Investigation of the Behaviour of Gold Mesh Electrodes in Electrically Controllable Membrane Electrode Assemblies

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Distributed Energy Laboratory

Picture: Public Relations Office HSU

Outline

- Introduction to Electrically Controllable Membranes
- Experimental Investigation
  - Integration & Electrical Contacting
  - Cyclic Voltammetry
  - Open Circuit Voltage
- Model Development
- Conclusion and Outlook

Introduction to Electrically Controllable Membranes

- Idea from Medical Application
  - Targeted blocking and releasing of ionic substances through electrical field
- Improved Dynamic Abilities
  - Load Steps
  - Short Circuit

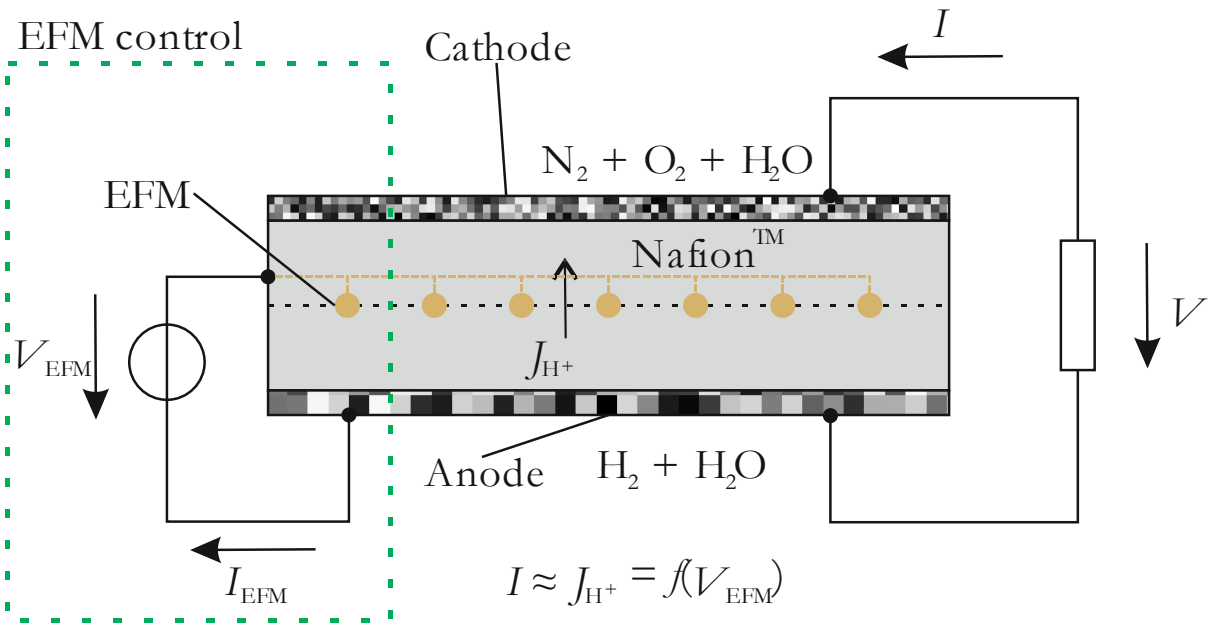
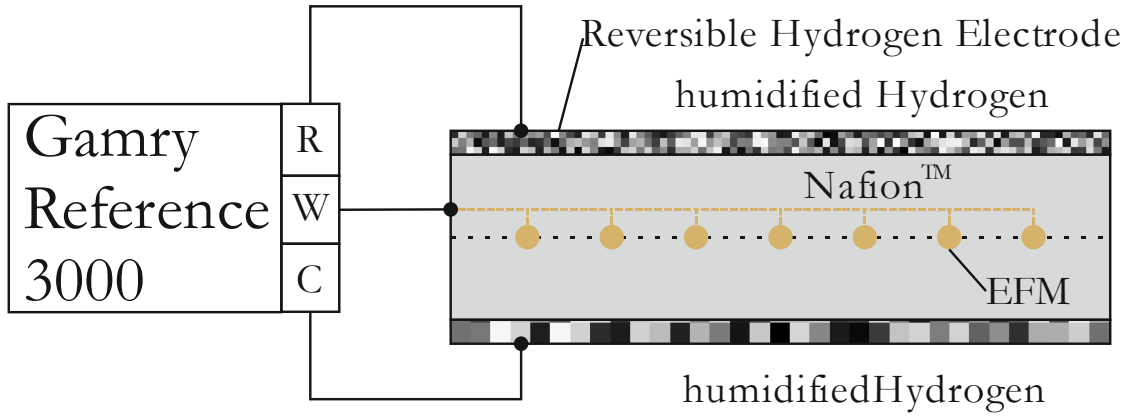
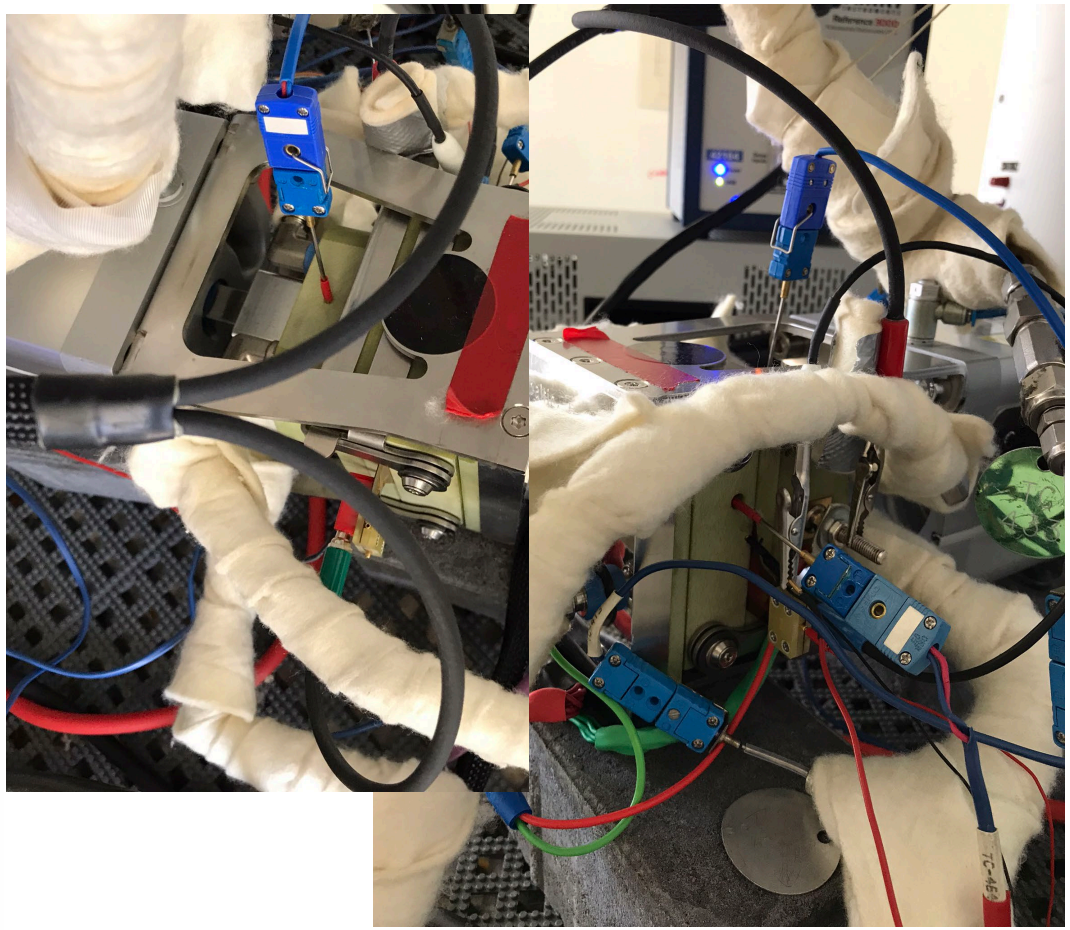


Figure: Cosse C. et al., 2022, International Journal of Hydrogen Energy
Patent: Schulz, D, 2017, WO 2013/087507

