Identification of Paint Resistance and Deposition Model Parameters for Electrodeposition Coating Simulation

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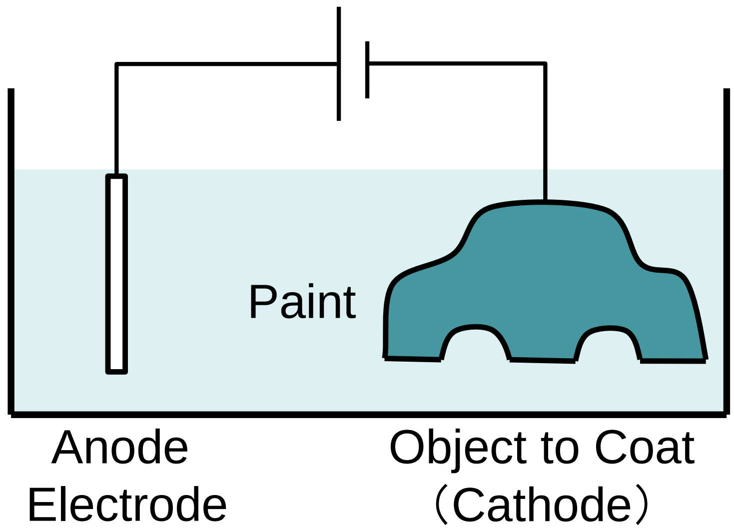
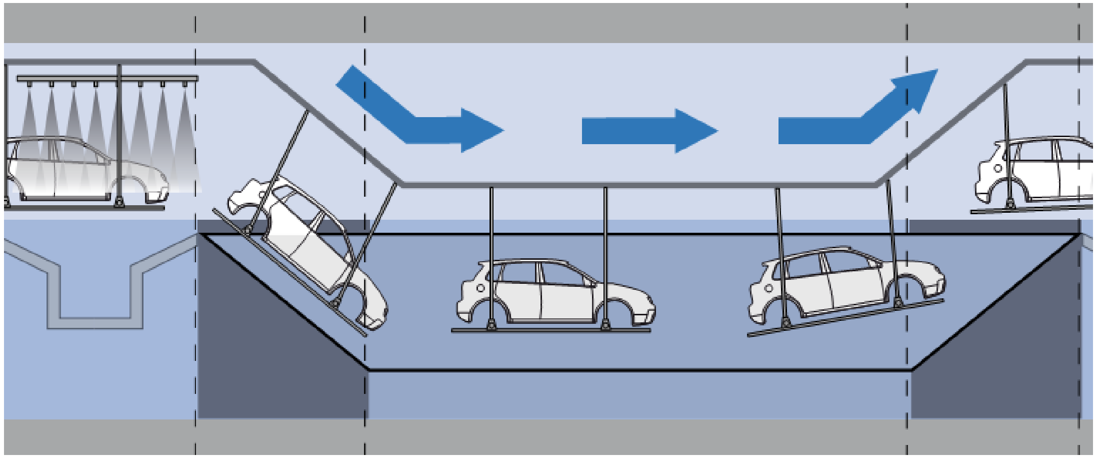
What is electrodeposition (ED) ?



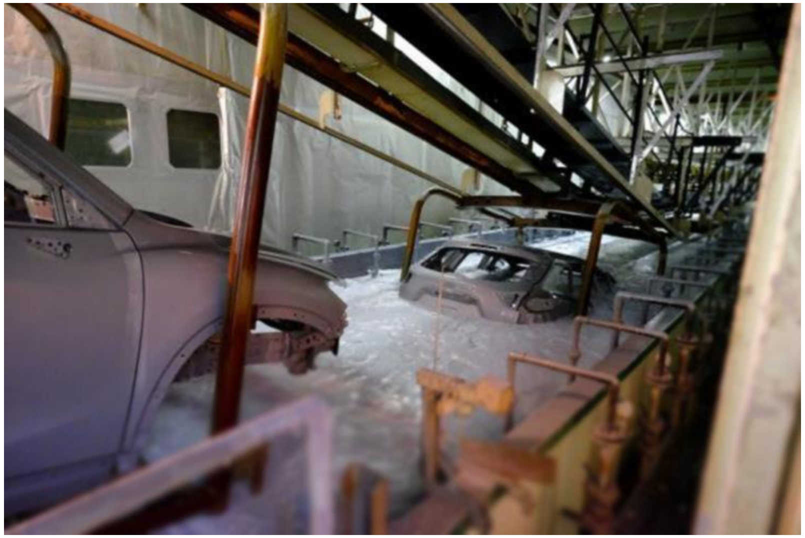


(By http://www.rodip.com.br/)

- One of the popular basecoat method for car bodies.
- Making coated film by passing a direct electric current.
- Coated film has a certain electrical resistance, and thus
- Electric current tends to flow on to thinner film areas.

⇨ ED is good at making coated objects with an uniform film thickness.

