



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

Ed Wright, Emily Price, Jonathan Sharman
Johnson Matthey Technology Centre



Johnson Matthey

Challenges for CCMs in PEMWE



Johnson Matthey

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

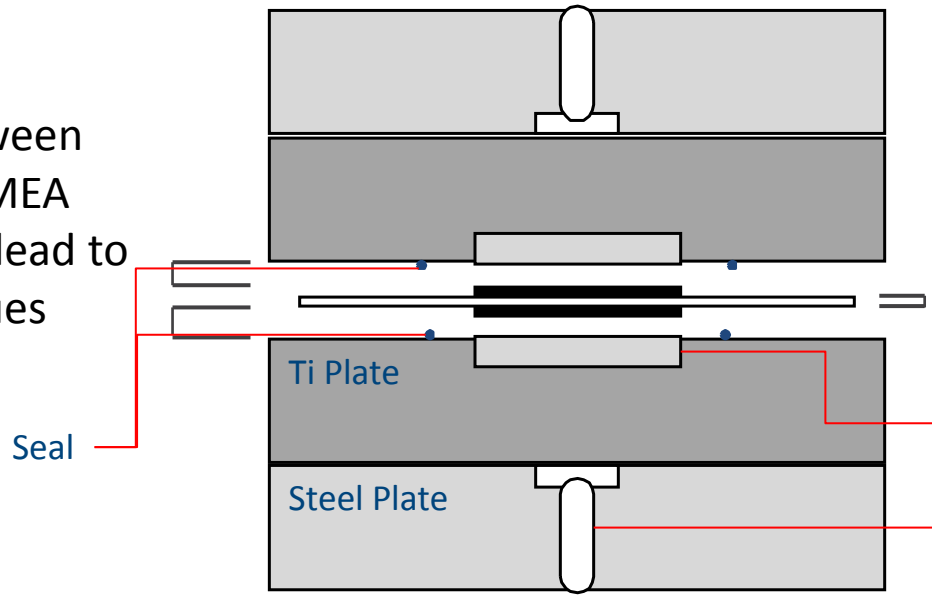


Cell sealing of typical single cell



Johnson Matthey

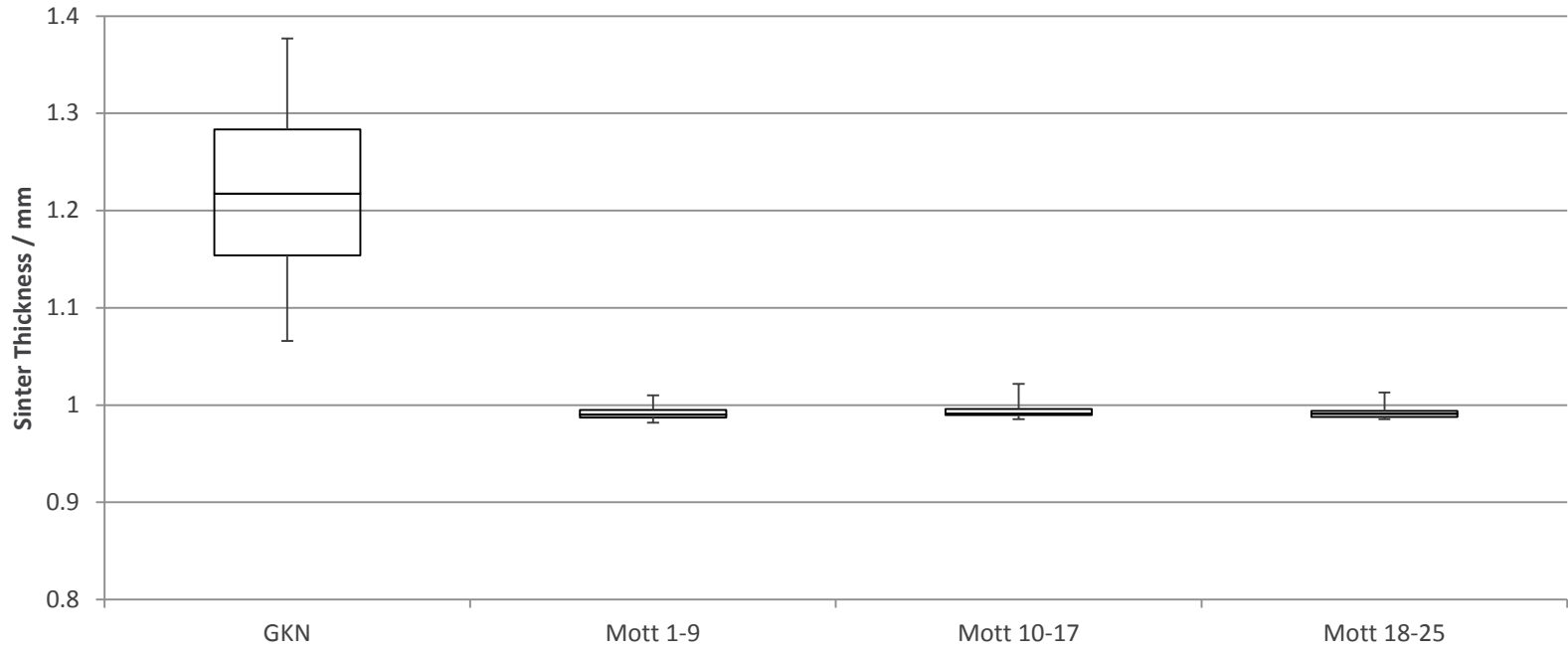
A mismatch between seal height and MEA step height may lead to compression issues



