The Impact of Non-uniform Electrodes on Performance and Gas Cross-over

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Challenges for CCMs in PEMWE

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Main target for PEMWE is cost reduction

- CCM one of the main focusses of cost reduction
  - Thrifting PGM content in catalyst layers
    - Novel catalysts both supported and unsupported being developed
  - Reducing membrane resistance
    - Thinner membranes
  - Reducing hydrogen crossover
    - Modifying chemistry / adding recombination catalyst
- Need to do above while maintaining performance and durability

- Porous titanium current collectors also add a significant cost
  - Tighter tolerances significantly increase costs
- CCM needs to interact well with the current collector to allow reduction in hardware costs

Cell sealing of typical single cell

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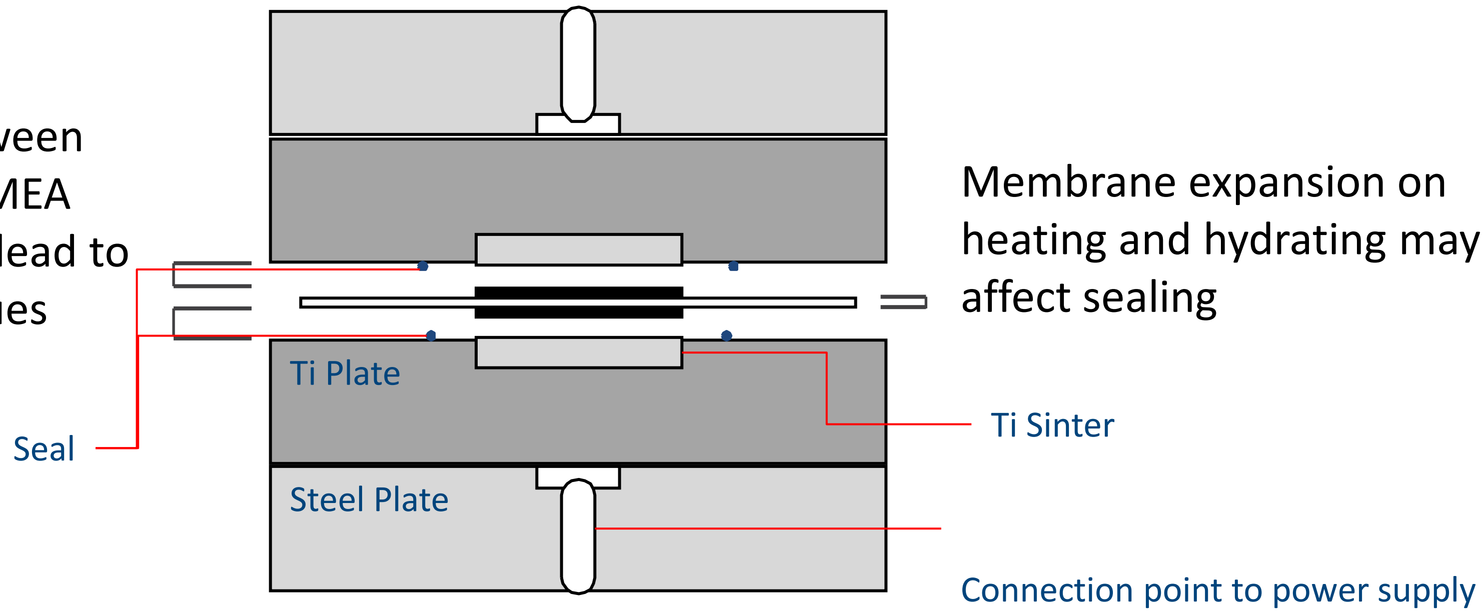
A mismatch between seal height and MEA step height may lead to compression issues



Membrane expansion on heating and hydrating may affect sealing

- Cell compressed by 9 bolts on edge, using fixed torque
- Assembly carried out at room temperature and with dry MEA
- Heating cell and hydrating MEA will lead to expansion of different components and so may affect compression

Sinter thickness

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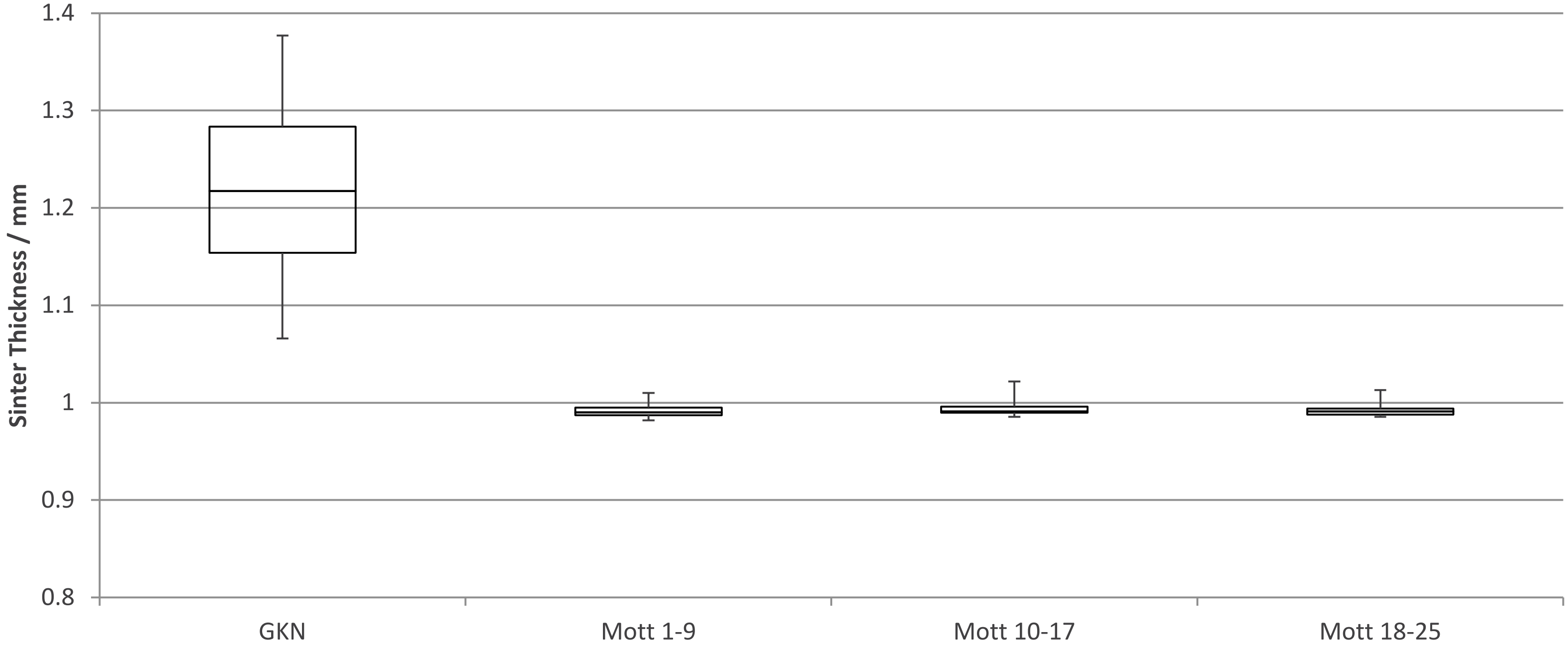