Photos of ED process line



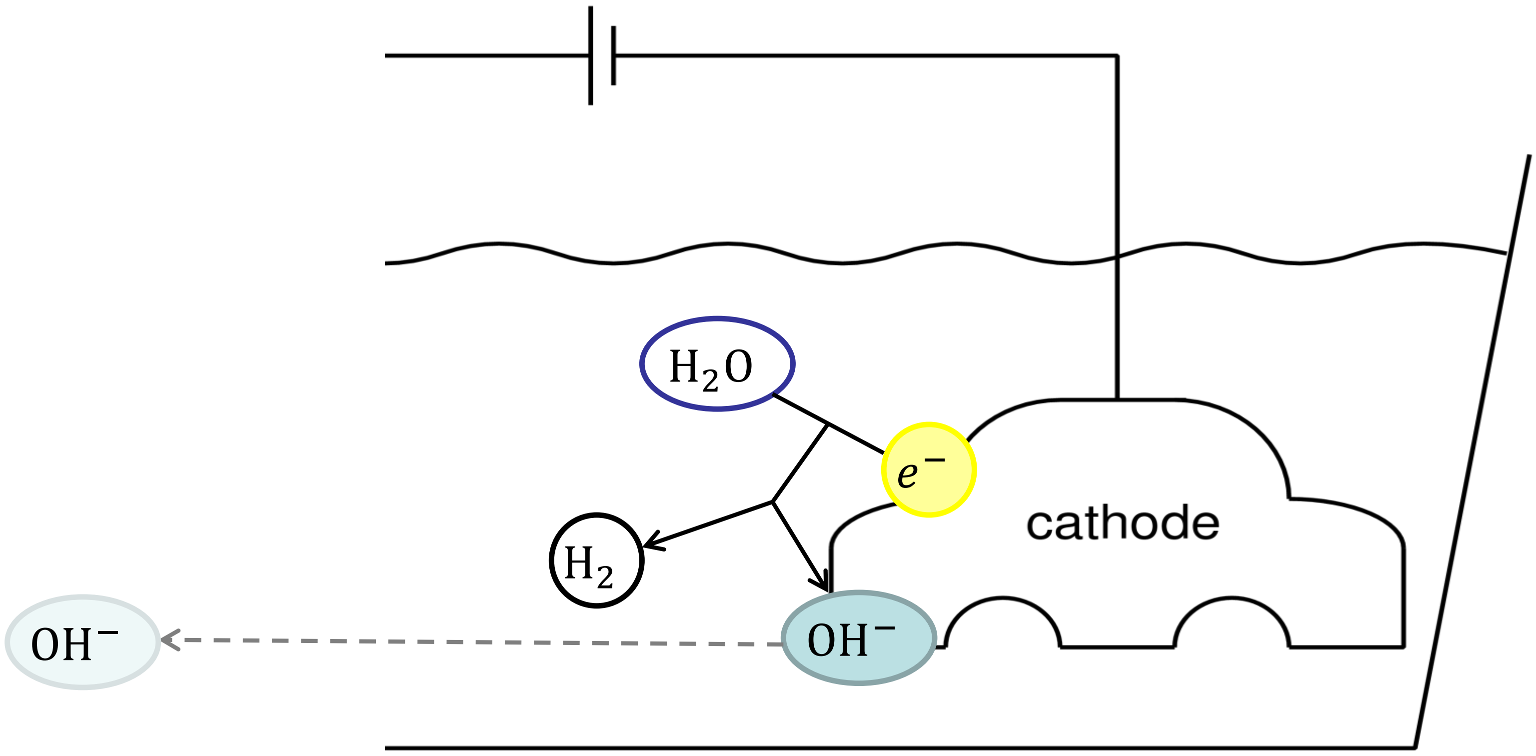
1. dipping and deposition process

2. water rinse process

We focus on this.