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



All sinters nominally 1 mm thick

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

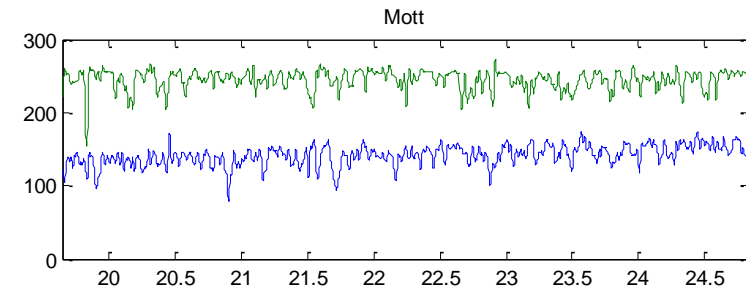
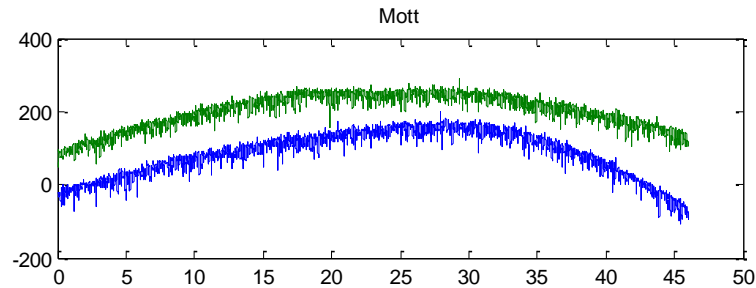
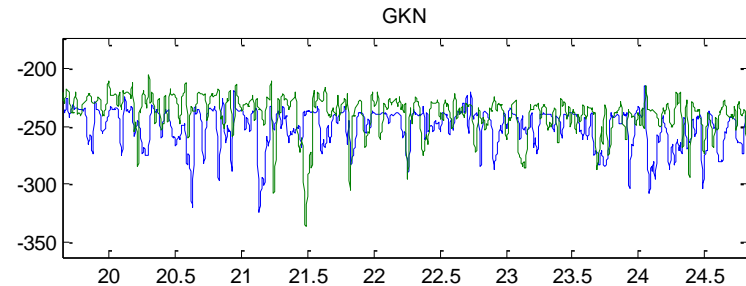
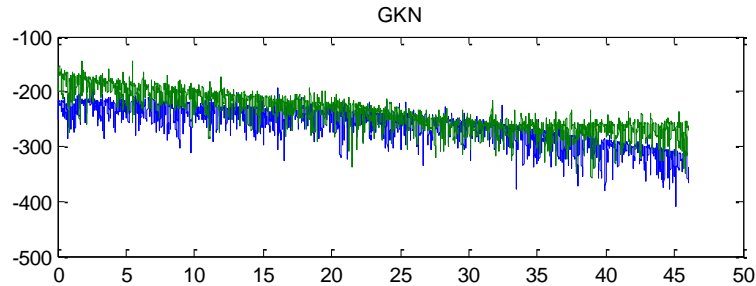
Mott sinters have <10 μm variation within a sheet and ~10 μm across the batch

Weight / Density shows similar trends

Surface profiles of typical sinters



Johnson Matthey



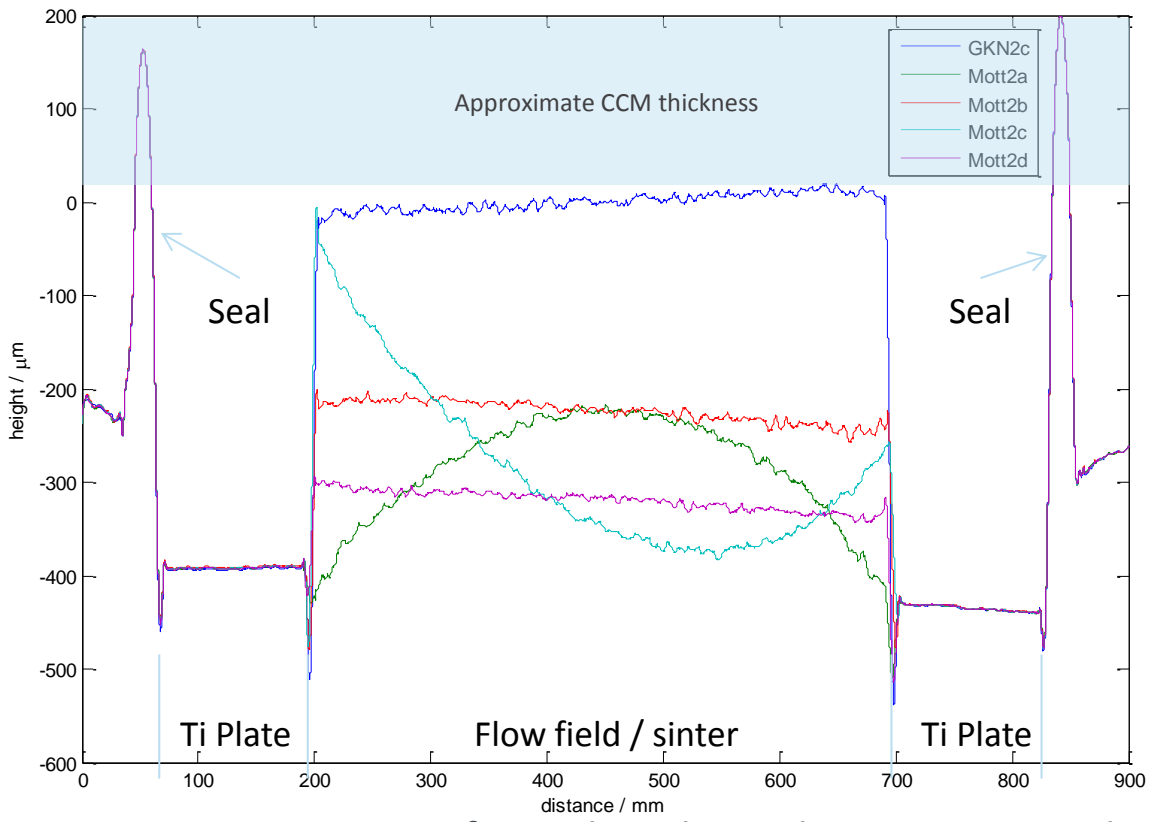
- Preparation method can have a significant effect on sinter
 - Cutting method can affect long range shape (bowing)
- Both sinters have similar roughness values
 - Ra values of 10.9 and 10.2 for GKN and Mott respectively
 - Gravity sintered (Mott) gives similar roughness above and below surface
 - Pressure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