All sinters nominally 1 mm thick

GKN sinters have 40 µm variation within a sheet and 90 µm across the batch

Mott sinters have <10 µm variation within a sheet and ~10 µm across the batch

Weight / Density shows similar trends

Surface profiles of typical sinters

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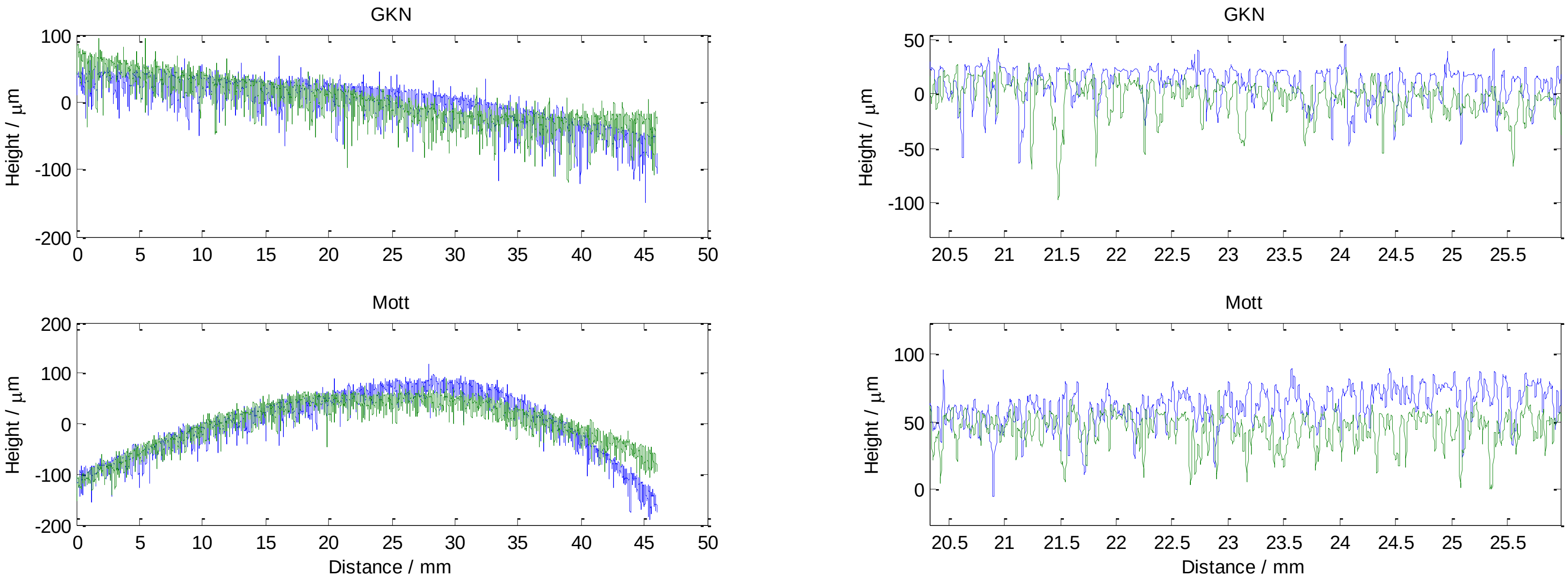

- Preparation method can have a significant effect on sinter
  - Cutting method can affect long range shape (bowing)
- Both sinters have similar roughness values
  - Ra values of 10.9 and 10.2 for GKN and Mott respectively
  - Gravity sintered (Mott) gives similar roughness above and below surface
  - Pressure sintered (GKN) has flat top surface with deep pores