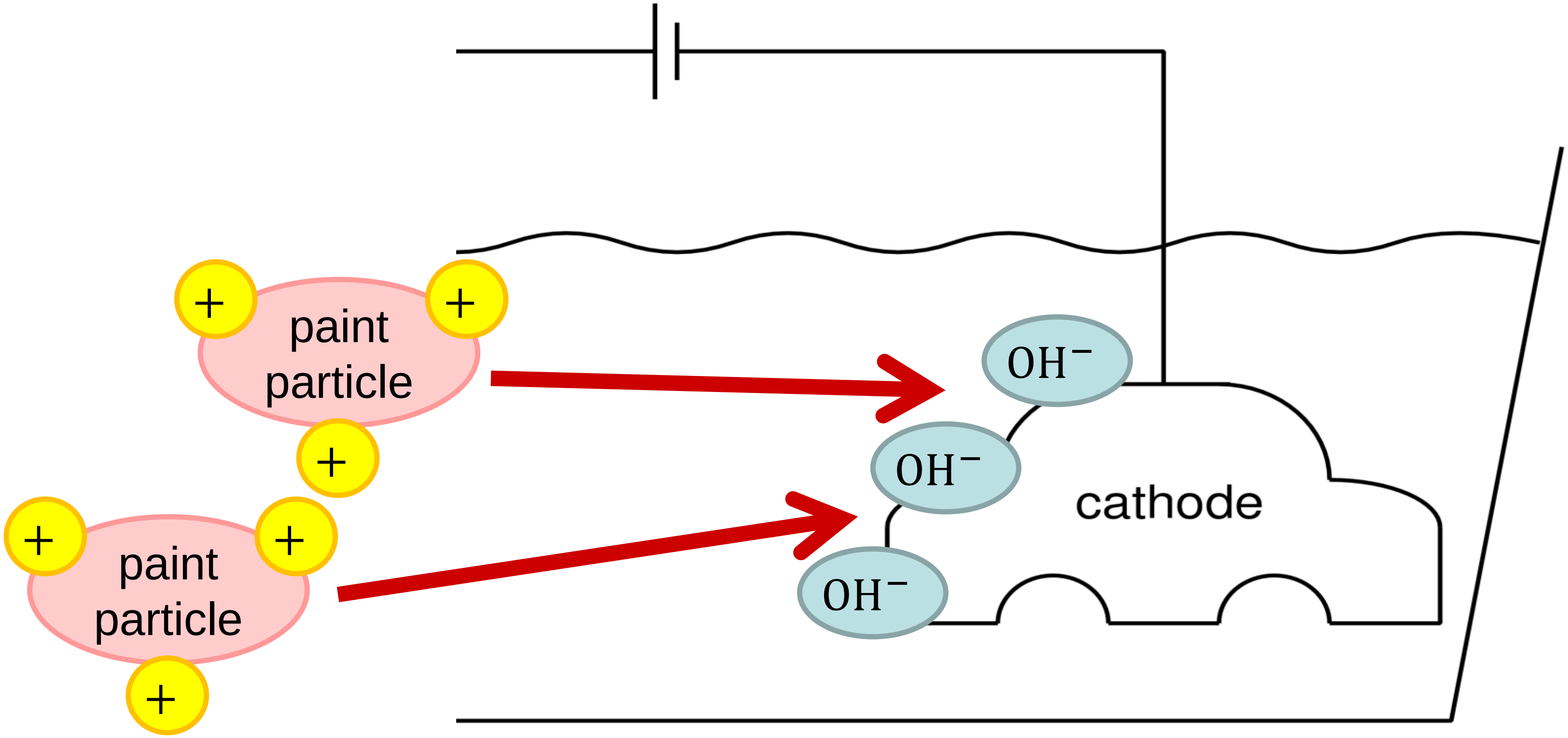
3. baking process

Outline of ED mechanism



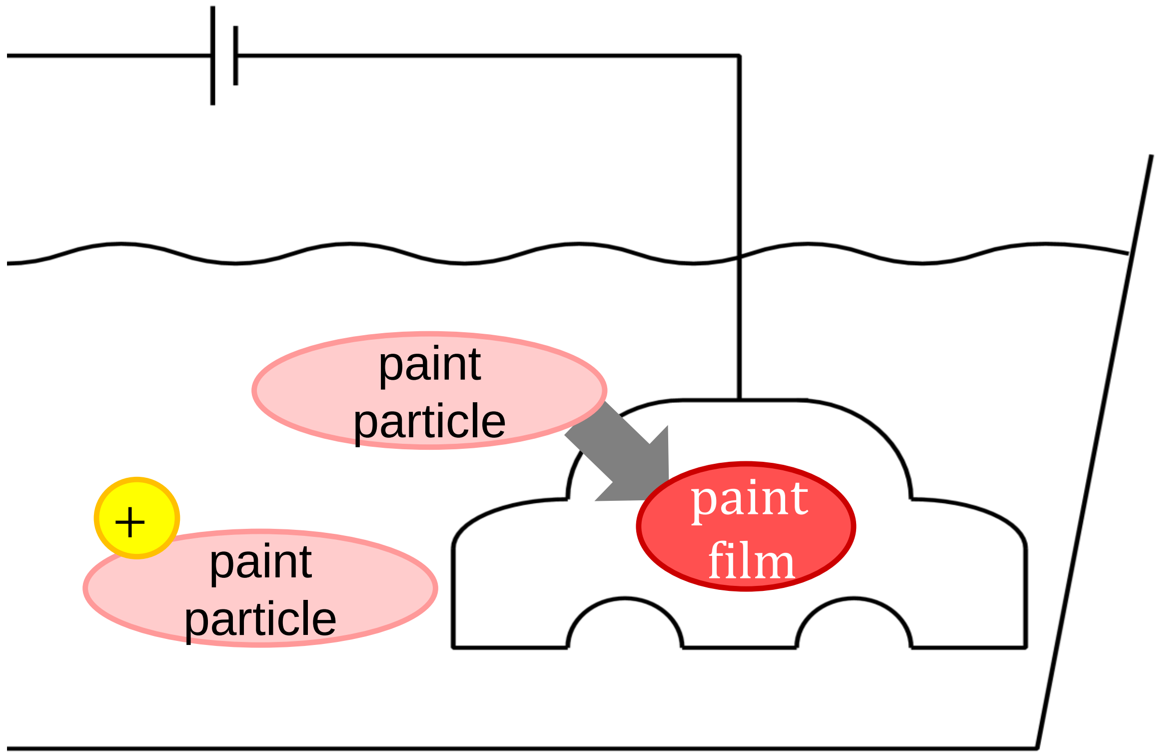
① Electric current generates OH^- and H_2 from H_2O on the cathode surface.

Outline of ED mechanism



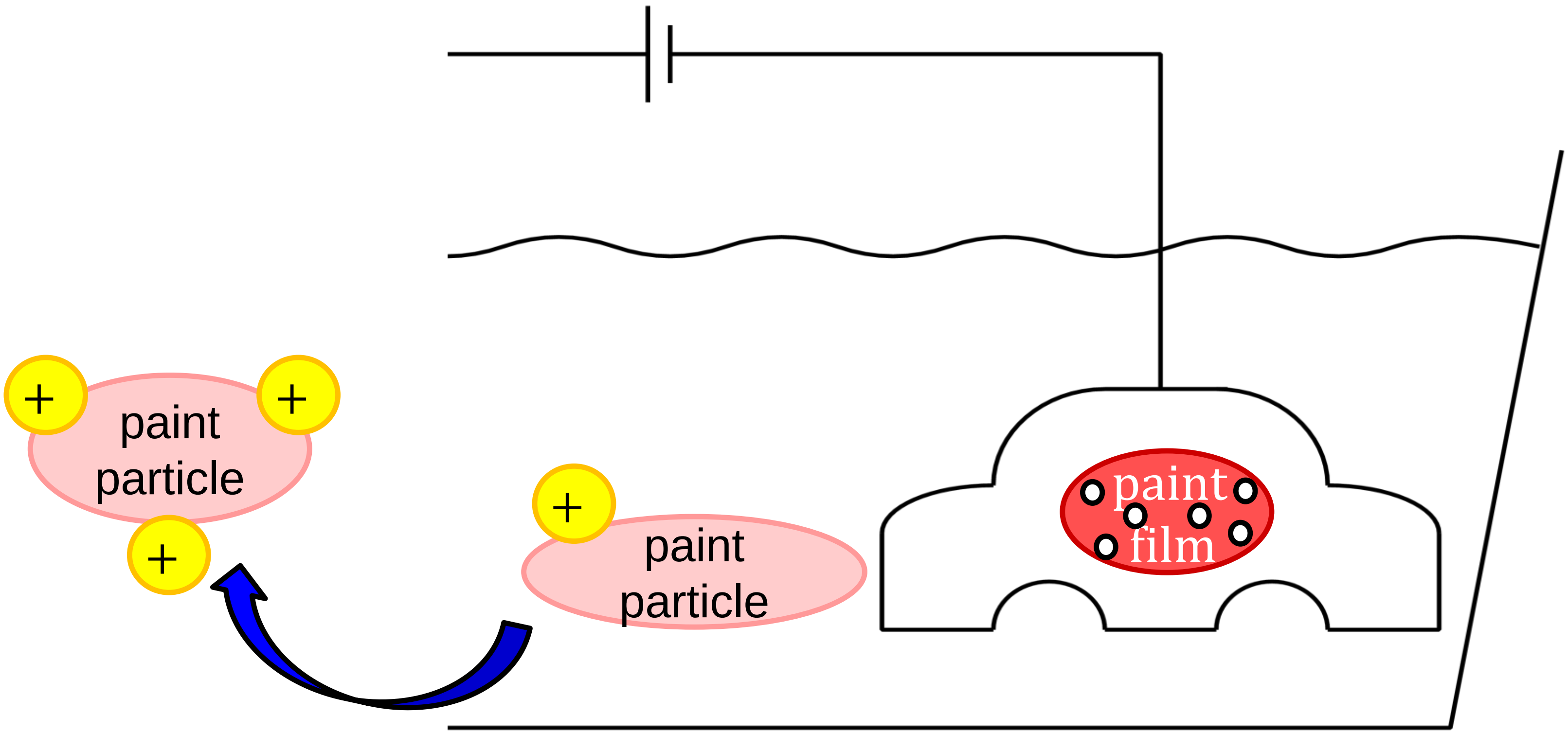
② Paint particle ions having positive (+) charge are attracted to OH^- toward the cathode.

Outline of ED mechanism



③ Some of the paint particle ions are neutralized and stick on the cathode surface, becoming a paint film.

Outline of ED mechanism



④ The rest of the paint particles are diffused and resolved again as ions.

⑤ The paint film soon has a number of **holes** to let the next OH^- and H_2 go through.

2 Complexities in ED phenomena

1. The electric resistance of the paint film is not linear with respect to the film thickness…

$$R \neq \alpha\, h$$

Due to a number of holes

R: resistance, α: const., h: film thickness.

2. The growth rate of the paint film is not linear with respect to the current density…

$$\dot{h} \neq \beta\, j$$

Due to the diffusive current

$\dot{h}$: film growth rate, β: const., j: current density.

(These complexities in experiments are shown later in this talk.)

Experimental ED process optimization costs high!
$\Longrightarrow$ Numerical ED simulation is important.