Complete anode plate assembly



Johnson Matthey



- 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?



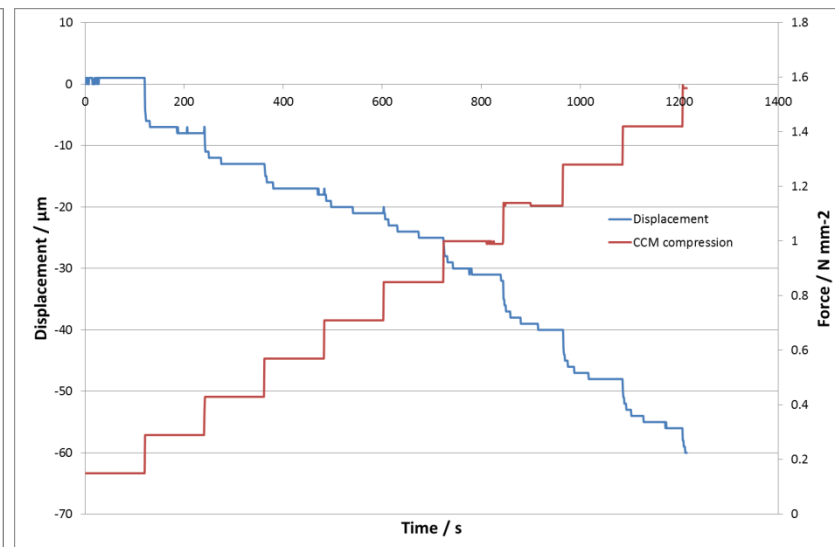
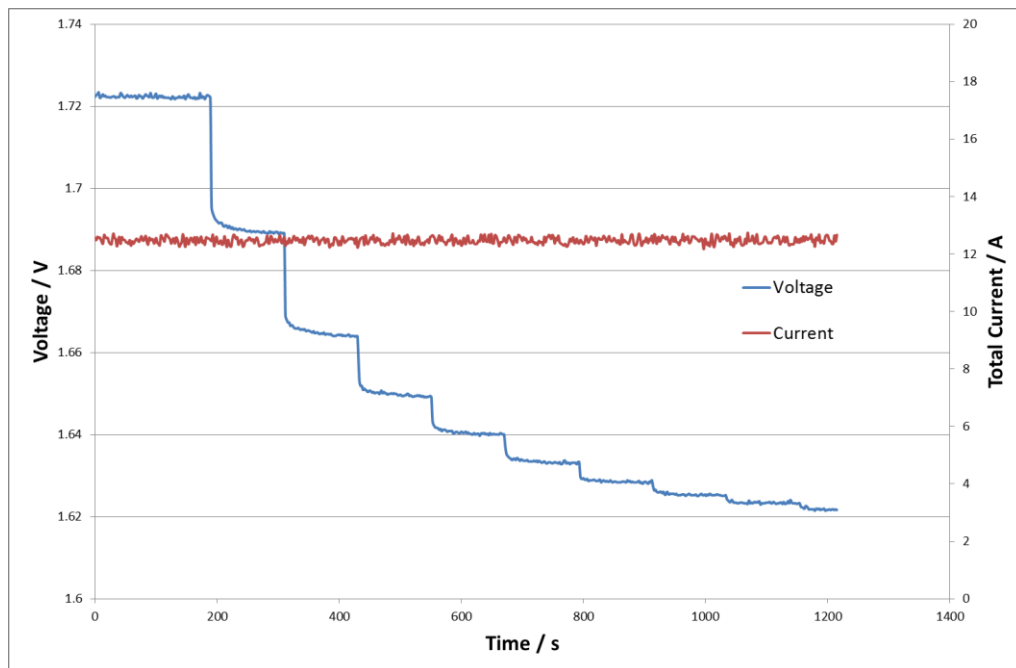
- Baltic fuel cell QCF25 cell hardware used
 - 5 x 5 cm active area
 - Ti flowfield on anode and C flowfield on cathode
 - Ti sinter as anode current collector
 - SGL 10BB carbon paper as cathode current collector (420 μm thick)
 - Compression measurement device fitted
 - Piston to control clamping force 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