Complete anode plate assembly

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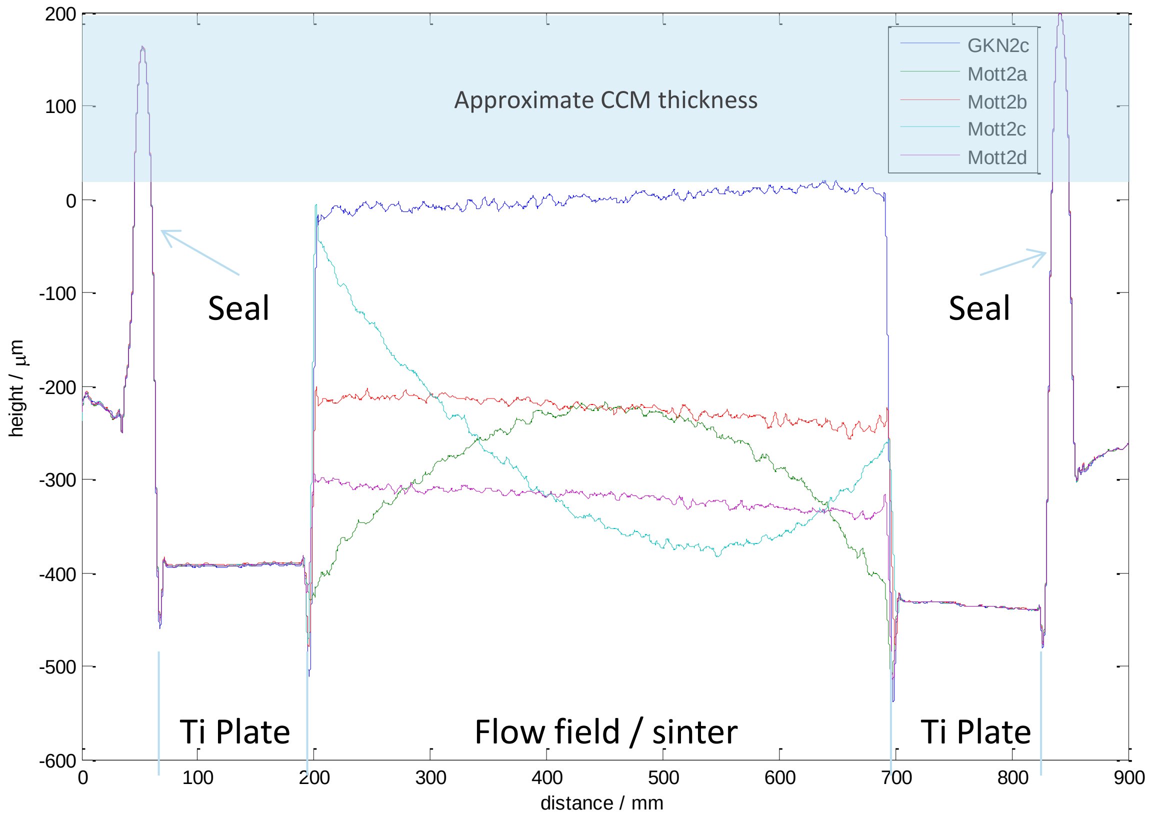

- Step height can vary up to 400 µm from plate depending on sinter and orientation
- Hard for < 200 µm CCM to accommodate such variation
- What are the effects of the non-uniform compression?

Experimental setup

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- Baltic fuel cell QCF25 cell hardware used
  - 5 x 5 cm active area
  - Ti flowfield on anode and C flowfield on cathode
    - Ti sinter as anode current collector
    - SGL 10BB carbon paper as cathode current collector (420 µm thick)
  - Compression measurement device fitted
    - Piston to control clamping force on active area
    - Linear transducer for displacement monitoring
  - Current mapping included
    - S++ system fitted behind cathode flowfield
    - 100 segments measured
- In house test station operating at 60 °C, ambient pressure, 500 ml min^{-1} water flow rate
  - Hydrogen crossover measured with TCD
- Tests carried out with in-house MEAs

Effect of increased compression

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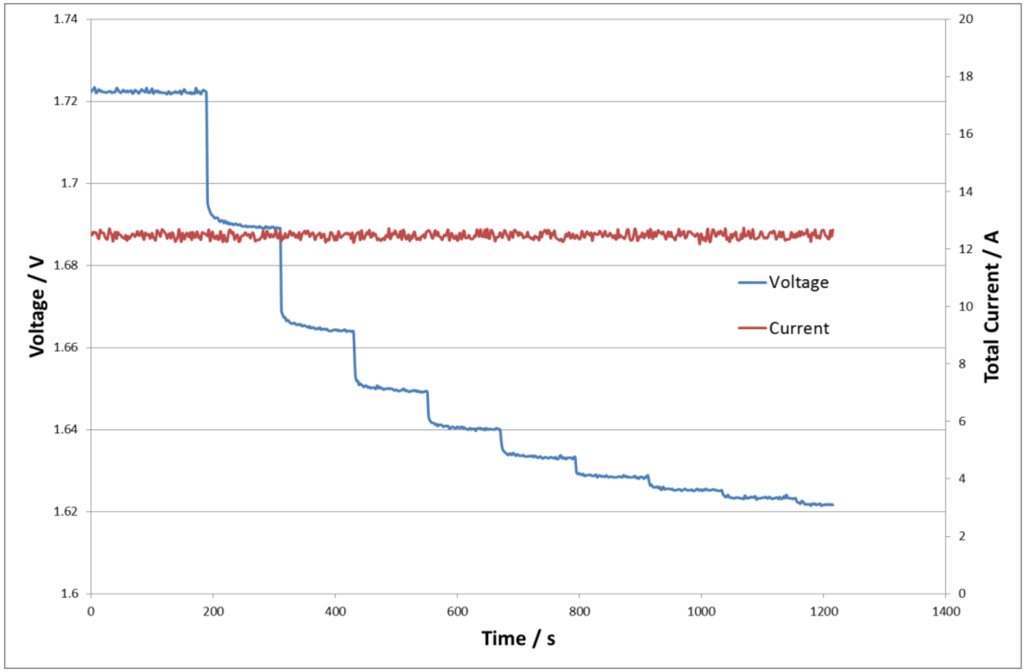

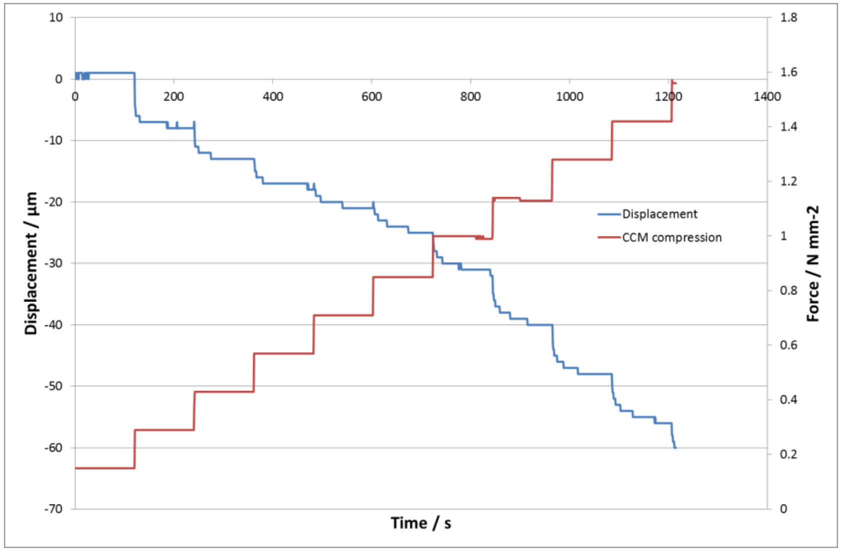

- MEA: IrO_2 (2mg cm-2) | N117 | Pt black (1 mg cm-2)
- Operation at 500 mA cm^{-2} (12.5 A total)
- Compression increased from 0.5 – 5.5 bar (0.16 – 1.72 N mm^{-2}) in 0.5 bar steps
- Cell voltage drops by ~ 100 mV at 0.5 A cm^{-2} operating point as compression increased
  - Displacement of 60 µm occurs as clamping force increased – likely to be carbon paper compressing