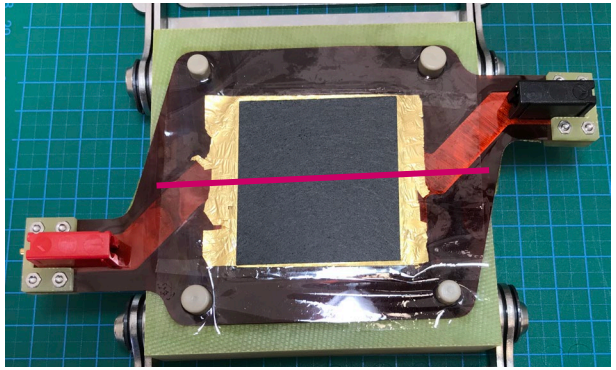
Experimental Investigation

- MEA humidified prior to Experiments
  - Hydrogen pumping at 1 A/cm², for 36 hours
  - 60 °C cell temperature
  - 57 °C dew point temperature
  - Ambient pressure

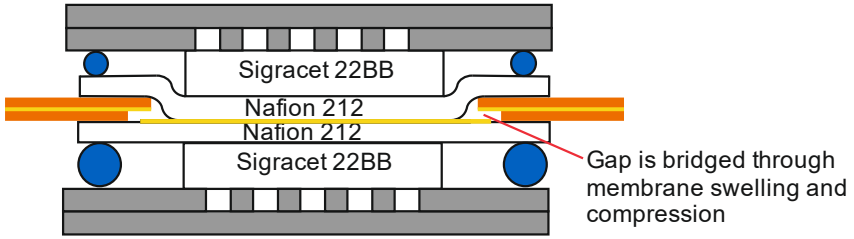




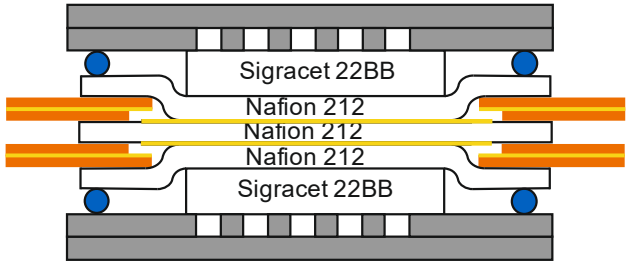
Experimental Investigation – Integration & Electrical Contacting



Schematic visualisation of the contacting of a single EFM



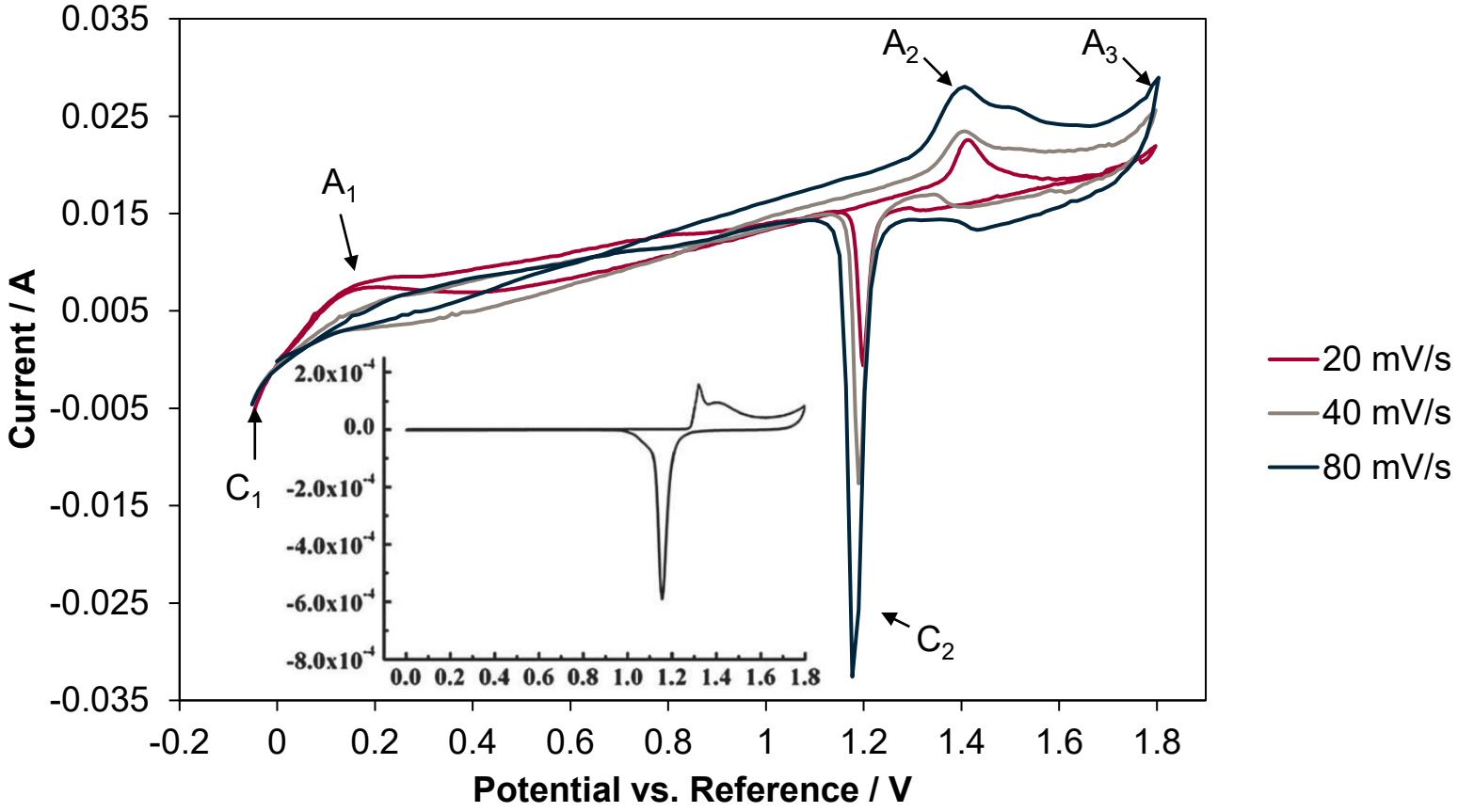
Schematic visualisation of the contacting of two EFMs



