Current distribution in PEMFC:
I-Validation step by ex-situ and in-situ electrical characterization

PhD student: Samir RACHIDI

PhD Director : Sergueï Martemianov

CEA tutors: Ludovic Rouillon, Joël Pauchet

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Plan

- Introduction
  - Why Current Density?
  - Current Density measurements, State Of Art

- Reverse method approach
  - Methodology
  - Wires' instrumentation
  - Electrical Model

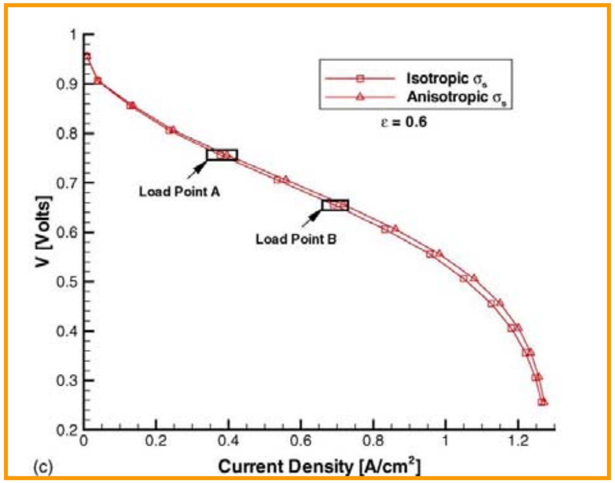
- Preliminary results and validation
  - Preliminary results
  - Model sensitivity
  - Potential measurements' validation

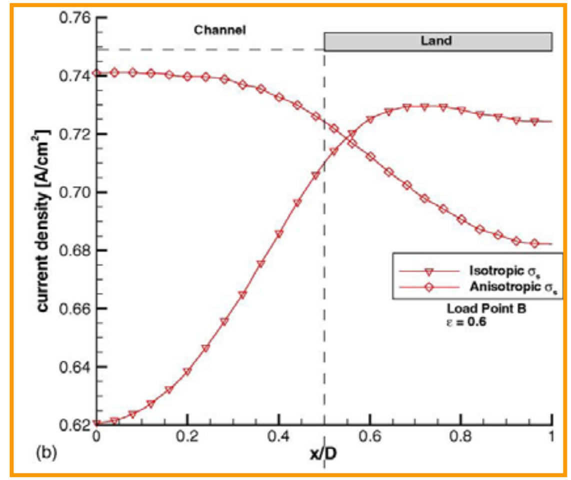
- Conclusions & perspectives

Why the current density?

- Key output of a PEMFC:
  - Globally: « Visualize » the cell performance

JG Pharoah et al., **2006**, JPS, 161





  - Locally: understand the non uniformity of the electrochemical reaction (rib/channel effect, flooding/drought aspect,…)

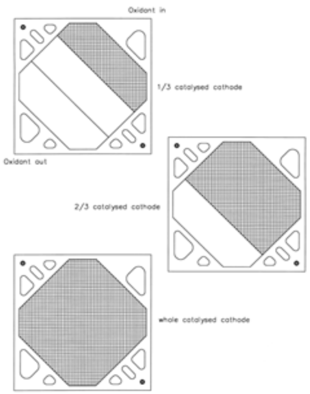
    ⇨ *Contribute in understanding local transfer phenomena*

- Feed/validate multi-physics models in our lab
  - Rib/channel scale: polarization curves not enough
  - All transfer phenomena into account

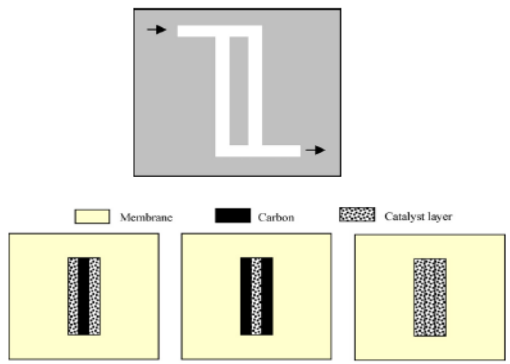
    ⇨ *Improve modeling predictability*

Current density measurements, State of Art

Partial Catalytic Deposit

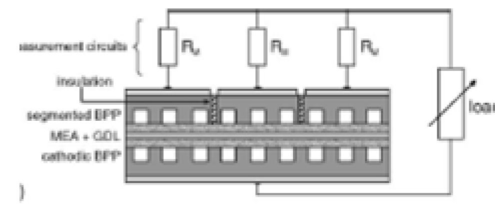


J.Stumper et al, Electrochimica Acta,1998.



