ionbond

Advanced Materials for PEM Electrolysis (H2-AMP)

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Performance Coatings for PEM Metallic Bipolar Plates

Ton Hurkmans

Short Company Introduction

IHI

Public company of Japanese origin; large industrial projects

ionbond

- PVD/PACVD service
- Shop-in-shop service

HAUZER

- PVD/PACVD equipment
- CVD equipment

Ionbond Worldwide Network

■ Ionbond Coating Centers

- All centers are ISO 9001 certified
- Additional certifications exist for specific markets, including

ISO/TS 16949 (automotive) ISO 13485 (medical)
EN 9100 / AS 9100 (aerospace) NADCAP (aerospace)
ISO 14001

Coating service portfolio

Medical
Medthin™ Series

Certified biocompatible coatings for implants and instruments.

Forming and Molding

Increased service life and better quality of tools and parts.

Deco, Sport & Luxury
Decobond™ Series

Superior hardness, wear resistance, and a metallic look.

Automotive

DLC coatings for increased engine efficiency and reduced environmental impact.

Components & Aerospace

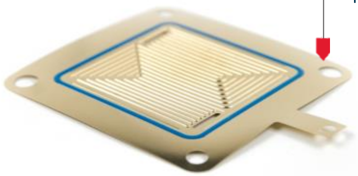
Extended load carrying capacity, reduced friction, improved wear behavior.

Cutting Tools

For every machining requirement and work piece material, from low to extremely high cutting speeds.

Fuel Cell & Electrolyzer

Protective coatings with high performance and durability for metallic bipolar plates



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Chapter 1

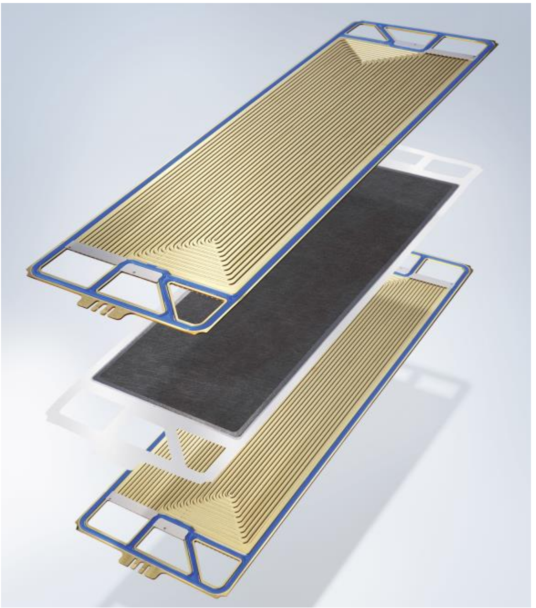
Motivation to provide coatings for PEM stack components

Bipolar Plates (BPP)

- Main challenges for PEM technology
  - Cost reduction
  - Weight reduction
  - Durability improvement

- Attention to Bipolar Plates
  - Substantial fraction of the total cost
  - Heaviest component
  - Providing physical strength

Mercedes-Benz GLC F-CELL



Source: www.greencarcongress.com

Typical Bipolar Plate Materials in PEM Stacks

- **Graphite (Fuel Cells)**
    - Limitations in mechanical strength (brittle in nature)
    - Not great for mobile applications of fuel cells
    - High machining costs
- **Titanium**
    - Expensive
    - Moderate formability
    - H_2 embrittlement
- **Stainless Steel**
    - Suitable mechanical properties
    - Good formability
    - High level of intrinsic corrosion resistance
    - Good electrical conductivity
    - Affordable

Need for coating of metal BPP

- **Enhanced corrosion resistance**
    - Inhibits harmful ions out-diffusion from stainless steel BPP
    - Inhibits hydrogen absorption and embrittlement of Ti BPP

- **Low and steady electrical contact resistance over the lifetime of the stack**
    - Low internal ohmic loss at high current density
    - Efficient and stable hydrogen to electricity conversion (FC)
    - Efficient and stable hydrogen generation (EL)