- Resistances measured with Hioki Milliohmmeter (HIOKI BT3561A)
- Degradation through CV Experiments and Operation

	Dry, at room temperature	Humidified, at temperature (60°C)	After CV Experiments (60°C)
R_{EFM} [mΩ]	57.32	86.9	126.6

Experimental Investigation – Cyclic Voltammetry (Scan Rate)



A_1: Desorption of adsorbed H

A_2: Formation of surface Oxide

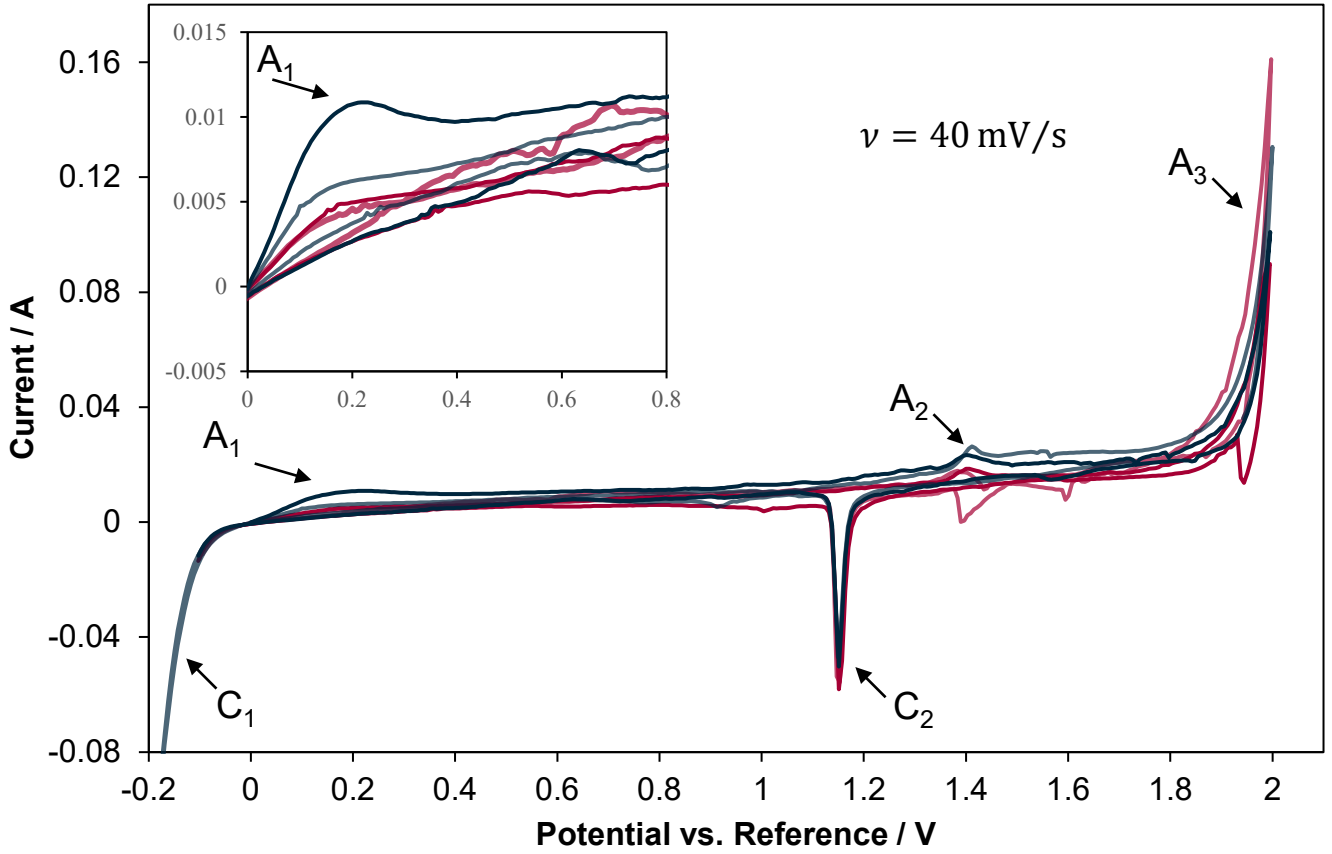
A_3: Onset of the OER

C_1: Adsorption of H, HER

C_2: Reduction of the Surface Oxide

Inset Figure: Diaz-Morales, O. et al., 2013, Chemical Science

Experimental Investigation – Cyclic Voltammetry (Charging)