Johnson Matthey



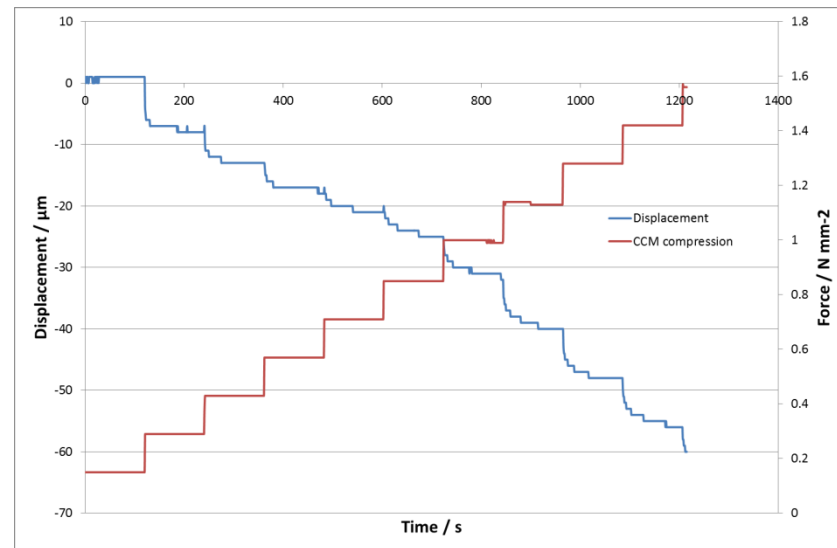
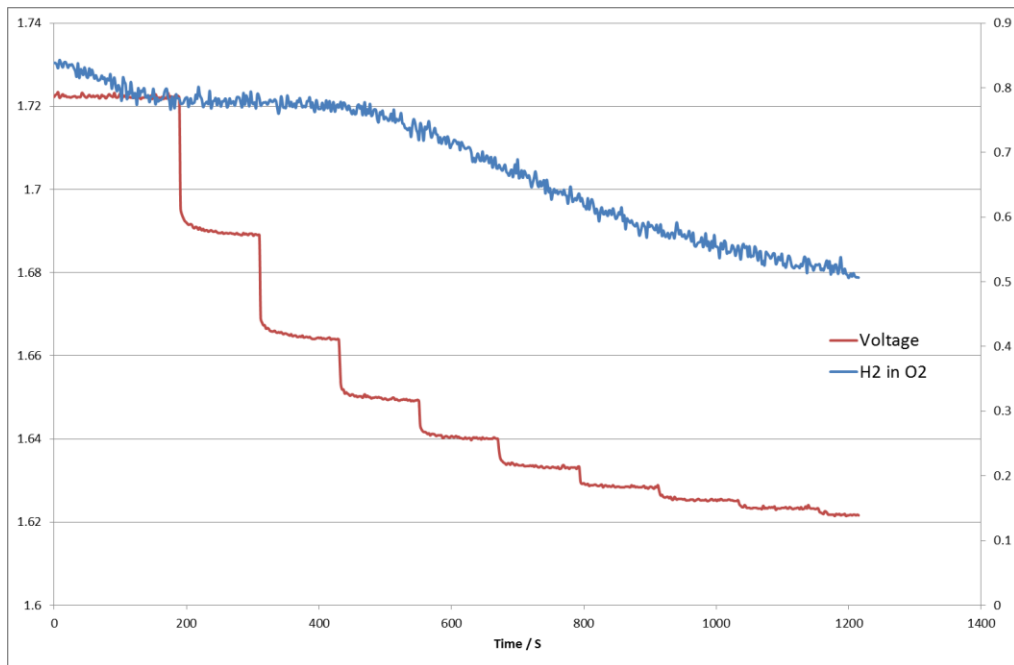
- MEA: IrO₂ (2mg cm⁻²) | N117 | Pt black (1 mg cm⁻²)
- Operation at 500 mA cm⁻² (12.5 A total)
- Compression increased from 0.5 – 5.5 bar (0.16 – 1.72 N mm⁻²) in 0.5 bar steps
- Cell voltage drops by ~ 100 mV at 0.5 A cm⁻² operating point as compression increased
 - Displacement of 60 μm occurs as clamping force increased – likely to be carbon paper compressing



Effect of increased compression - crossover



Johnson Matthey



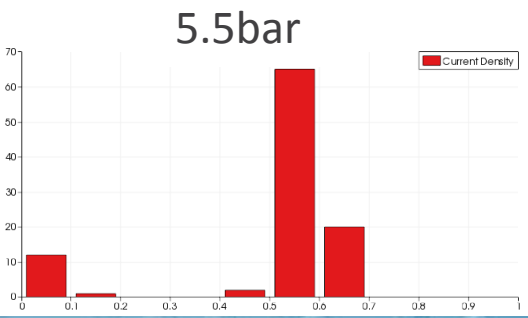
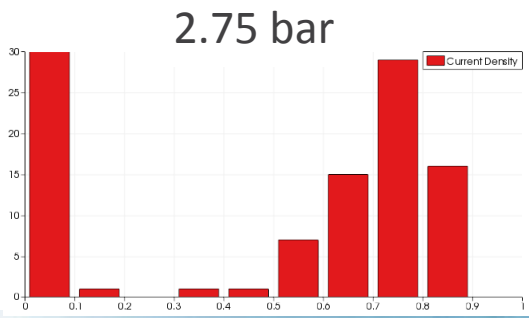
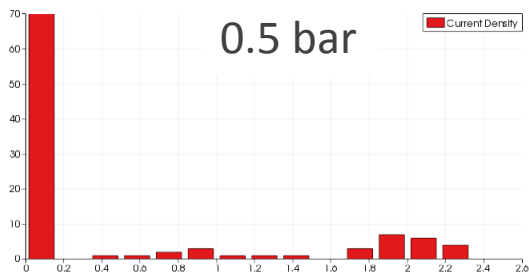
- Crossover decreases as compression increased
- All other cell parameters kept constant
 - Crossover not expected to be affected by compression / operating voltage