Objective

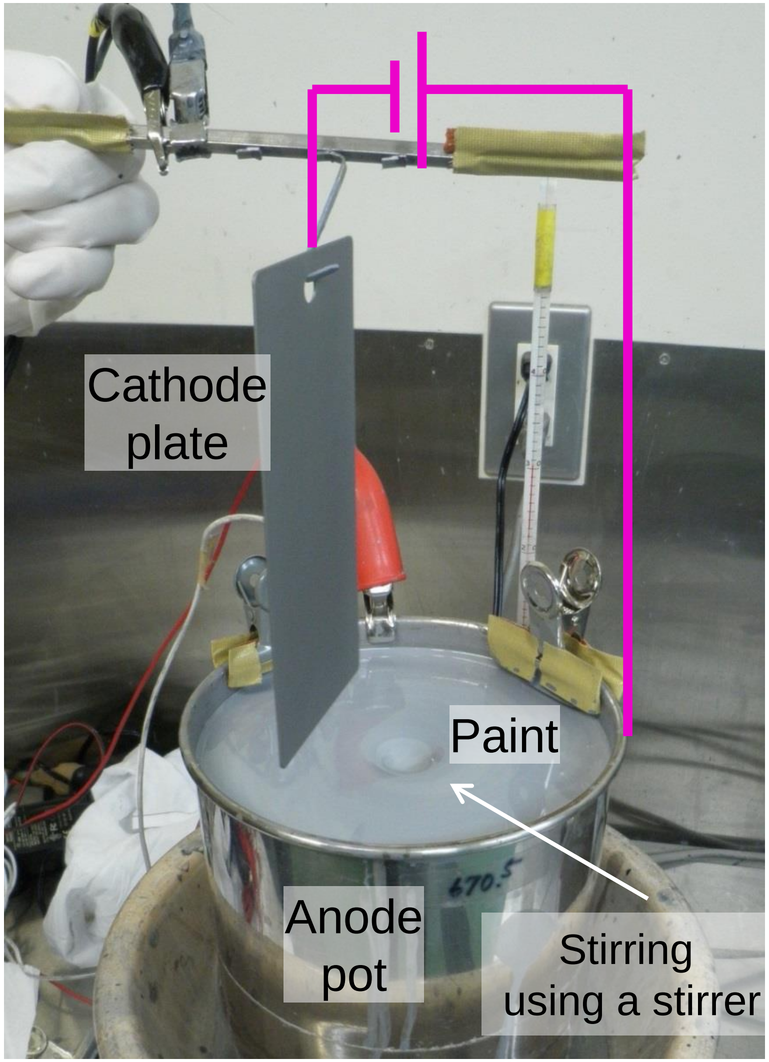
Identify the two fundamental ED models,
1. a nonlinear film resistance model and
2. a nonlinear film growth model,

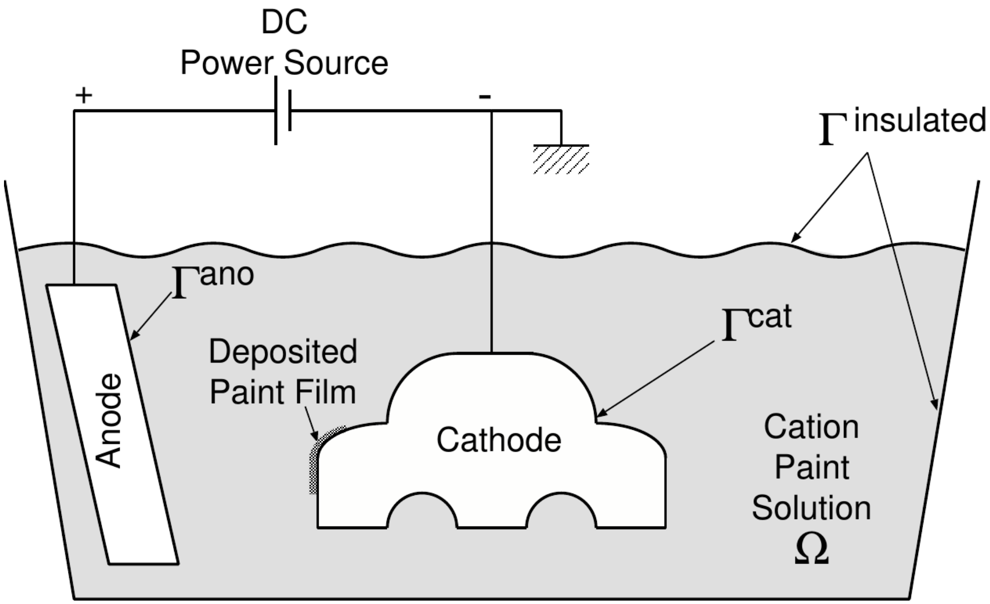
via basic ED experiments
for accurate numerical ED simulation.

Table of body contents:
- Basic ED experiments
- Our new models
- Validation results
- Summary

Basic ED Experiments

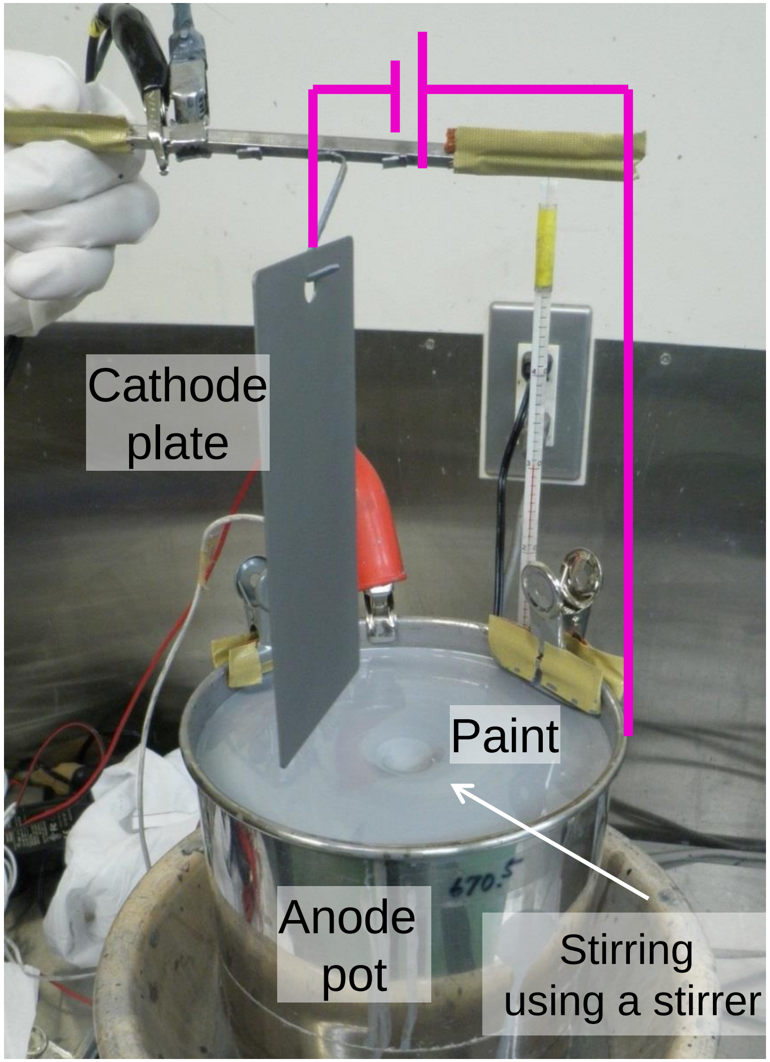
Outline of the one-plate test





- Use a rectangular steel plate instead of a car body.
- Use a SS pot instead of the paint pool and anode electrodes.