A_1: Desorption of adsorbed H

A_2: Formation of surface Oxide

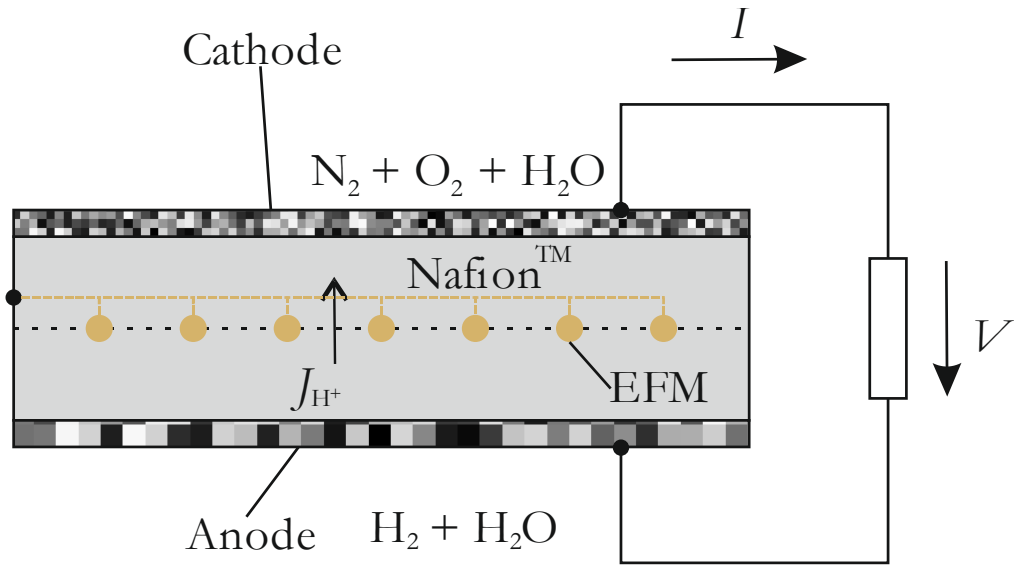
A_3: Onset of the OER

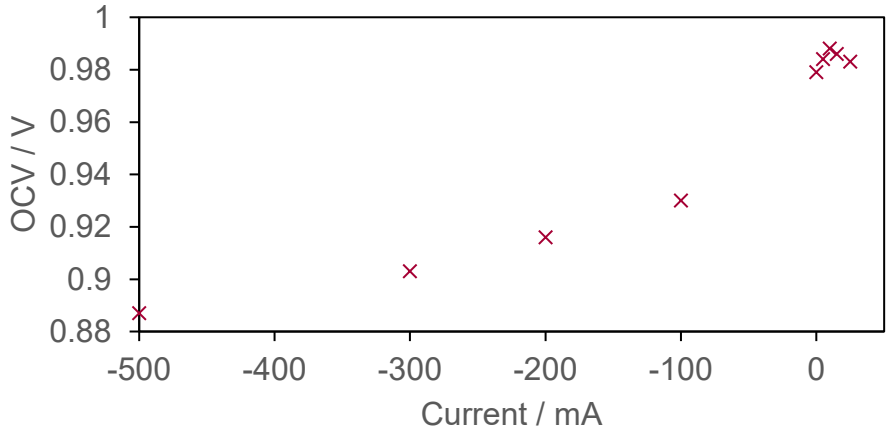
C_1: Adsorption of H, HER

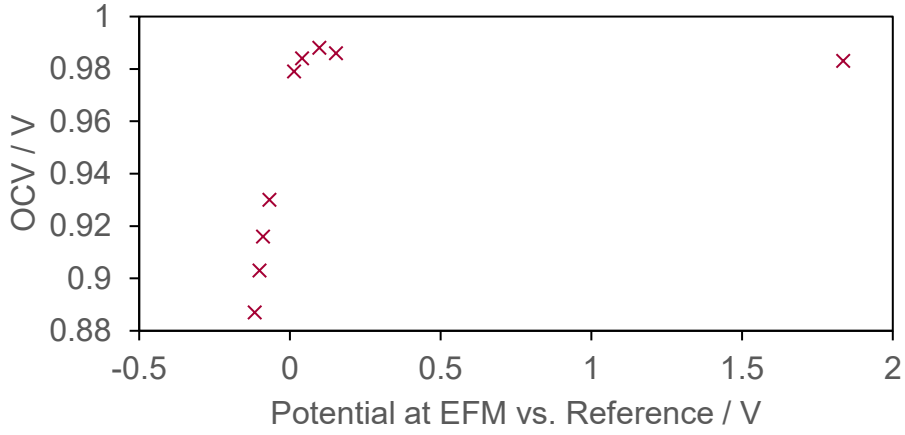
C_2: Reduction of the Surface Oxide

Experimental Investigation – Open Circuit Voltage

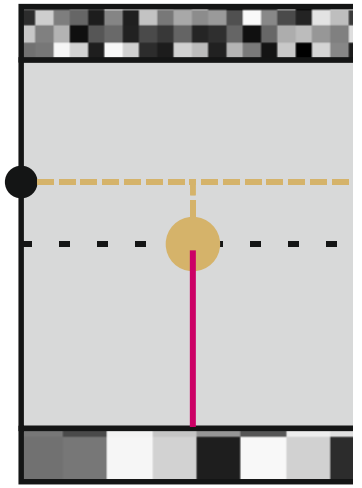
- HER at EFM reduces Diffusion path for H_2 toward Cathode
- Increasing H_2 crossover reduces OCV







Model Development



- 1D-Model (2.5µm Au Domain, 50.4 µm Electrolyte Domain)
- Langmuir-Hinshelwood Adsorption

$$r_{\mathrm{ads}\,i} = k_{\mathrm{a}\,i} c_i - k_{\mathrm{d}\,i} \theta_{\mathrm{ads}\,i}$$

- Butler-Volmer Charge-Transfer Reactions at Electrode Surface

$$j = \mathrm{j_0}\left[\mathrm{C_R}\exp\left(\frac{\alpha_a F\eta}{RT}\right) - \mathrm{C_O}\exp\left(\frac{\alpha_c F\eta}{RT}\right)\right]$$

  - Multi Step Reaction Mechanism

$$4\mathrm{Au^*(OH)_2} + \mathrm{H_2O} \rightleftharpoons \mathrm{Au(OH)_3} + 3\mathrm{Au} + (\mathrm{H^+} + \mathrm{e^-})$$

