Quantitative video-rate hydration imaging of Nafion® proton exchange membranes with THz radiation

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***Abstract* – Nafion® polymeric membranes are the prime electrolyte material for proton exchange membrane fuel cells (PEMFC), which require adequate hydration in order to reach high proton conductivity. The relatively high attenuation of terahertz (THz) radiation of liquid water compared to the surrounding polymer assembly enables a contrast to be observed for inspecting water build-up in Nafion® membranes. This paper investigates the feasibility of a compact THz camera for liquid water mapping and quantification in Nafion® polymeric membrane.**

I. INTRODUCTION

PEMFC are electrochemical devices at the forefront of clean energy production for portable, transportation and, to a lesser extent, stationary applications. Water management is a key issue in these devices: during the fuel cell operation, protons emerge from the anodic hydrogen oxidation and flow across the polymer electrolyte membrane (PEM) to the cathode, combining with the electrons coming from the external load circuit and oxygen in the process to form water. Product water must be removed promptly from the cell, as it can flood catalytically active sites and hinder reactant mass transport. At the same time, the prime material for PEMs is Nafion®, a perfluorinated ionomer membrane, which requires adequate hydration to achieve high proton conductivity and avoid material damage [1]. Therefore a good balance of hydration needs to be maintained. As such, various imaging techniques have been proposed to better understand the complex physical phenomena involving liquid water droplet condensation and transport within the PEMFC. Examples of these techniques include MRI, neutron, x-ray, infrared and direct visualisation [2]. In general, techniques such as MRI, neutron and synchrotron x-ray imaging/tomography can provide in-situ information on liquid water transport through visually opaque components at high spatial resolution, but are limited in terms of time resolution and availability. On the other hand, direct visualisation and infrared imaging use compact and mobile devices with high time and spatial resolution but requires optically transparent windows in a PEMFC in order to yield useful information on liquid water content.

THz radiation can penetrate through optically opaque dielectric materials, such as polymers, while being strongly attenuated by liquid water thus making THz imaging techniques attractive for non-destructive quality control applications [3]. With the recent available of a compact, low-cost THz camera, this paper explores the feasibility of a THz camera for inspecting liquid water in Nafion® PEMs.

II. RESULTS

A THz system, consisting of an IMPATT 0.1 THz source and a THz camera comprising a 16x16 array of GaAs-based semiconductor detectors, was realised. THz intensity maps were acquired in the form of videos at 30 Hz framerate and at a 1.5 mm pixel size. To benchmark the THz intensity readings against gravimetric measurements, the mass of the hydrated membrane was monitored throughout the liquid dehydration process. To demonstrate the imaging system's ability to quantify liquid water, THz transmission images were also acquired through a custom-made liquid cell with pre-determined water thickness, where the relative intensities at regions of interest was found to be in a good agreement with the estimated intensities using Beer-Lambert law for a range of water thicknesses (Fig. 1).

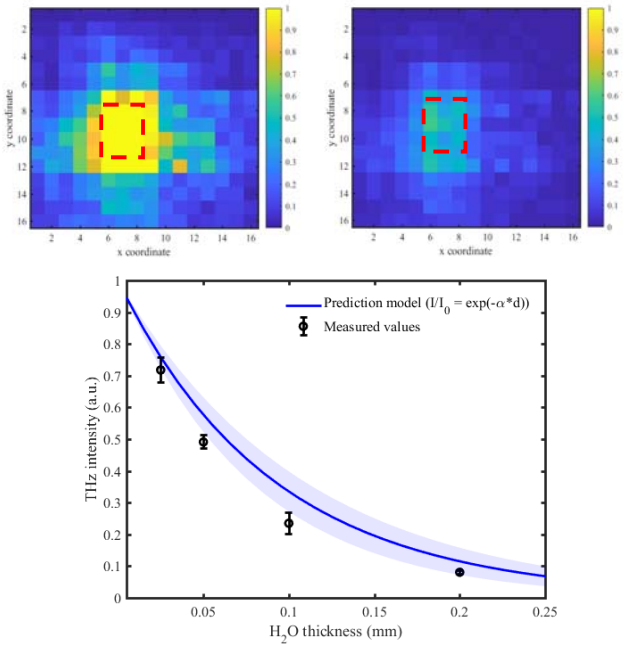

Fig. 1. THz liquid water content sensitivity analysis. THz intensity maps relative to empty and water filled liquid cell and a region of interest is used to estimate the liquid water thickness in the cell for comparison against Beer Lambert model.

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REFERENCES

[1] M. Schalenbach, W. Lueke, W. Lehnert, D. Stolten, "The influence of water channel geometry and proton mobility on the conductivity of Nafion", *Electrochim. Acta*, vol. 214, pp. 362-369, 2016.
[2] A. Bazylak, "Liquid water visualisation in PEM fuel cells: A review", *Int. J. Hydrog. Energy*, vol. 34, pp. 3845-3857, 2009.
[3] J. F. Federici, "Review of moisture and liquid detection and mapping using terahertz imaging", *J. Infrared Millim. Terahertz Waves*, vol. 33, no. 2, pp. 97-126, 2012.