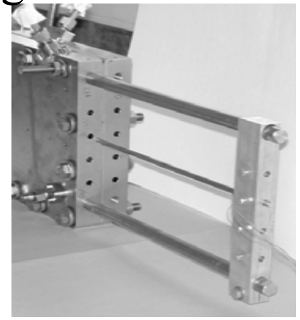
L.Wang et al, JPS 180 (2008)

Segmented Electrodes



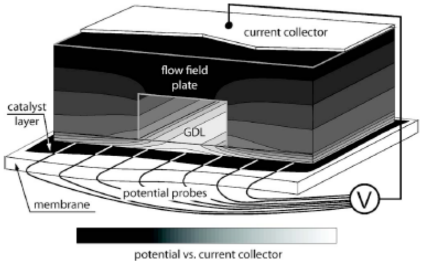
R. Eckl, et al., JPS 154 (2006)

Magnetic field Method



D. Candusso et al,. J. Appl. Phys. 25, 67–74 (2004).

Wire approach



Stefan A. Freunberger et al, (2006)

Spatial resolution of measurements evolved from centimeters to a sub-millimeter scale

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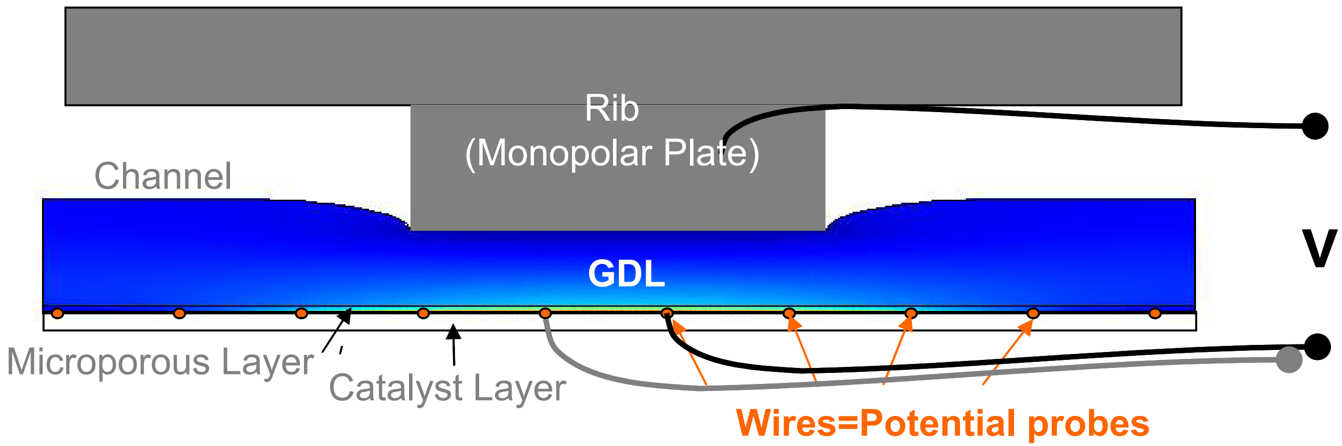
Methodology

1/ Potential measurement between each wire and monopolar plate



2/ Implementation of the potential profile as a boundary condition in an electrical model

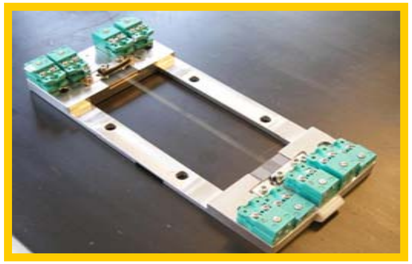
3/ Determination of local current density thanks to the model via Laplace Equation:

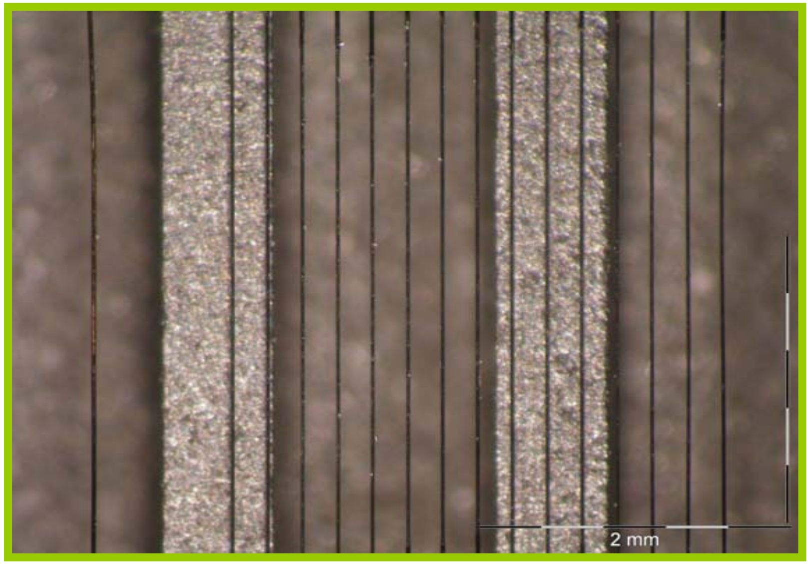
$$\nabla.(-\underline{\sigma}.\nabla V) = 0$$

Reverse Method : Potential —(Modeling)→ Current density

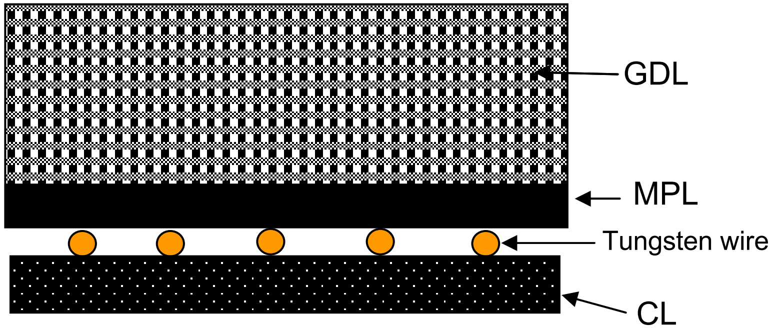
Wires' Instrumentation

- Potential Probes:
  - Tungsten (W) wires insulated by a polyimide layer
  - Diameter: 25 µm of tungsten + 5µm of polyimide
  - Insulating layer removed from the measurement zone
  - Minimal achievable distance between two wires : 115µm



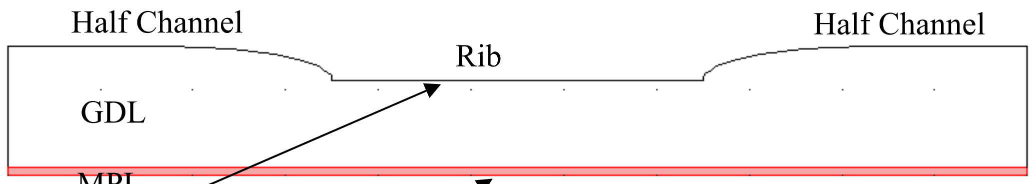


2mm



➡ Improvement of the spatial resolution of potential measurements (500µm until now)

Electrical Model



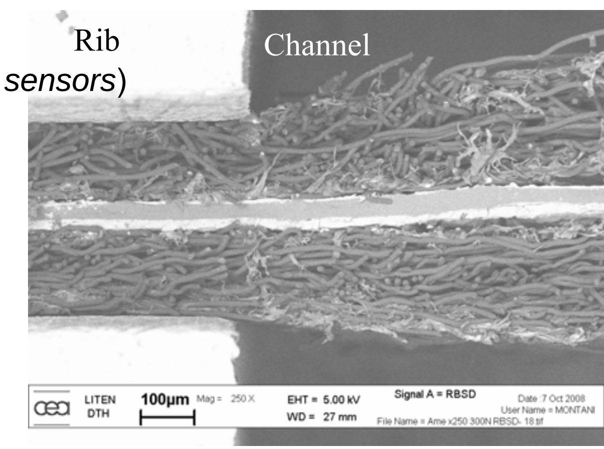
- Software: Comsol Multiphysics

- Boundary conditions:
  - Rib : Contact Resistance
  - MPL outer boundary: Measured potential profile

- Model Inputs :
  - Electrical conductivity tensor (*measured in-house under stress by 4-points sensors*)

$$\underline{\sigma} = \begin{pmatrix} \sigma_{//} & 0 \\ 0 & \sigma_{\perp} \end{pmatrix}$$

  - Electrical contact resistance (in-house values)