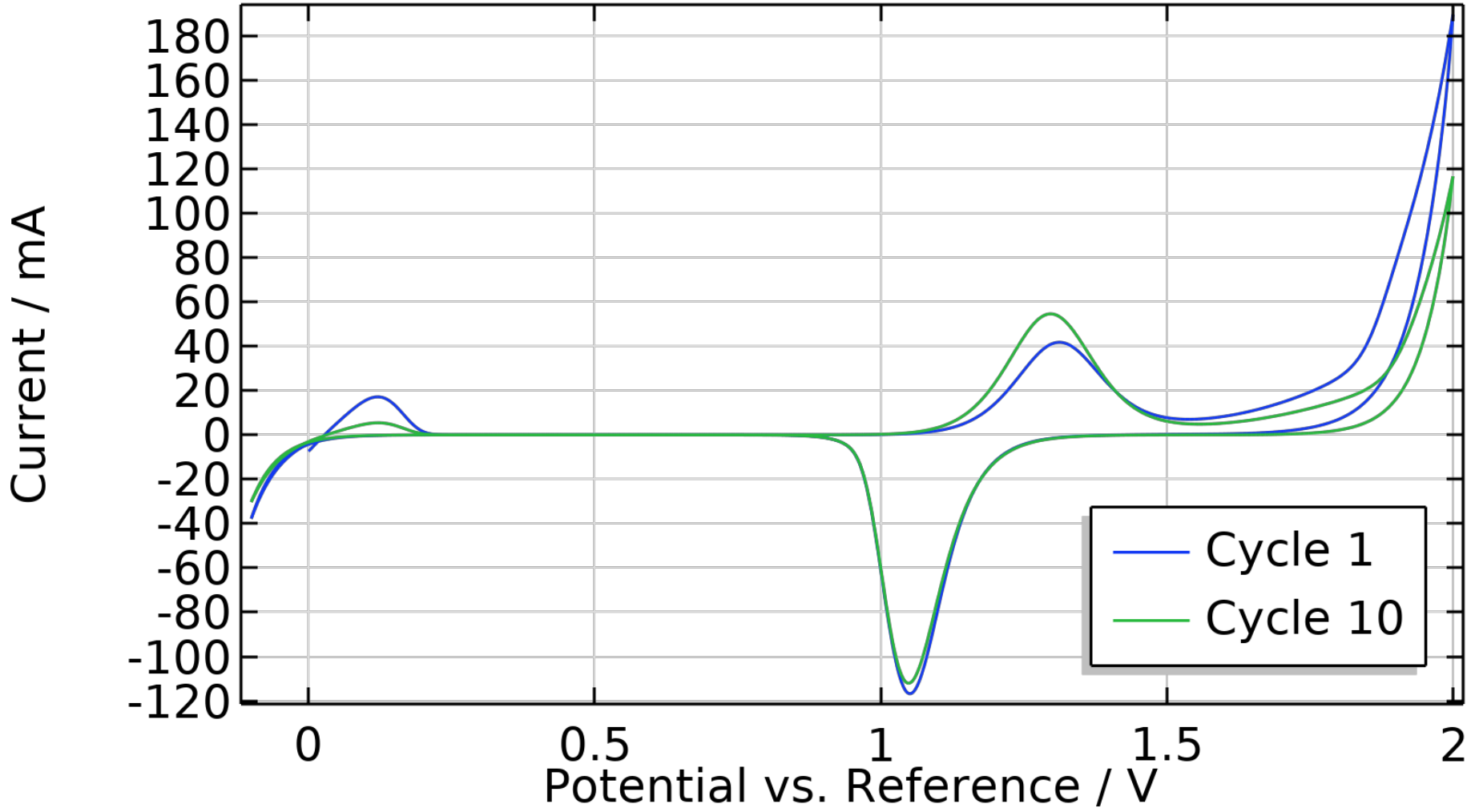
$$\mathrm{Au(OH)_3} + \mathrm{Au^*} + \mathrm{H_2O} \rightleftharpoons 2\mathrm{AuOOH} + 3(\mathrm{H^+} + \mathrm{e^-})$$

$$5\mathrm{AuOOH} \rightleftharpoons \mathrm{Au_2O_3} + \mathrm{Au} + 2\mathrm{O_2} + 5(\mathrm{H^+} + \mathrm{e^-})$$

- Linear Diffusion of absorbed atomic Hydrogen in Gold

Reaction Mechanism: Diaz-Morales, O. et al., 2013, Chemical Science

Model Development



Conclusion and Outlook

- Gold in Nafion shows similar CV characteristics as gold in acid
- HER at Au Surface at negative potentials
  - “Charging” of gold with hydrogen seems likely to explain anodic peak after prolonged negative potential
  - OCV reduction confirms HER
- Next steps (for Full Paper)
  - Parametrise the Model (Least Square Fit)
  - Dynamic Pulse on EFM supplied with Signal Generator (Signal i.e. Square Wave, etc.)

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Thank you for your attention!

Picture: Public Relations Office HSU