THz) spectroscopy, time-domain as well as continuous wave, are among the standard non-invasive spectroscopic techniques used for investigating hydration level in plants. THz radiation is highly absorbed by liquid water, hence is very sensitive to minute change in water level. Other advantages of this technique over other techniques are – it is safe for biological sample due to its low photon energy and provides both refractive index and absorption coefficient as electric field is measured instead of intensity [2]. THz spectroscopy and imaging has been employed by different research groups to investigate water status in different agricultural crops [3].

However, this technique is limited by factors such as low THz emitted power, slow acquisition and size of the measurement systems. For field deployability, the technique needs to be rapid, accurate and compact. Quantum cascade Laser (QCL) based Laser Feedback Interferometry (LFI) is one such technique which uses the same QCL as both emitter and detector and works on the principle of self-mixing [4]. The radiation emitted from the QCL interacts with the target and is reflected back into the laser. This back – reflected radiation mixes with the intra-cavity electric field and hence results in change in the laser parameters. In this work, THz QCL based LFI imaging is used for monitoring water status in stressed Tiger-grass *(Thysanolaena latifolia*) plant leaves *in-vivo*. The response of stressed plant leaves after watering was systematically investigated over time.

2. Experimental setup and sample details

The THz QCL used as the source and the detector operated at a frequency of ~ 2.75 THz. A custom built laser driver was used to drive the THz QCL in pulse mode. Sterling cryocooler was used to maintain the operating temperature of the QCL at 50 K. The experimental setup is similar to [5] with a polished Tsurupica lens (f = 50 mm) collimating the beam, a TPX lens (f = 100 mm) focusing the beam on the target and an external cavity length of ~1.6 m. In this setup, the self-mixed signal is monitored via laser terminal voltage and the amplitude of the signal mapped spatially across the target. The amplitude of the self-mixing signal is highly dependent on the target reflectivity with higher reflection giving typically stronger amplitude signals.

The plants were collected from Brisbane Garden Nursery (-27°28' S, 152°58' E), Brisbane, Australia. The plants were mature and of almost the same age. After obtaining the samples, they were placed in partial sunlight and provided with 100 ml of water each day. The average temperature and humidity during the storage time was 25° C and 55 % respectively. The plants appeared visually healthy and showed no sign of disease. Prior to imaging the plants were stressed for ~48 hours and the first set of raster scan images were obtained (0 hr). They were then watered and reimaged at 1 hr and 2 hrs later. The time required for recording each image of dimension (24 × 24) mm^2 was around 15 minutes. The resolution of the images was set as 0.2 mm in both dimensions. The leaves themselves were mounted on a metal plate, which in turn, was mounted on a three dimensional translational stage (see Fig. 1(a)).

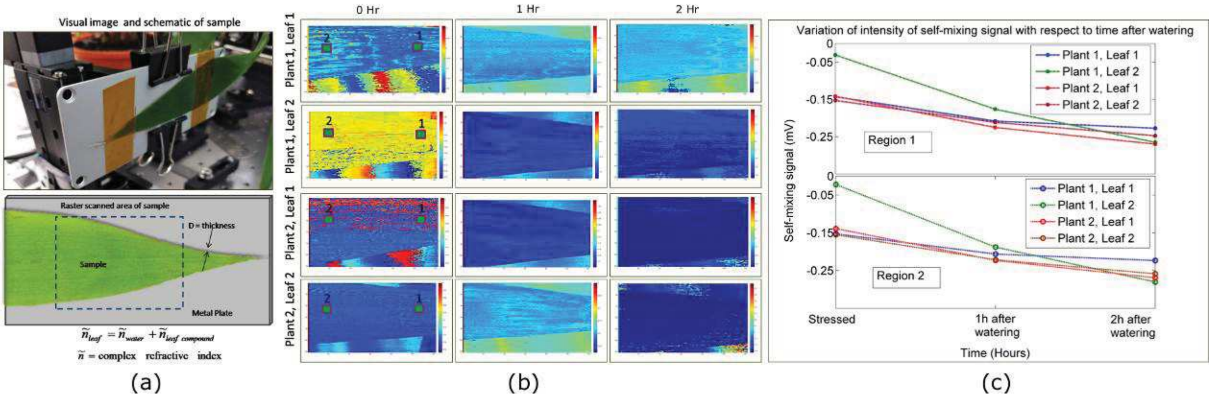

Figure 1 (a) Visual image of sample mounted on the stage, schematic diagram of sample with the detail of scanned area (b) Raster scanned raw intensity images of the samples at different steps and (v) plot showing variation of intensity at two regions of the samples at different stages(normalised to metal plate)

3. Result and discussion

The leaf samples are biological reactors where several physiological processes take place simultaneously. The raster scanned intensity images of the samples at different stages are shown in Fig. 1(b). Two regions, each of 4 pixels have been selected from each sample, and the average intensity was obtained. All the samples show same trend of intensity variation, both in region 1 and region 2.

The THz radiation from QCL incident on the leaf is reflected back into the laser. As THz radiation is strongly absorbed by water, a 'drier' leaf offers a greater reflection and thus higher amplitude in the measured image. A 'hydrated' leaf conversely produces a signal with lower reflectivity due to the higher water content. The variation of the extracted self-mixing signal intensity with time shows the amplitude decreasing with time. This signifies that the absorption in leaf increases since the water content increases in it over time and hence less reflection from the leaf. The consistency of system performance was ensured by calibrating (normalising) it against the reflectivity from the metal plate over the entire acquisition time.

4. Conclusion

The THz QCL based Laser Feedback Interferometry imaging can be used as an efficient tool for monitoring hydration dynamics in plant *in-vivo*. Since the absorption of water is higher above 2 THz and the operating frequency of the QCL employed here as source operates as ~ 2.75 THz, this is very sensitive to even a small change in hydration level. Our future work would extend these present qualitative analyses into quantitative estimation of water content in in-vivo plants under normal and drought stressed conditions.

5. Acknowledgements

The authors would like to acknowledge the support of the Defence Research and Development Organization (DRDO) vide Grant #DFTM/03/3203/M/JATC, the Department of Atomic Energy-Board of Research in Nuclear Science (DAE-BRNS) vide Grant # 37(3)/14/01/2016-BRNS/37015, the Australian Research Council Discovery Project (DP160103910), the Engineering and Physical Sciences Research Council (EPSRC), UK HyperTerahertz programme (EP/P021859/1), European Cooperation in Science and Technology (COST) (BM1205 Action), the Royal Society and the Wolfson Foundation.

6. References

1. H.G. Jones, Monitoring plant and soil water status: established and novel methods revisited and their relevance to studies of drought tolerance, J. Exp. Bot., **58**, 119 (2007).
2. P. Nie et al., Detection of water content in rapeseed leaves using terahertz spectroscopy, Sensors, **17**, 2830 (2017).
3. F. Qu et al., Review of theoretical methods and research aspects for detecting leaf water content using terahertz spectroscopy and imaging, Int. J. Agric. & Biol. Eng., **11**, 27 (2018).
4. A.D. Rakić et al., Sensing and imaging using laser feedback interferometry with quantum cascade lasers, Appl. Phys. Rev., **6**, 021320 (2019)
5. Y.L. Lim et al., Coherent imaging using laser feedback interferometry with pulsed-mode terahertz quantum cascade lasers, Opt. Express, **27**, 10221 (2019).