Current mapping during compression



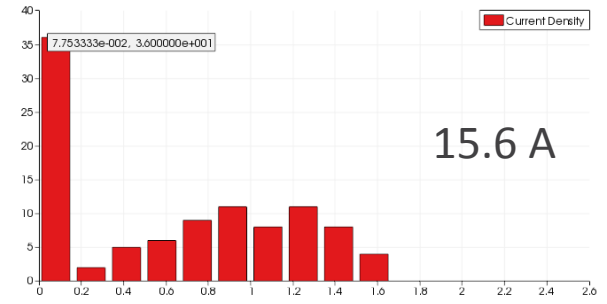
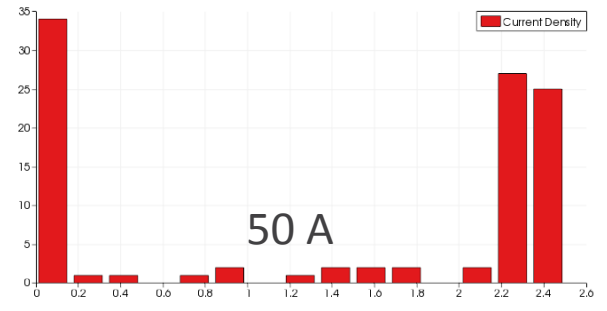
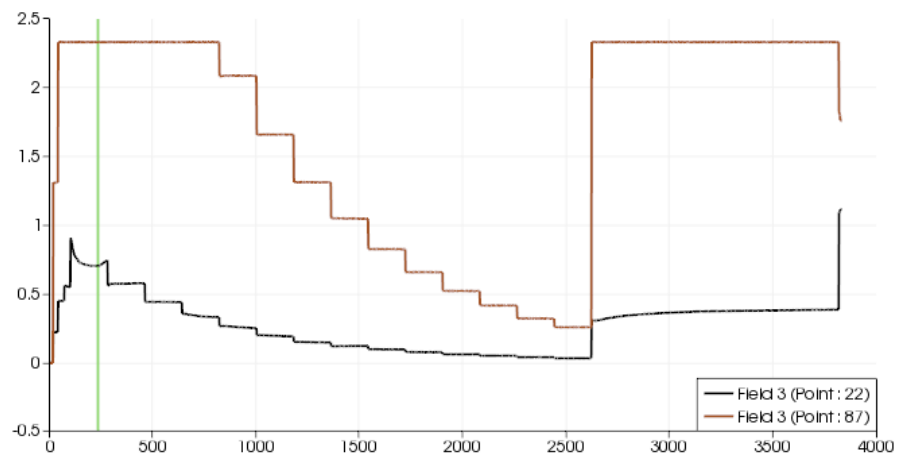
- Compression stepped from 0.5 bar to 5.5 bar in 10 steps of 120s
- Histograms show number of segments (%) operating within a current range
 - Far left bar indicates number of inactive segments
- At low compression 70% is inactive, at 2.75 bar 30% is inactive and at 5.5 bar ~ 10% is inactive



Segmented polarisation curve 2 bar compression



Johnson Matthey



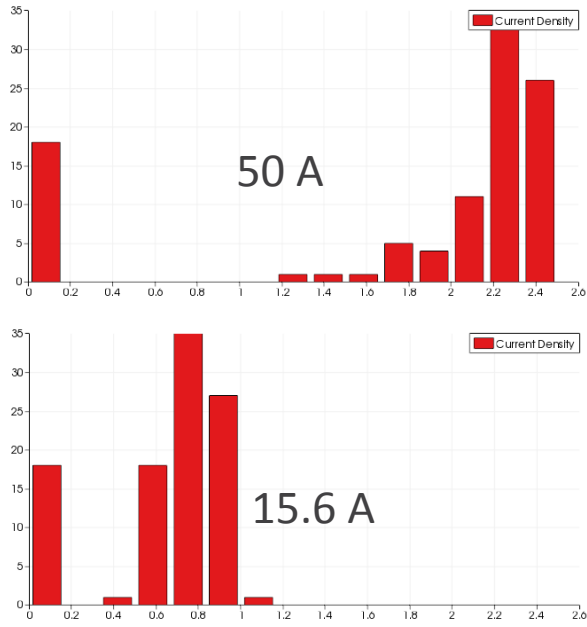
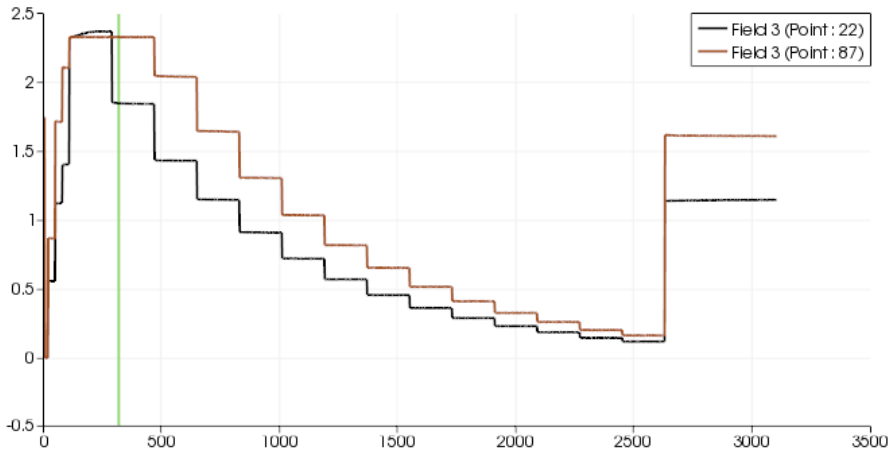
- Uncoated Mott sinter used with 10BB cathode GDL
 - Test carried out after compression test so GDL may be compression set
- Significant performance difference between segments
- Some segments are saturated so not reporting true current density
- ~30% of area inactive