- Computing of the electrical potential field "V"
  - Current density calculation in a post processing step: local Ohm's law "J= $-\underline{\sigma}.\nabla V$"

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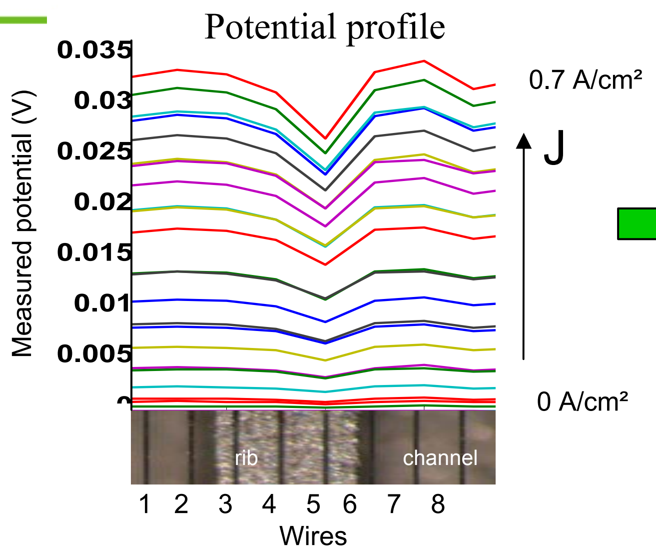
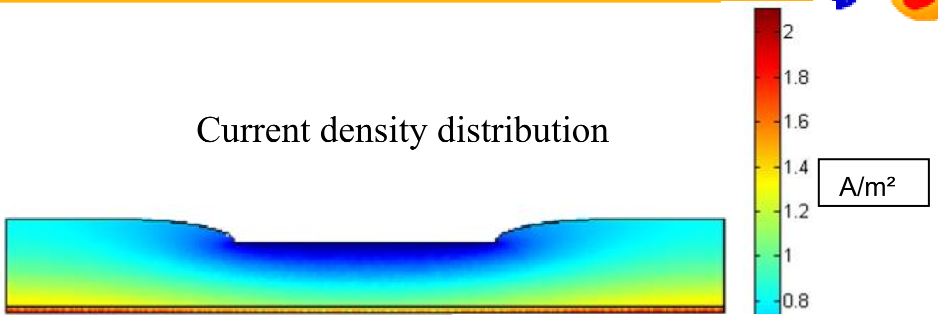
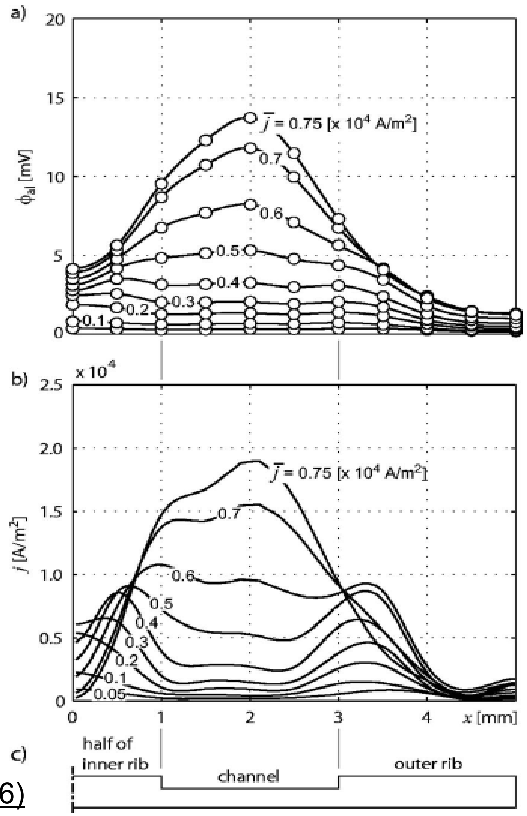
Preliminary results







•Electrical potential higher under the channel in both studies

•The same order of magnitude of potential difference between the wires encountered in the PSI study (some mV)

•Two operating phases:

- •At low loads : *current density* higher under the rib
- •At high Loads: *current density* higher under the channel