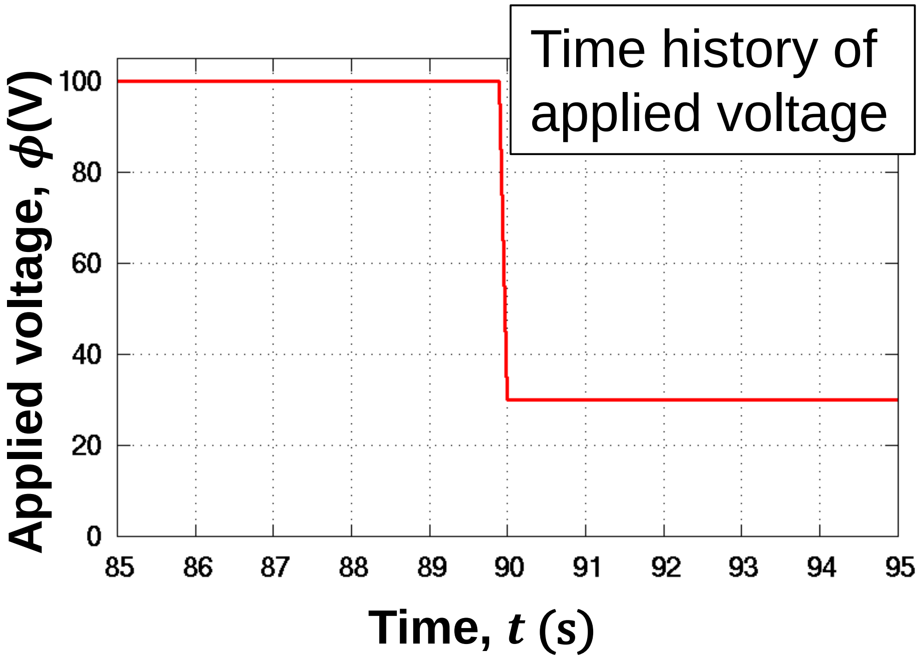
Outline of the one-plate test

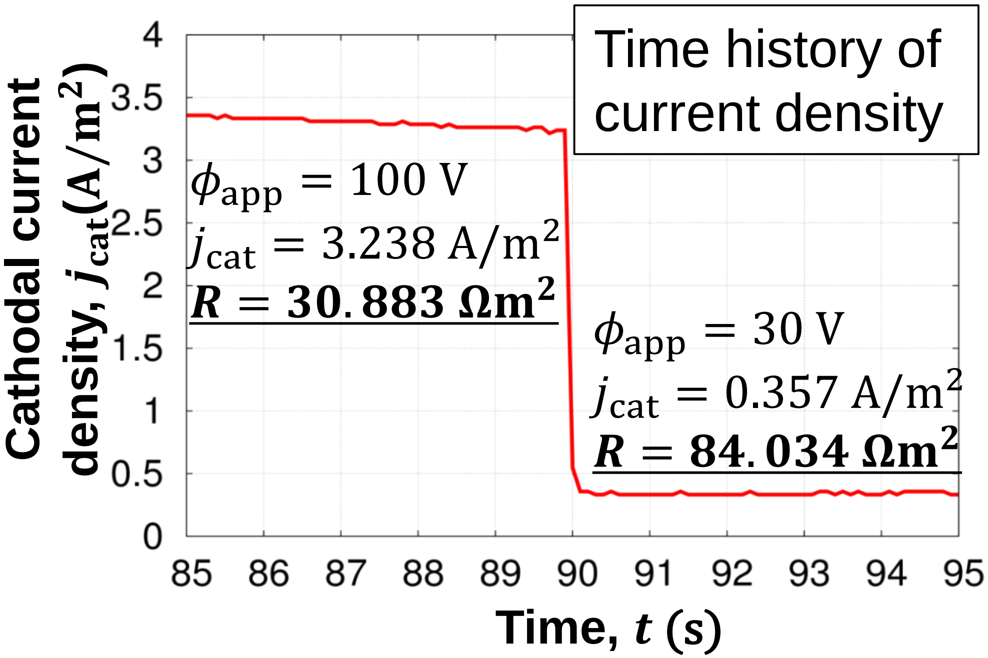


- Dip a steel plate into the paint pot.
- Apply voltage up to 250 V between the plate and pot.
- Measure time-histories of
  - applied voltage,
  - current,
  - film thickness.

An example of film resistance nonlinearity

In the middle of an ED test, we changed the applied voltage quickly from 100 V to 30 V. Then, the film resistance before/after the change was estimated.



