Chapter 5

Conclusions and Future Work

The work in this thesis was motivated by a desire to propose a new alternative technique for studying water distribution in proton exchange membrane (PEM) fuel cell. The purpose of the work presented in this thesis was to investigate the possibility of reflective terahertz (THz) imaging to detect and indicate water at flow channel. This thesis, furthermore, includes visible imaging technique for investigation water-droplet dynamics in the flow channel of the PEM fuel cell.

5.1 Conclusion and Discussion

Water presence in the flow channel of the PEM fuel cell has been successfully observed *via* both visible and THz imaging techniques. The model transparent fuel cell consists of the machine-through made of nickel-coated brass flow channel and the poly-methyl-methacrylate (PMMA) window on the cathode side. The visible image obtained by direct visualization offers process of water droplets formation and growth in the real PEM fuel cell under operation. A preliminary experiment was performed to study the transient response of the cell with respect to load changes. We found that the cell voltage responded almost instantaneously to a change in drawing current, while the water content in the flow channel and on the gas diffusion layer (GDL) surface could not as quickly respond. Under the conditions tested in this study, it took about 10 seconds to alter the water distribution in the flow channel as a result of load changes. When the cell reached steady state for each drawing current, we observed a slightly increase in water accumulation for higher current densities. The process of water-droplet formation and removal in the flow channel and on the top surface of the

GDL was investigated at a fixed current density. At 5 seconds after drawn current, water started to accumulate and build up, particularly at the bend of channel where the reactant gas was denser, i.e., more reactions. Land-touching droplets appeared after 5 min from drawing the current, and some of them grew and expanded until became water column. The removal process sped up when the water droplets became smaller in size; some droplets eventually were removed from the cell. However, the water droplet at the corner of the bend of channel was hardly removed out of the cell due to wall adhesion effects. The inefficient water removal process could cause clogging and flooding resulting in lower cell performance.

For THz imaging, the reflective THz imaging system was successfully established and the THz images were obtained from two types of THz window materials. Both PMMA and silicon (Si) windows can satisfactory distinguish water-filled region in the machine-through-brass flow channel from the air-filled region. However, the Si window provides greater reflected signals yielding more depth into details of the image than the PMMA window. The line-scan plot is adopted in order to quantitatively compare spatial resolution of the THz image. Under the current setup with 30 degree of incident angle, insertion of a polarizer to our THz imaging system results in image resolutions of 2.3 ± 0.5 mm and 2.2 ± 0.5 mm for p-polarized and s-polarized THz radiation, respectively. Increasing incident angle should improve the resolution using the polarizer. Using metal mesh filtering is another way to improve the image resolution. We placed a copper mesh grid wire in our THz imaging system. The calculation suggests lower frequency components will be filtered out more with higher mesh number, which results in smaller focusing beam. The insertion of metal mesh in the THz imaging system is consistent with the calculation as the spatial resolution of 380x380 μm^2 mesh is 1.9 ± 0.5 mm, while that of 180x180 μm^2 mesh is 1.7 ± 0.5 mm. The THz imaging technique is proved to be a promising tool for studying water management in the PEM fuel cell.

5.2 Future Work

The work presented in this thesis has shown that reflective THz imaging has the potential to distinguish water region in the flow channel. However, this technique is not yet more valuable imaging modalities for water management studies than visible imaging. For this to become possible, more detailed studies of the interaction of THz radiation with components of PEM fuel cell and model fuel cells must be undertaken in order to understand the physical principles that give rise to the detected signals. Studies have shown that there is statistical difference in the THz reflection signals of a flow channel plate and in flow channel. The work presented in this thesis has also established that reflective THz image resolution is better by using s-polarized THz radiation and/or grid mesh filter. Future developments extending from this work, therefore, are focused on *in situ* investigation of PEM fuel cell and improvement of THz image spatial resolution through combination of polarizer and metal mesh filter together.

THz imaging will continue to be developed to improve the spatial and temporal resolutions. Reflective THz imaging of water droplet within the PEM fuel cell will demand submicron resolution since the droplet itself can be smaller than 10 μm. However, the spatial resolution of conventional THz imaging is diffraction limited and thus only features with dimensions of hundreds of micrometers to millimeters are resolvable. This limit can be overcome by utilizing near-field imaging techniques that achieve spatial resolutions of up to $10^{-6}\lambda$ [27]. However, extremely brilliant sources are necessary to compensate for losses in intensity since most techniques employ apertures to confine THz radiation at cost of total power.