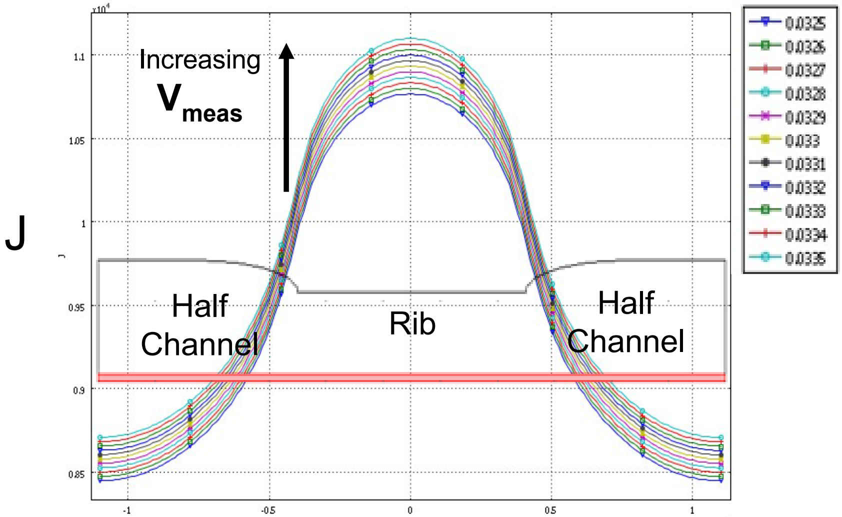
•Interesting technique: understand local transfer phenomena

Stefan A. Freunberger et al. ECS, (2006)

Model Sensitivity

- Our approach is based on experimental measurements that feed an electrical model
  ⇒ Need to evaluate the *model sensitivity* towards measurements' *uncertainties*

- Four measured parameters:
  - Electrical potential measured locally :$\mathbf{V_{meas}}$; [0; 34 mV]
  - Through plane electrical conductivity : $\boldsymbol{\sigma_\perp}$; [70; 200 S/m]
  - In plane electrical conductivity $\boldsymbol{\sigma_{//}}$; [8400; 10600 S/m]
  - Contact Resistance between the BPP and the GDL: arround **Rc** = 2.10^{-7}ohm.m²
- We vary each measured parameter *separately* and we observe the relative change in current density profile (ΔJ/J)

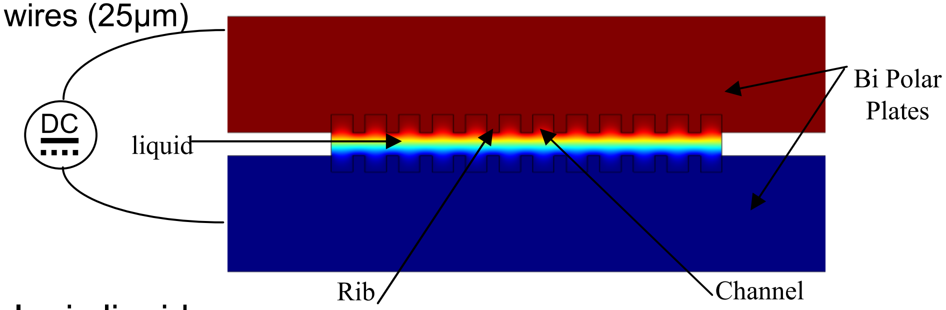


Parameter	ΔJ/J < 10%	ΔJ/J < 5%
$\mathbf{V_{meas}}$ (µV)	+/-100	+/-10
$\boldsymbol{\sigma_\perp}$ (S/m)	+/-10	+/-1
$\boldsymbol{\sigma_{//}}$ (S/m)	+/-1000	+/-100
Rc (ohm.m²)	$+/-0.1*10^{-7}$	$+/-0.01*10^{-7}$

⇒ Electrical model strongly depends on the electrical contact resistance
In plane conductivity $\sigma_{//}$ isn't a sensitive parameter