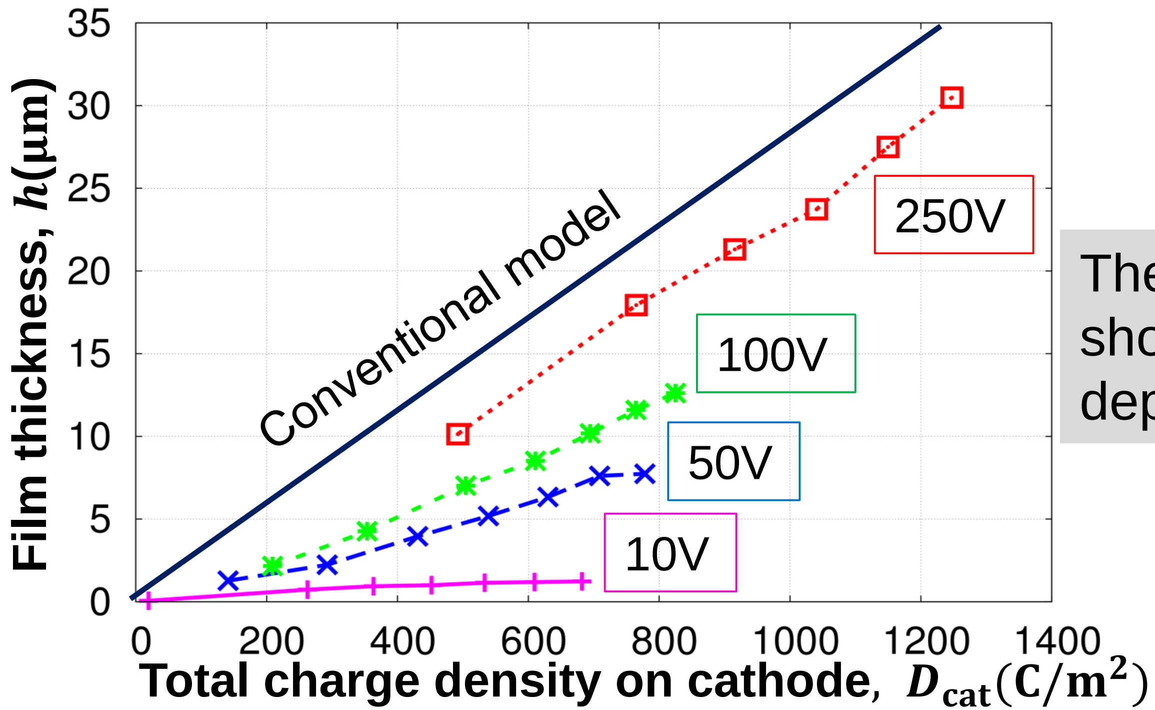


The film thickness is same, but **the resistance changes quickly.**

The film resistance should be modeled with a polarization curve depending on film thickness.

An example of film growth nonlinearity

Relation between total charge density and film thickness.



The inclination shows the deposition efficiency.

The total charge density is same, but
the deposition efficiencies are different.

The film growth model should include the effect of the diffusive current depending on the voltage and film thickness.