Effect of increased compression - crossover

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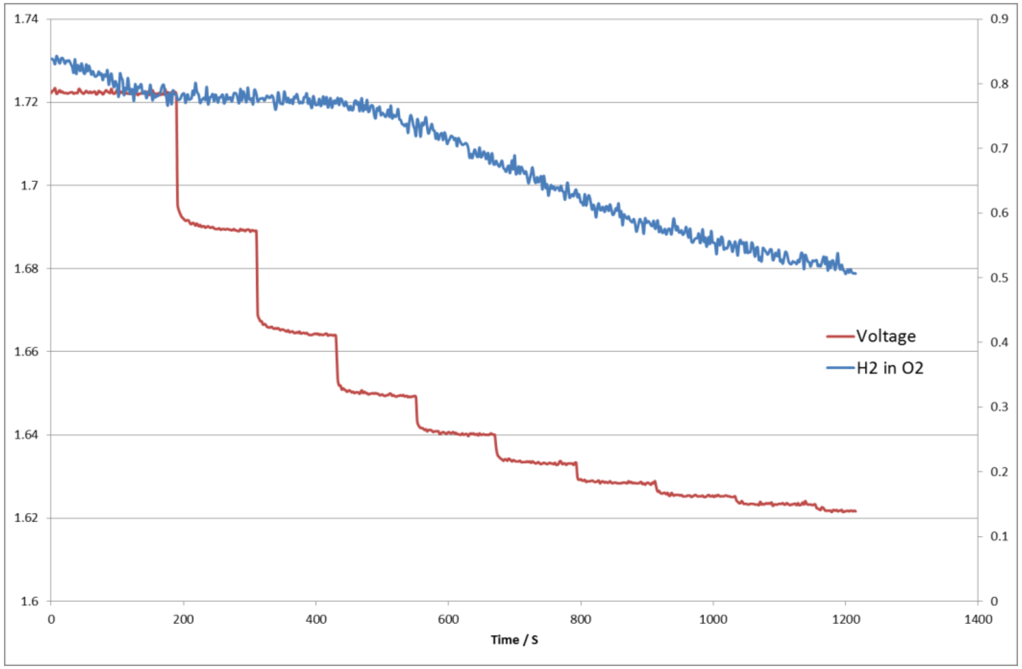

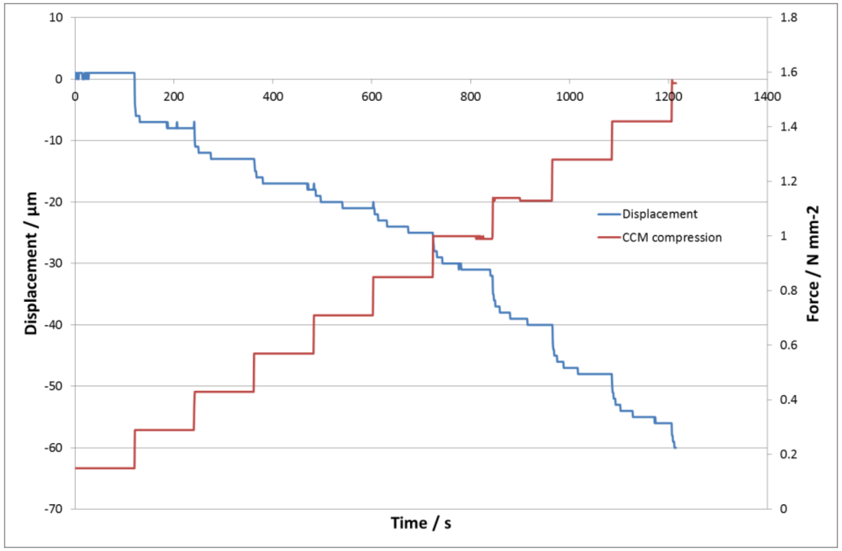

- Crossover decreases as compression increased
- All other cell parameters kept constant
  - Crossover not expected to be affected by compression / operating voltage