Potential measurements' validation

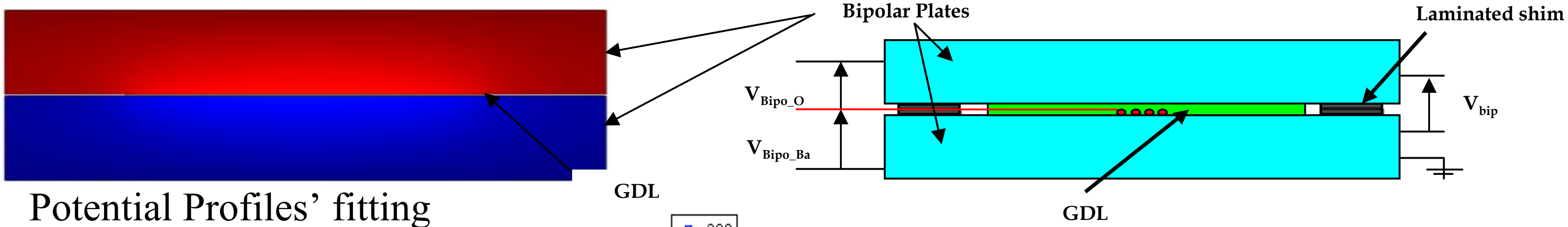
- **<u>Why?:</u>** Small potential difference between the wires + Model sensitivity towards the measured potential
  - ⇨ Need to validate the in-situ potential measurements
- **<u>Idea:</u>** *Verify electrical conductivity* of some known materials via *<u>potential measurements</u>*
- **<u>HOW?:</u>** confront the experimental and the theoretical potential profiles
- Case1: electrical conducting liquids
  - Isotropy
  - Homogeneity
  - Environment continuity at the scale of tungsten wires (25µm)
- The choice of the liquid
  - High electrical conductivity
  - Wettability
- Liquids used: Aqueous solutions e.g. (K^+;Cl^-); Ionic liquids



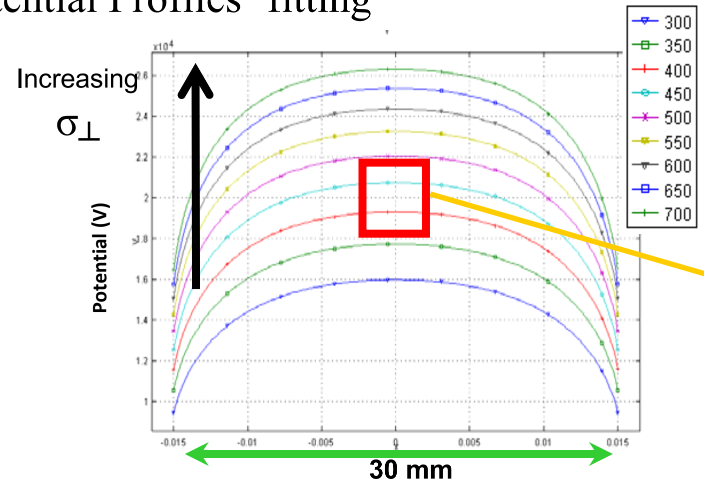
⇨ Experiments and results' exploitation in progress

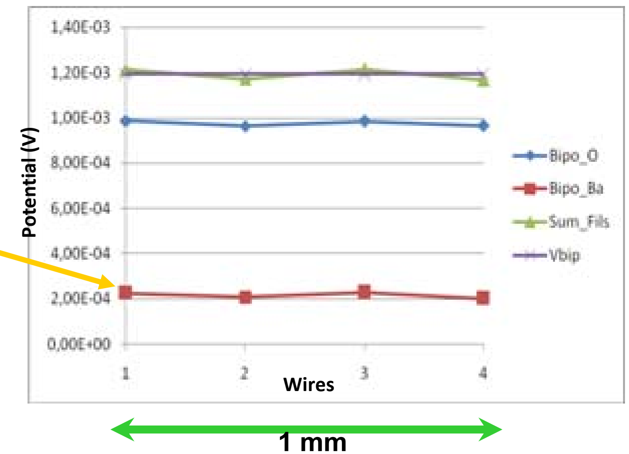
- Case 2: Through plane conductivity of a GDL, σ⊥

- Confronting *theoretical* and *experimental* potential profiles



- Potential Profiles' fitting





Satisfying conductivity values with a good approximation

The wire system can be used as a 4-points sensor

(see J. Kleemann, F. Finsterwalder, W. Tillmetz Journal of Power Sources 190 (**2009**) 92–102)

Conclusions

- A very interesting approach to understand local transfer phenomena in the PEMFC's core
  - Efficient tool in the future for on-line diagnosis of an operating stack

- A reverse method has been set up to determine current density distribution

- The sensitivity of the electrical model towards measured parameters used was studied

- Improvement of the spatial resolution of the in-situ potential measurements

  115µm instead of 500µm

- A validation procedure was initiated in order to verify the potential measurements' quality

Perspectives

- The reverse method will be used to determine a local current density distribution in a PEMFC
- Finalize the validation step
- Implementing wires in an operating cell
- Results and model exploitation
- Coupling local thermal measurements
- Tests on an instrumented stack