Segmented polarisation curve 5.5 bar



Johnson Matthey



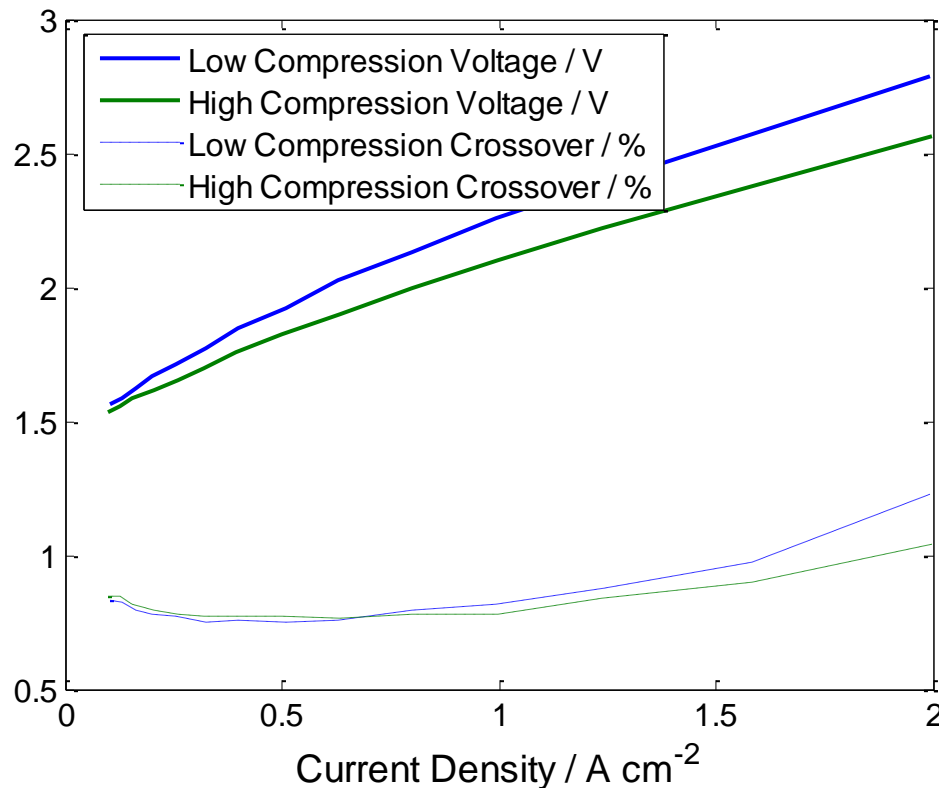
- Significant improvement in uniformity
- Still significant region inactive (15 – 20%)
- Fresh GDL may improve uniformity further



Overall Polarisation



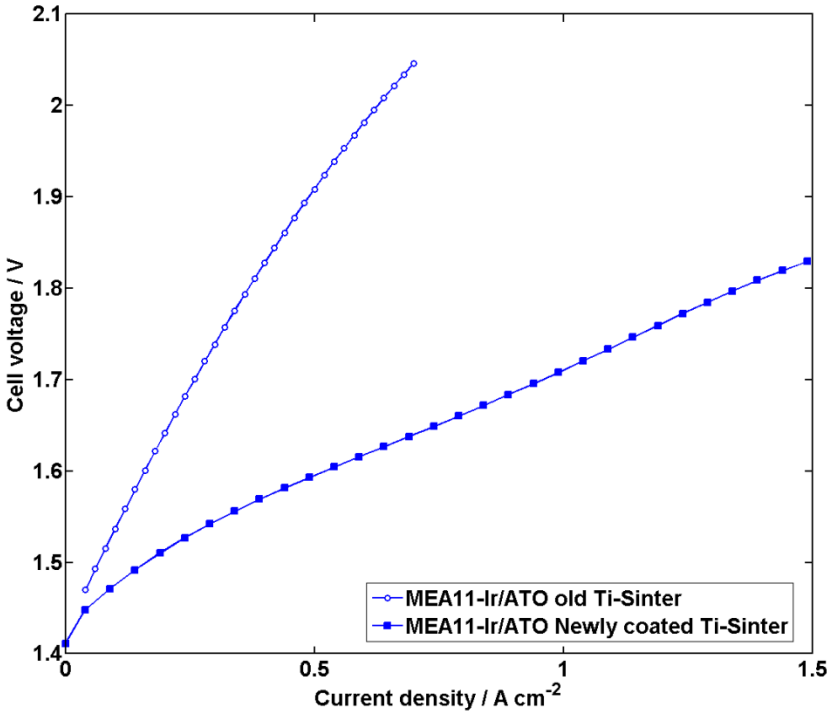
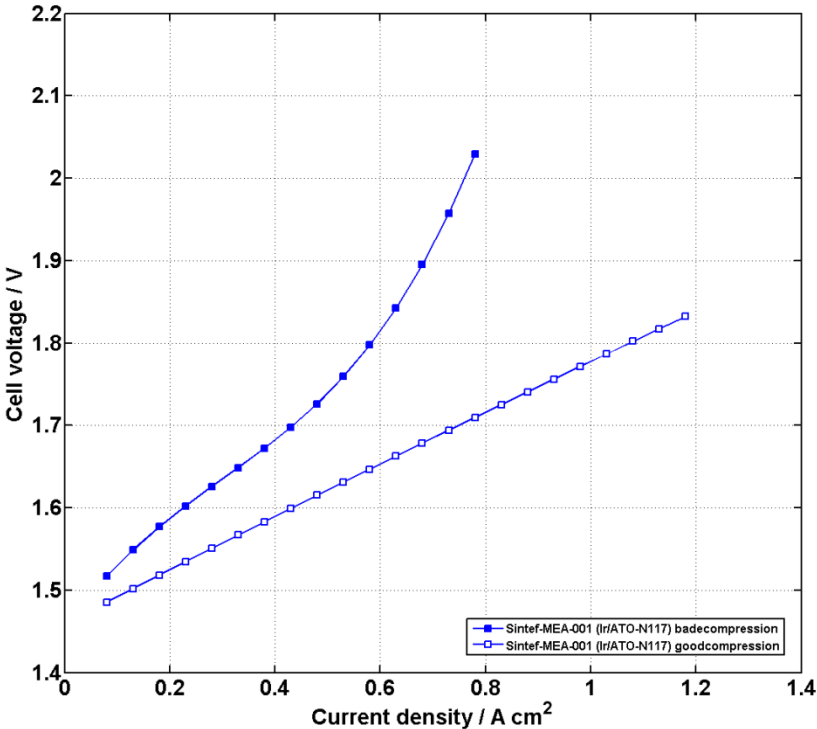
Johnson Matthey