Current mapping during compression

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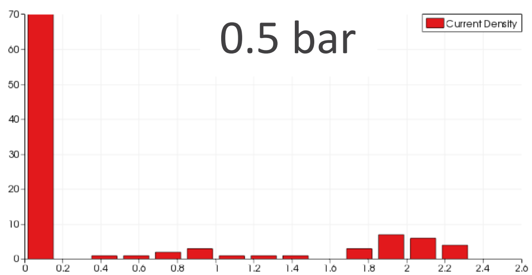
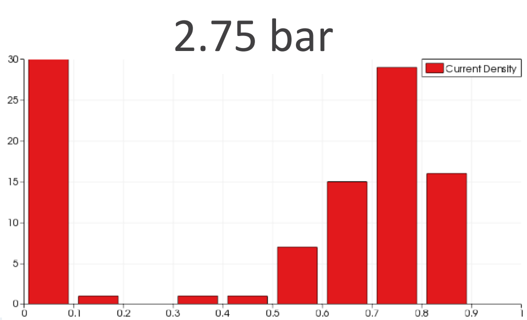
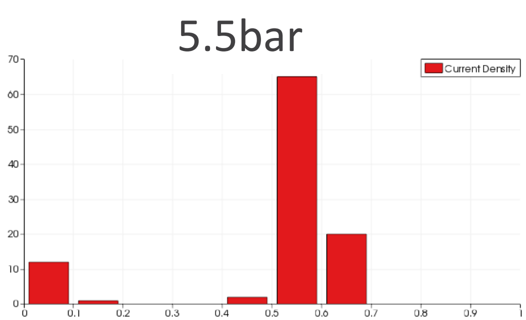
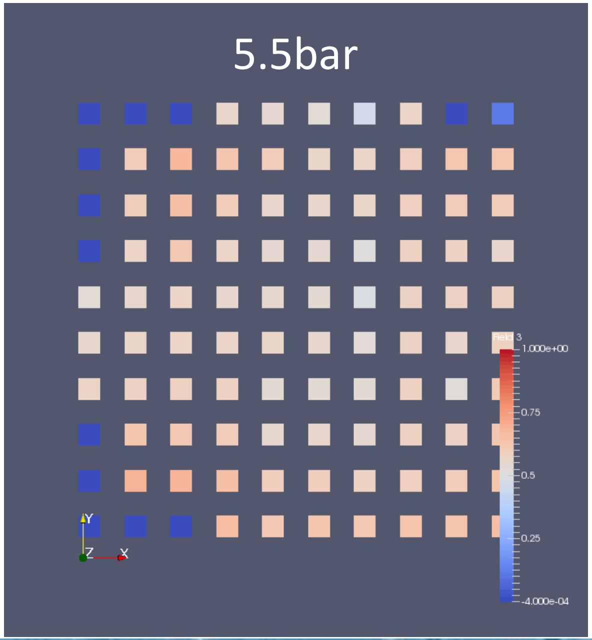
- Compression stepped from 0.5 bar to 5.5 bar in 10 steps of 120s
- Histograms show number of segments (%) operating within a current range
  - Far left bar indicates number of inactive segments
- At low compression 70% is inactive, at 2.75 bar 30% is inactive and at 5.5 bar ~ 10% is inactive









Segmented polarisation curve 2 bar compression

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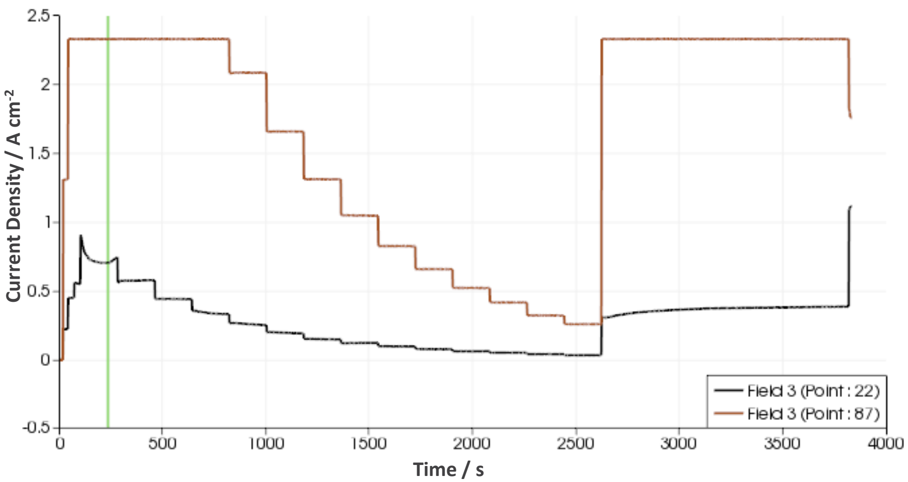

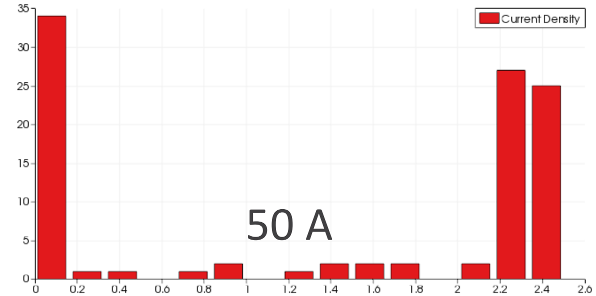

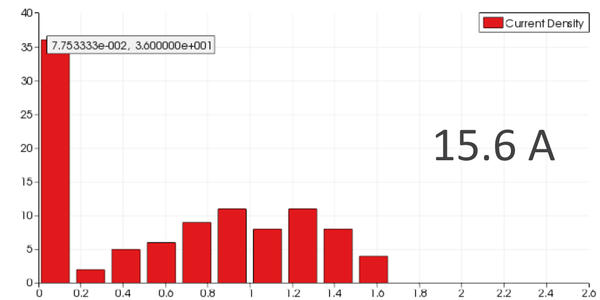

- Uncoated Mott sinter used with 10BB cathode GDL
  - Test carried out after compression test so GDL may be compression set
- Significant performance difference between segments
- Some segments are saturated so not reporting true current density
- ~30% of area inactive