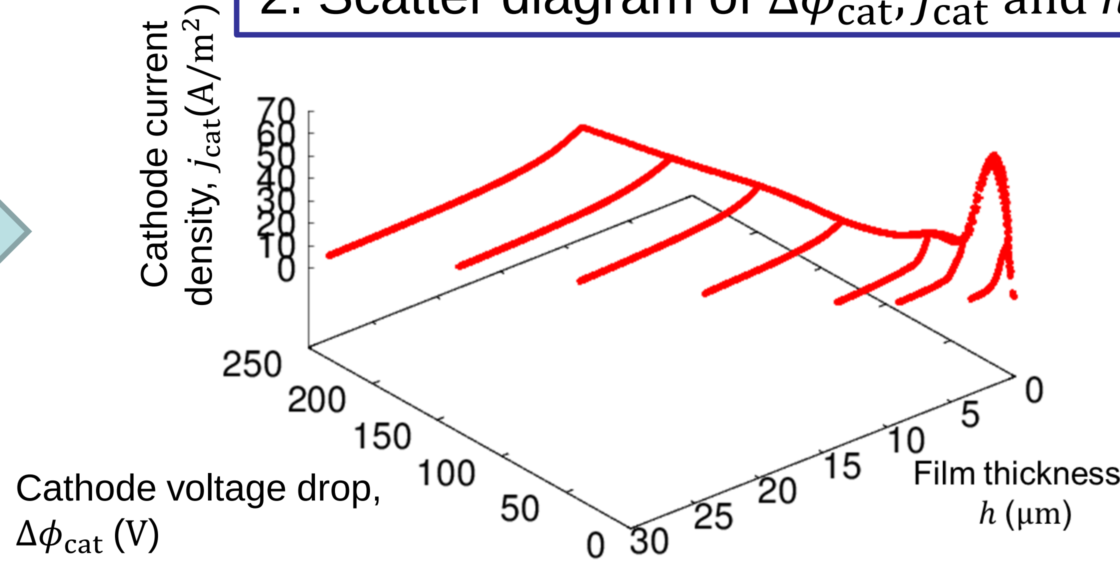
Our new models

Procedure to identify resistance model

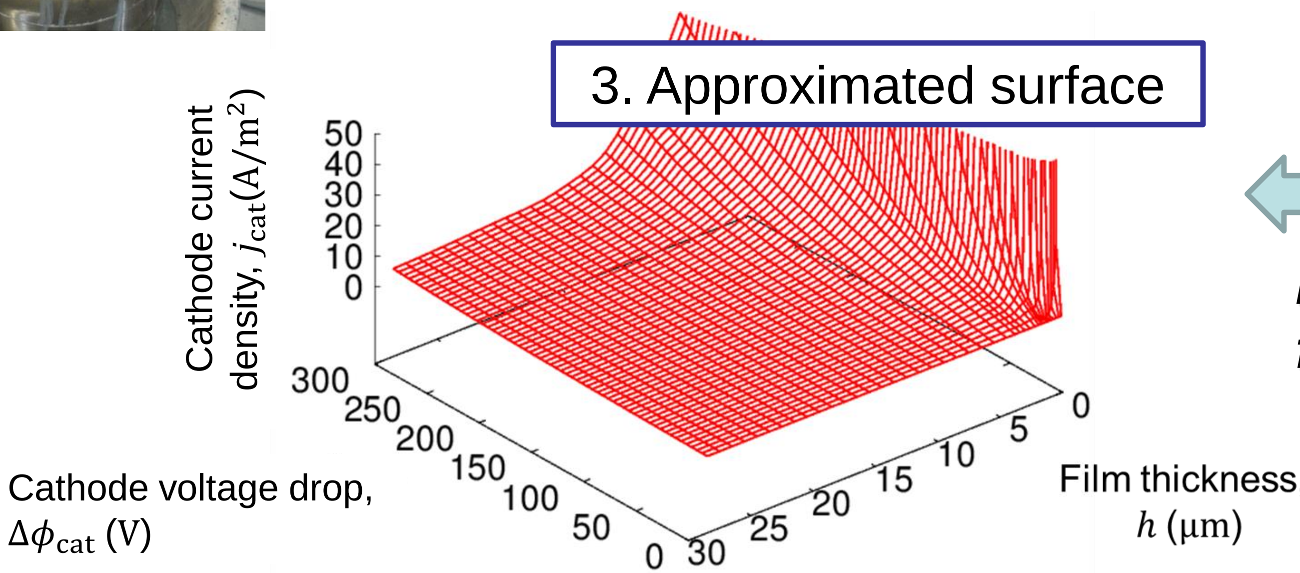
1. One-plate tests

Plot

2. Scatter diagram of $\Delta\phi_{cat}, j_{cat}$ and h



3. Approximated surface



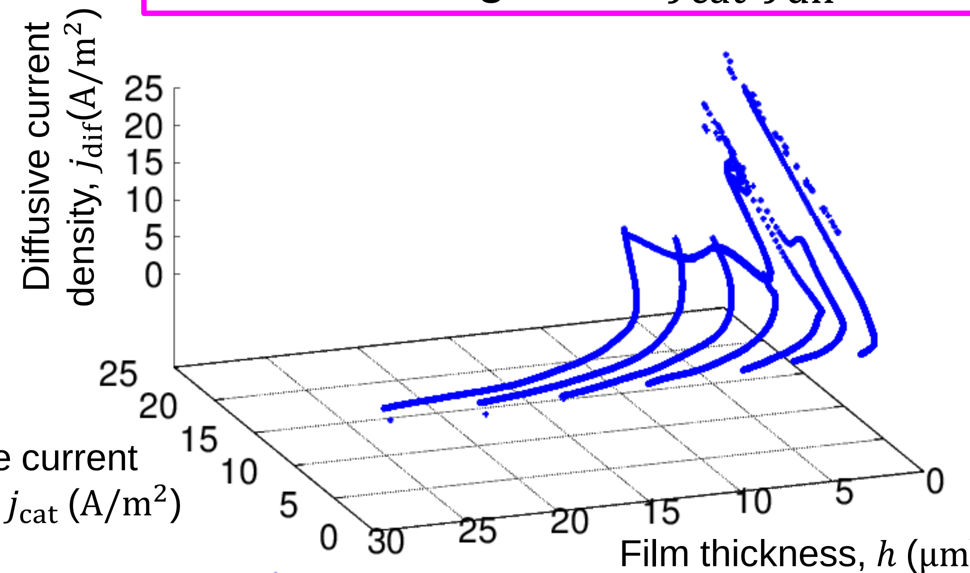
Data fitting

Procedure to identify film growth model

1. One-plate tests

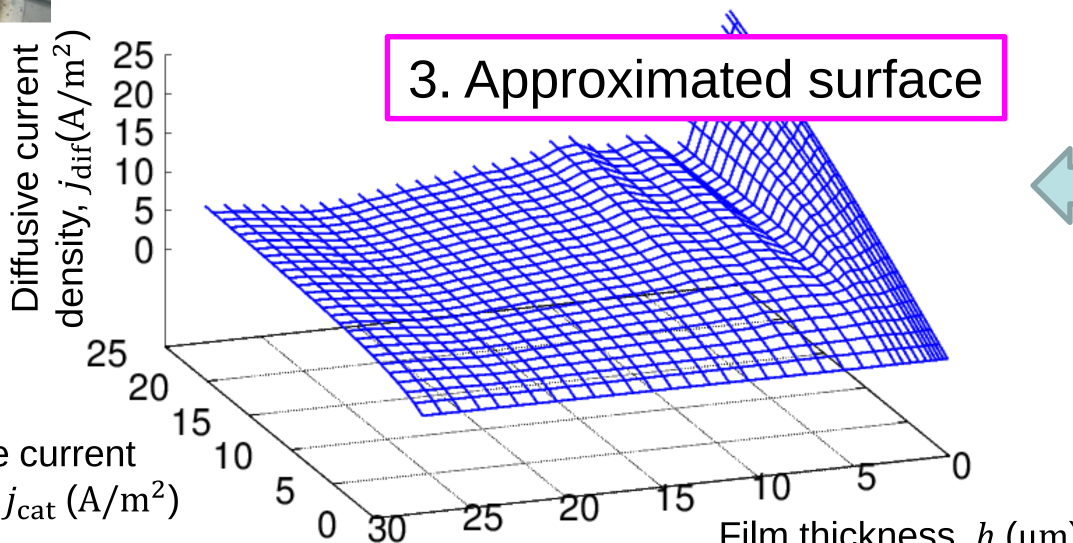
Plot

2. Scatter diagram of j_{cat}, j_{dif} and h



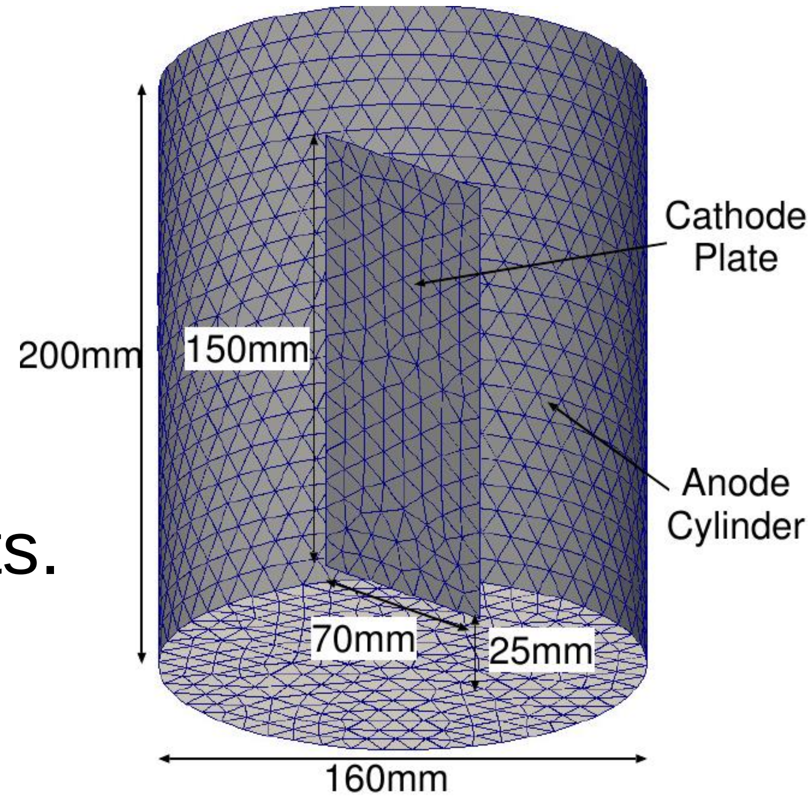
Data fitting

3. Approximated surface



Validation Results

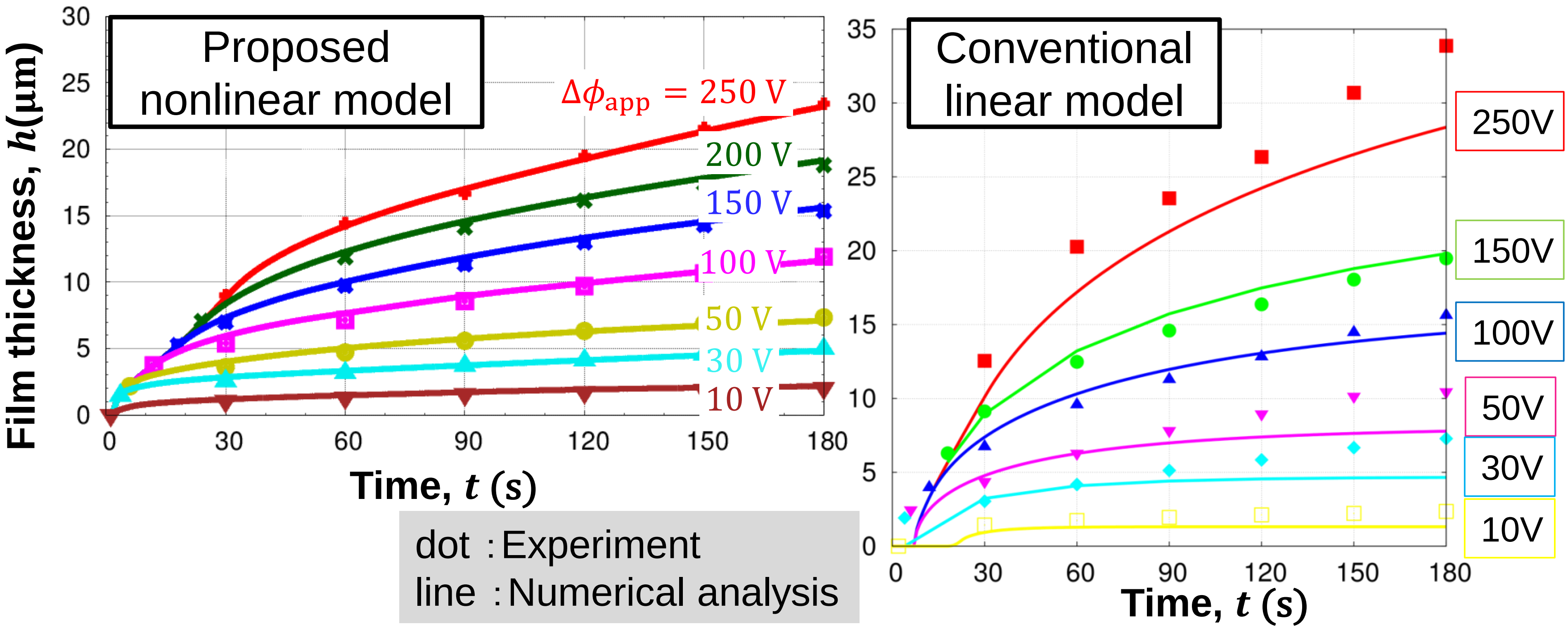
Our ED simulator



- In-house finite element code.
- 2^{nd} order tetrahedral elements.

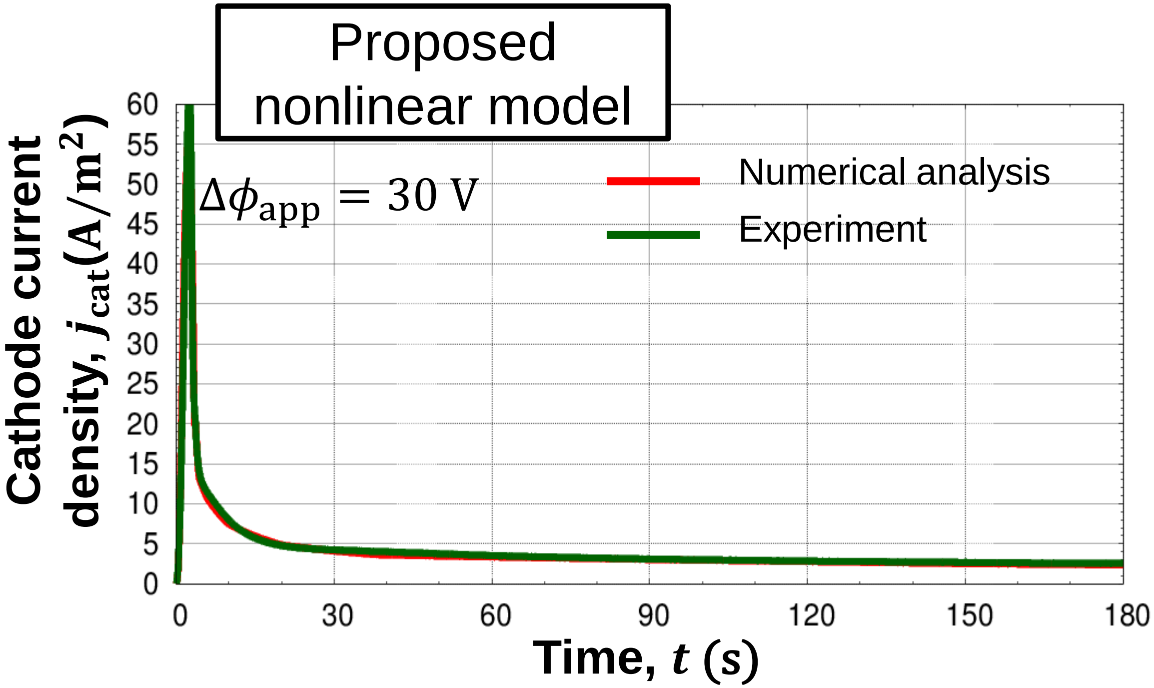
The **experimental** results of the one-plate tests are compared to the results of our simulator with the **proposed nonlinear models** and those with the **conventional linear models**.