- 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



Polarization curves and CVs



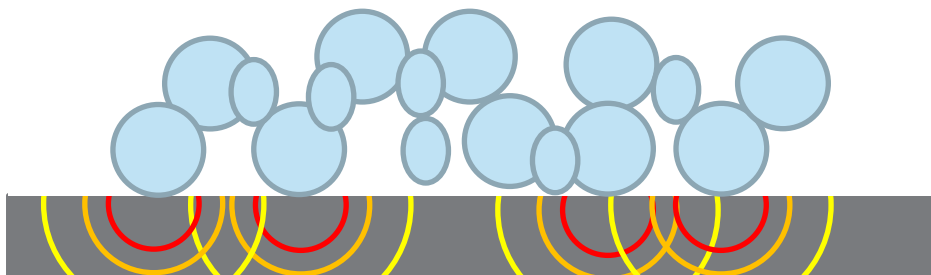
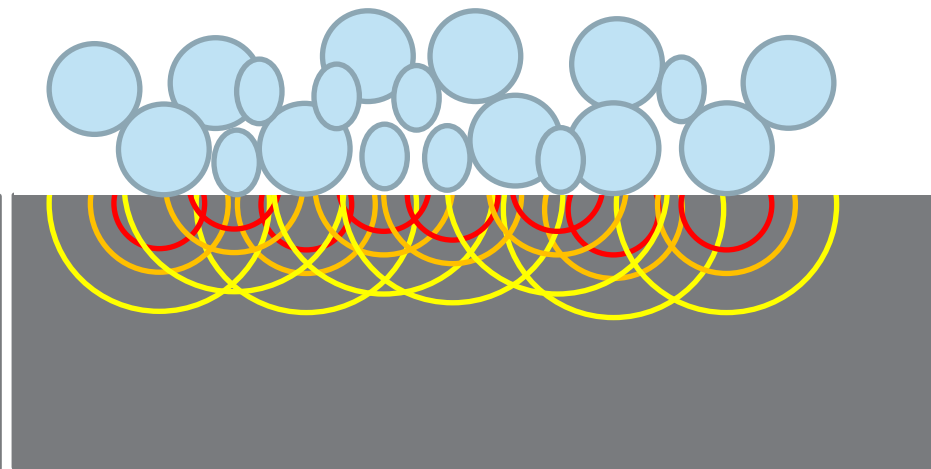
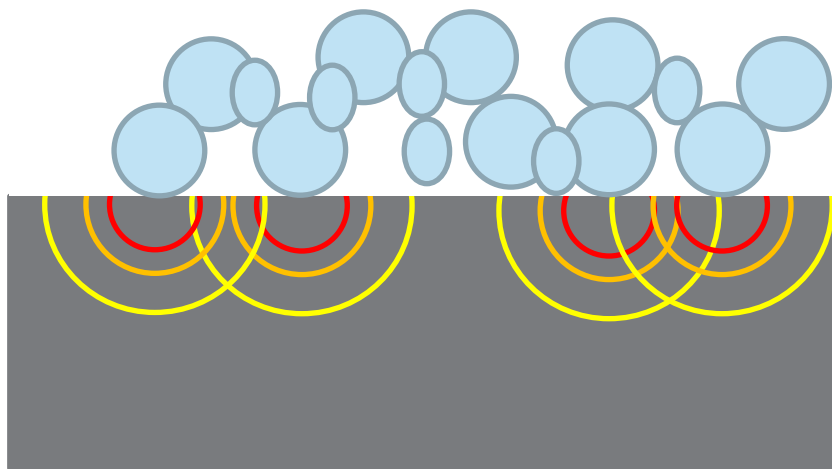
- Layers with lower catalyst loadings or novel OER catalysts can show increased sensitivity to compression / contact resistance
- Effects cannot always be removed by increasing cell compression
 - Over compression can crush carbon papers or crack plates