Segmented polarisation curve 5.5 bar

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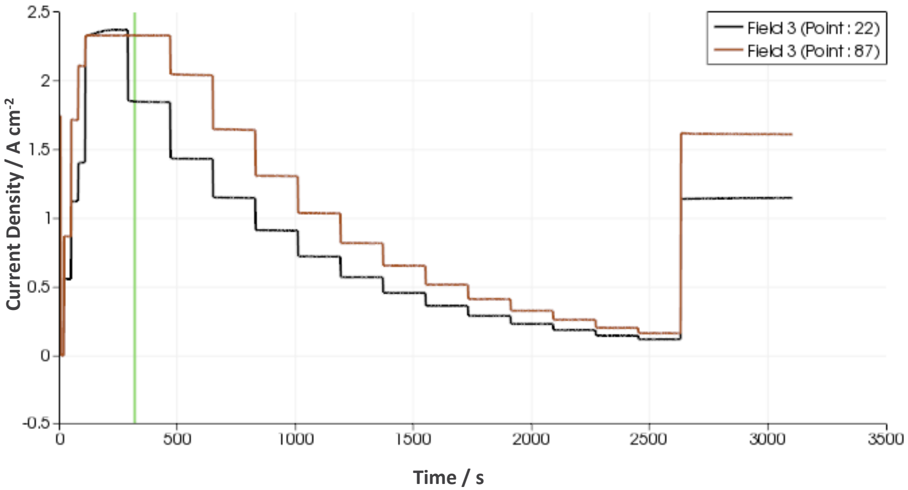
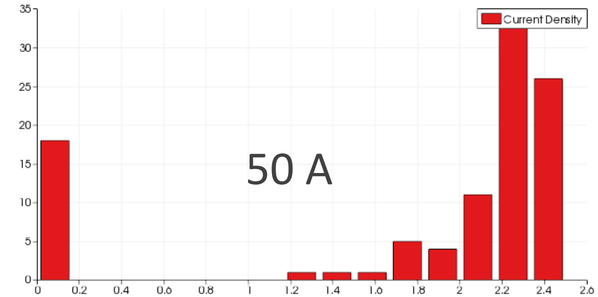
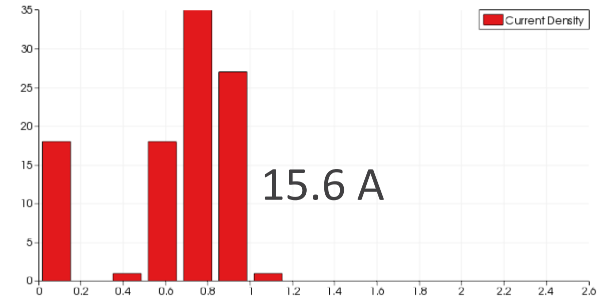
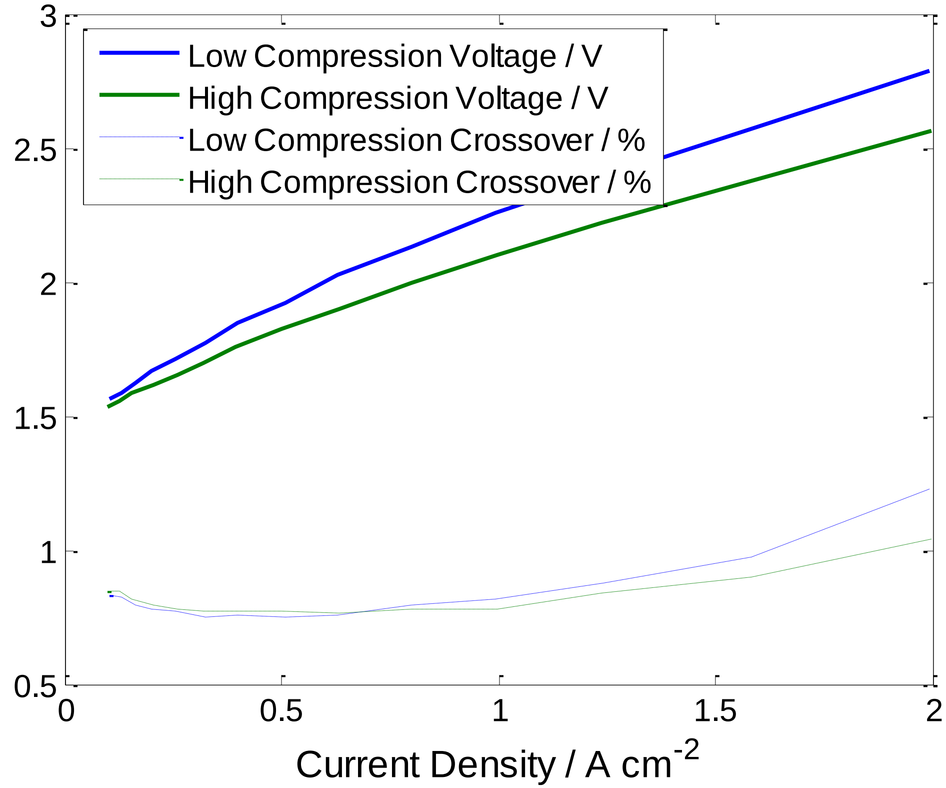






- Significant improvement in uniformity
- Still significant region inactive (15 – 20%)
- Fresh GDL may improve uniformity further

Overall Polarisation



- Crossover can be seen to increase as current density increases
  - Typically expect fixed diffusion through membrane and so lower crossover at higher currents (increased O_2 production)
  - Effect more dramatic for lower compression / less uniform layer

Performance of supported Ir catalysts

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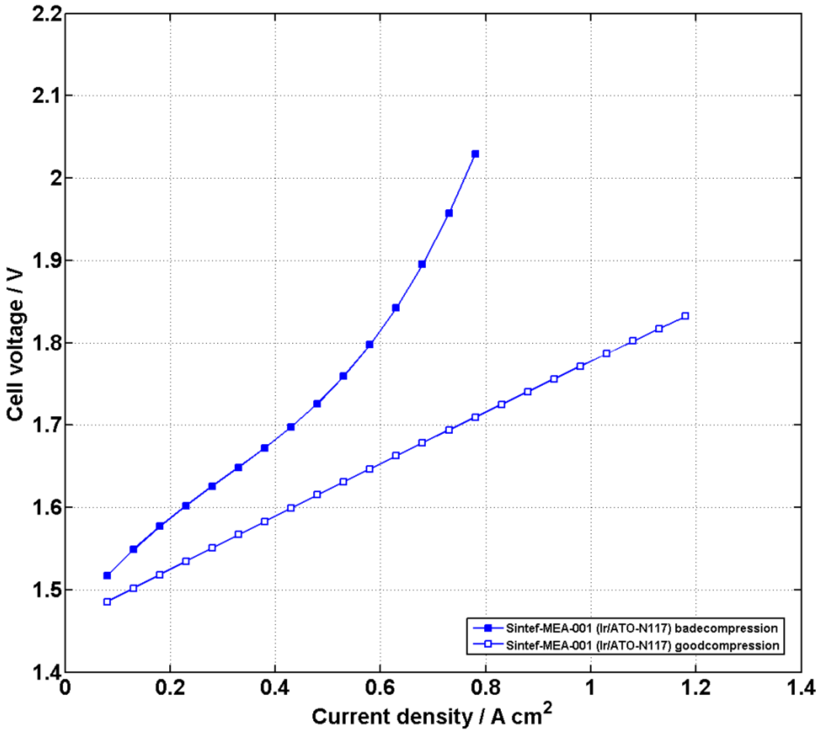