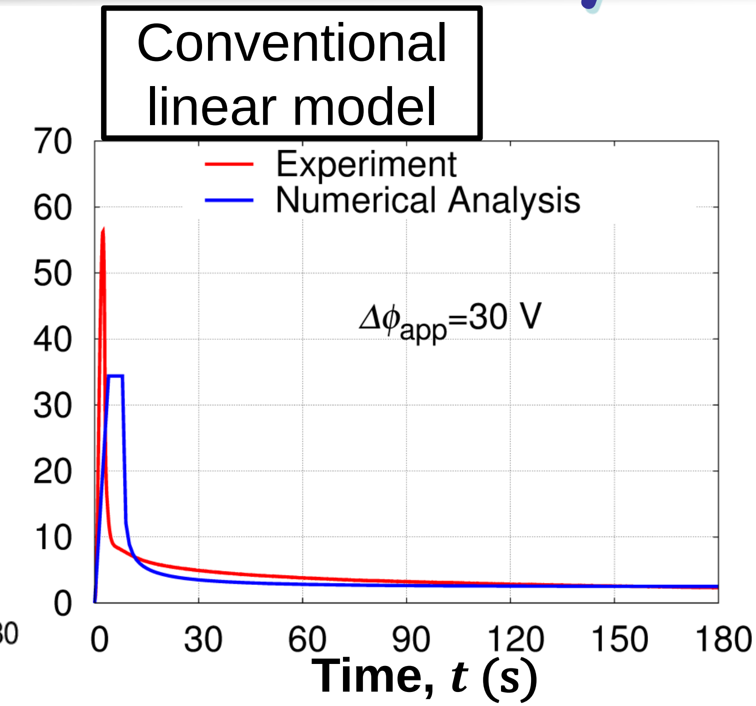
Time history of film thickness



- Conventional linear models fail to represent the experimental data…
- Our new nonlinear models succeeded in reproducing the experiments!

Time history of current density





- Conventional linear models fail to represent the experimental data…
- Our new nonlinear models succeeded in reproducing the experiments!

Summary

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- A new **nonlinear** film resistance model and film growth model for accurate electrodeposition (ED) simulation were proposed.
- The model parameters were identified via the one-plate ED tests.
- Our new models improved the accuracy in time histories of the film thickness and current density compared to the conventional linear models.

Thank you for your kind attention.