Effect of sinter on catalyst layer



Johnson Matthey



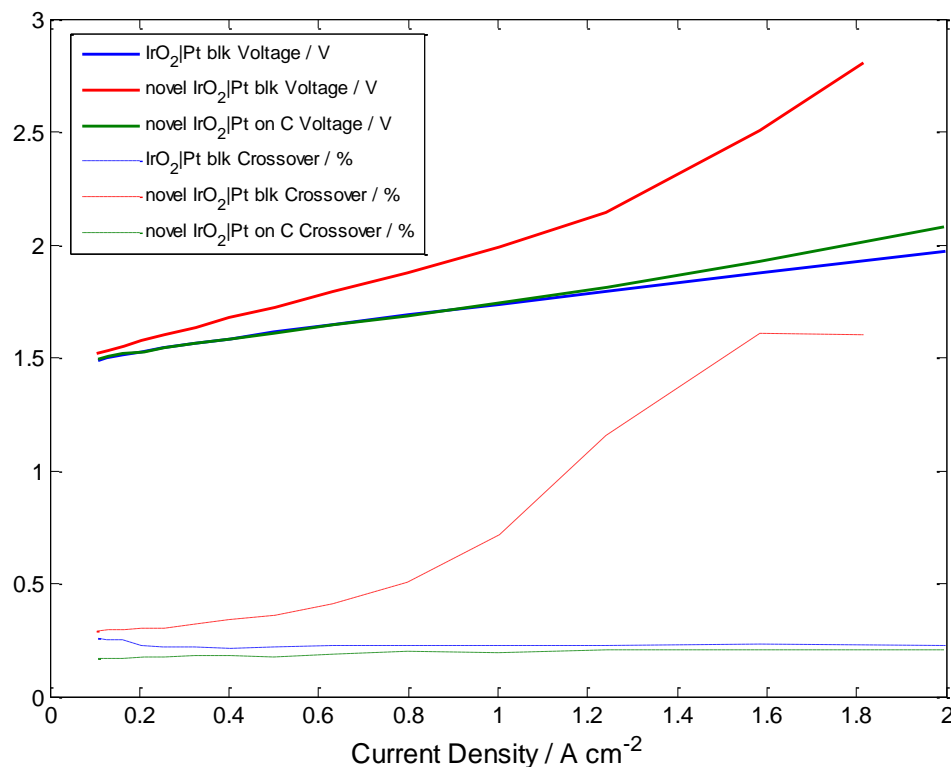
- Larger gaps in sinter may lead to inactive regions
- Effect will be exaggerated for thin layers
- Effect will be exaggerated for low conductivity layers
- Low activity regions may experience high voltages increasing oxidation of sinter and so rapidly deactivating completely



Effect on low loading layers



Johnson Matthey



- Conventional IrO₂ layer printed at $\sim 2 \text{ mg}_{\text{Ir}} \text{ cm}^{-2}$
- Novel IrO₂ layers printed at $\sim 1 \text{ mg}_{\text{Ir}} \text{ cm}^{-2}$
- 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

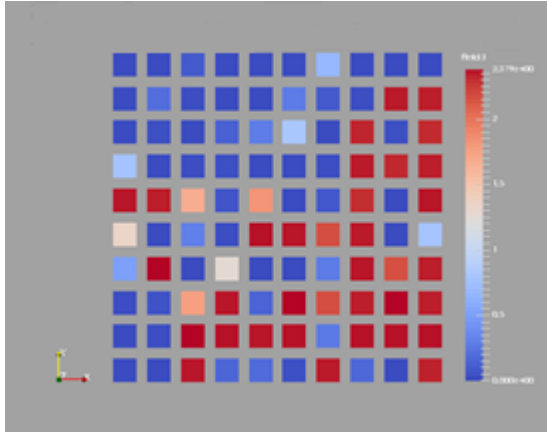
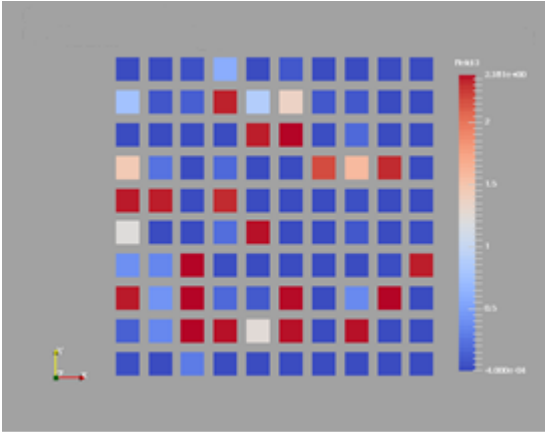
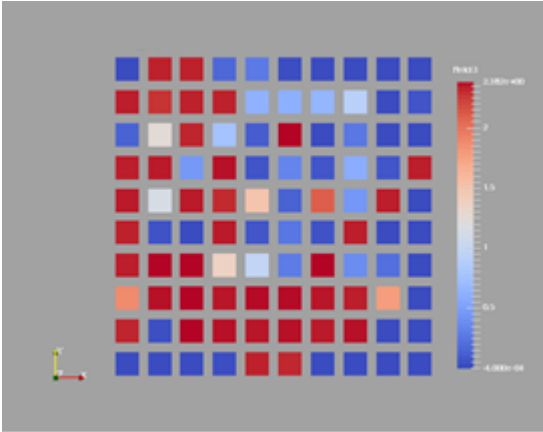


Johnson Matthey

IrO₂ black 2 mg_{Ir} cm⁻² anode, Pt black cathode, recom cat membrane, 5.5bar, 60°C

Novel IrO₂ ~ 1 mg_{Ir} cm⁻² anode, Pt black cathode, recom cat membrane, 5.5bar, 60°C

Novel IrO₂ 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 IrO₂ layer
- Cathode / overall CCM thickness may be important for good contact



- 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 $< 100 \mu\text{m}$ variation for plate / current collector combination not practical
- CCM / Hardware interactions need to be well understood to help reduce costs



Acknowledgements



Johnson Matthey

- NOVEL Project partners particularly
 - Magnus Thomassen, Tommy Mokkelbost and Alejandro Oyarce Barnett at SINTEF
 - Tom Smolinka and Thomas Lickert Fraunhofer ISE

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) for the Fuel Cells and Hydrogen Joint Technology Initiative under grant agreement n° [303484] (Novel)