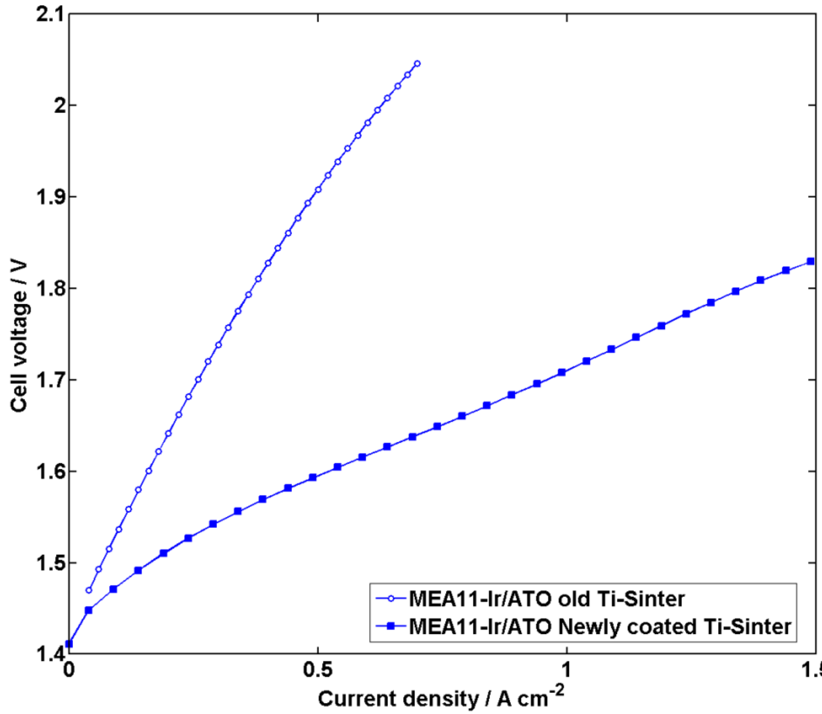

- Layers with lower catalyst loadings or novel OER catalysts can show increased sensitivity to compression / contact resistance
- Effects cannot always be removed by increasing cell compression
  - Over compression can crush carbon papers or crack plates

Data provided by SINTEF

Effect of sinter on catalyst layer

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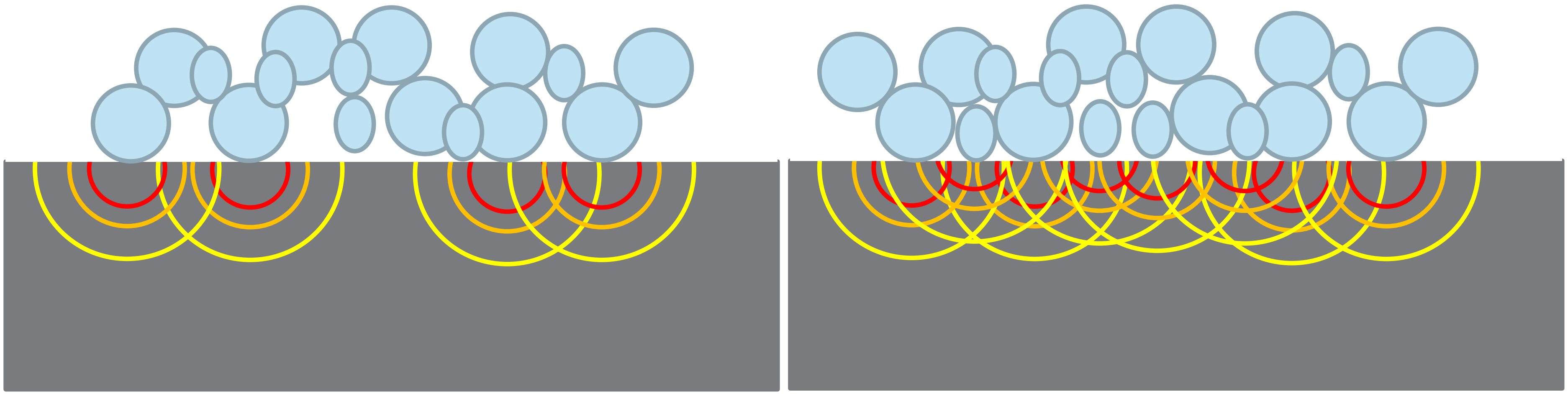

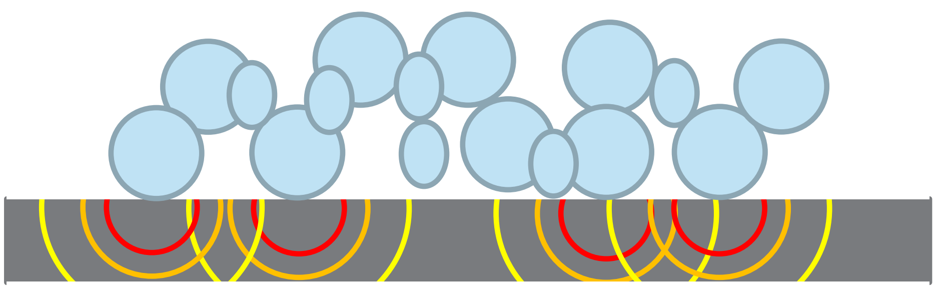

- Larger gaps in sinter may lead to inactive regions
- Effect will be exaggerated for thin layers
- Effect will be exaggerated for low conductivity layers
- Low activity regions may experience high voltages increasing oxidation of sinter and so rapidly deactivating completely

Effect on low loading layers

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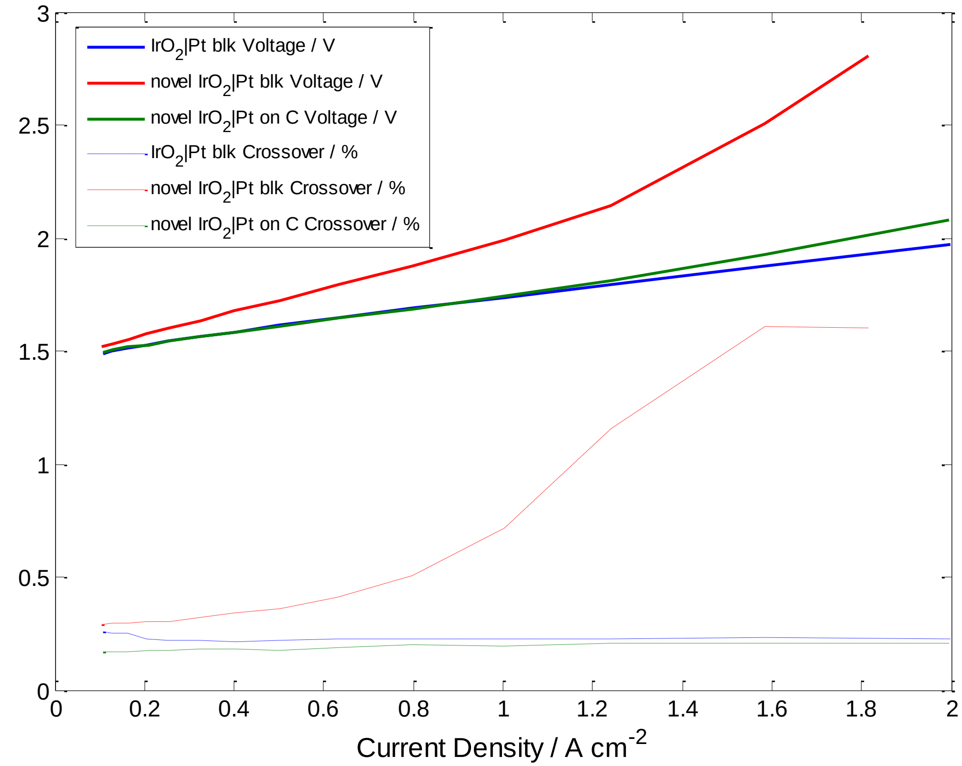

- Conventional IrO_2 layer printed at ~ 2 mg_{Ir} cm^{-2}
- Novel IrO_2 layers printed at ~ 1 mg_{Ir} cm^{-2}
- Thin reinforced membrane with recombination catalyst used for all samples

- Lower loading catalyst layers more sensitive to cathode catalyst layer
- Pt on C cathode will be thicker and more compressible than Pt black

Current Mapping

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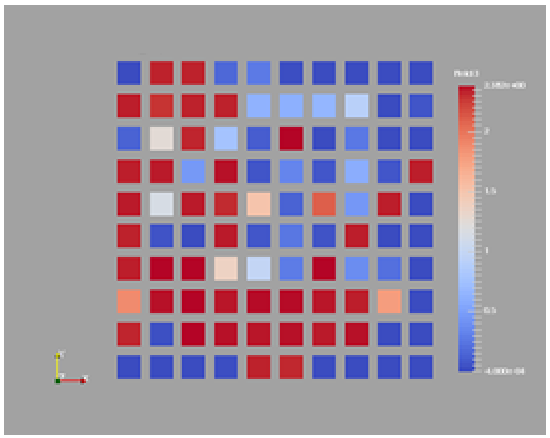
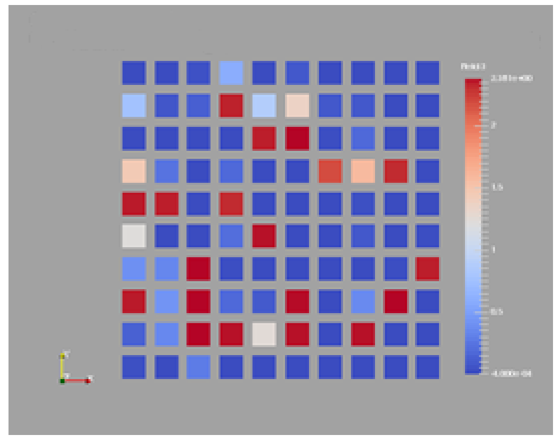
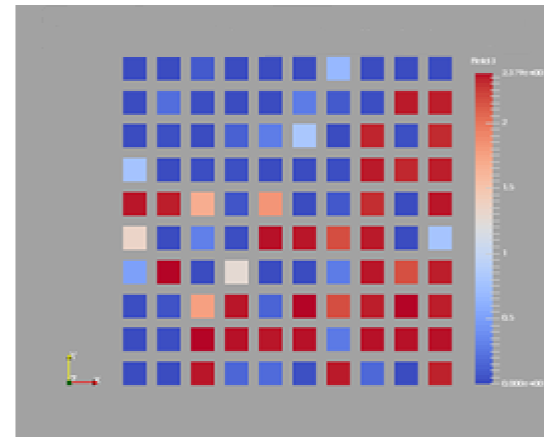
IrO_2 black 2 mg_{Ir} cm^{-2} anode, Pt black cathode, recom cat membrane, 5.5bar, 60°C



Novel IrO_2 ~ 1 mg_{Ir} cm^{-2} anode, Pt black cathode, recom cat membrane, 5.5bar, 60°C



Novel IrO_2 1 mg_{Ir} cm^{-2} anode, Pt/C cathode, recom cat membrane, 5.5bar, 60°C



- Current maps taken from highest current density
- Conventional 2 mg_{Ir} cm^{-2} layer shows most uniform activity
- Novel 1 mg_{Ir} cm^{-2} anode with Pt black cathode shows worst uniformity
  - Novel 1 mg_{Ir} cm^{-2} anode with Pt on C cathode more uniform but not as good as thicker commercial IrO_2 layer
- Cathode / overall CCM thickness may be important for good contact

Conclusions

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- Poor compression leads to non-uniform PEMWE performance
- Gas crossover increases with decreasing uniformity
  - Crossover seen to increase at high current densities for non-uniform layers
- Sinters vary considerably in thickness, curvature and contact with CCM
  - Thickness variations of similar magnitude to total CCM thickness
  - Poor compression / contact leads to non-uniform performance
- Novel OER catalysts or reduced loadings will exaggerate the effects
- Cathode type / thickness can help improve uniformity / crossover
- Thinner membranes will reduce the ability of the CCM to compensate for hardware variations
- Machining components to give < 100 µm variation for plate / current collector combination not practical
- CCM / Hardware interactions need to be well understood to help reduce costs

Acknowledgements

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