Chapter 2

The Challenge for Coatings

Challenging Operation Conditions for BPP’s

• Mass volume PEM Fuel Cell (passenger cars);	expected lifetime	5.000 – 10.000 hr
• Demanding application (trains, trucks, aerospace);	expected lifetime	20.000 – 30.000 hr
• Electrolyzers;	expected lifetime	> 80.000 hr

Challenging Operation Conditions for BPP’s

- Acids (pH 2 to 4)
- Humidity
- Cell operating voltages, especially for electrolyzers
- Elevated temperatures
- Corrosion Rate < 1 $\mu A.cm^{-2}$
- High Current densities > 2 $A. cm^{-2}$
- Low ICR < 10 $m\Omega. cm^2$
- Low Hydrogen Permeability < $2E^{-6}$ $cm^3/cm^2.s$

One Coating Solution should cover all requirements!

Coating Designs

- Use conductive materials in order to obtain the high current densities and low ICR
- Build a diffusion barrier layer to avoid metal ions leaching and/or H_2 embrittlement
- Make a perfectly closed layer system in order to avoid pitting corrosion and possibly coating adhesion losses
- If there would be defects, give the coating “self-healing” properties to self repair damages

- There is a basic conflict in the design criteria of a coating:
  - Corrosion resistance calls for low electrochemical conductivity
  - Electrical power requirements call for a high electrical conductivity

Coatings in the Market Place (and more)

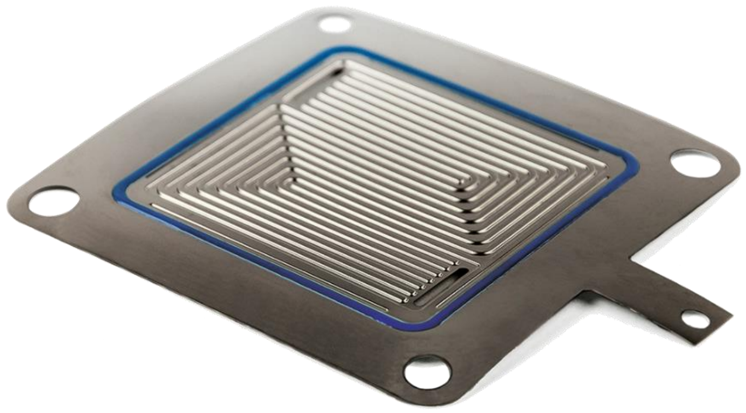
- **Electroplating**
  - Au
  - Pt
- **Other**
  - Nitriding / Carburizing
  - Pack cementation
  - Thermal Spray
- **PVD/CVD/PACVD**
  - Au
  - TiN
  - CrN
  - Carbon
  - Max Phase

Chapter 3

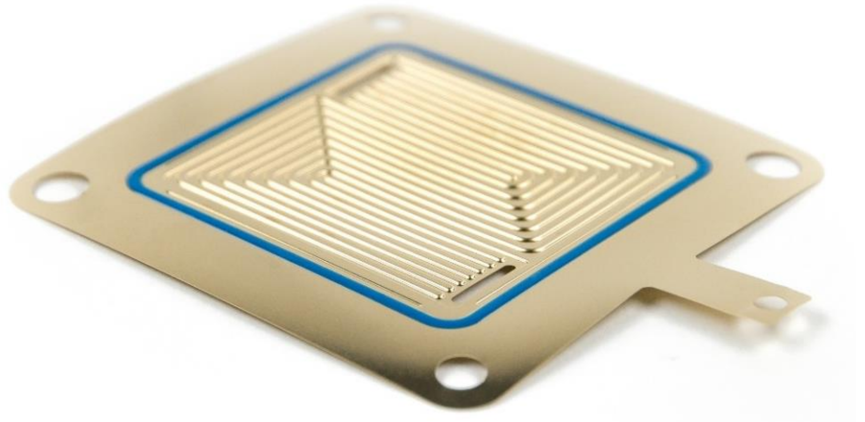
Coatings from Ionbond; Current Focus

Ionbond coatings for Bipolar Plates, PTL's, and Current Collectors

- **Ti + Carbon by PVD**
  - Typically for stainless steel
  - Medium Lifetime expectation (Passenger Cars)



- **DOT™ Technology (Thermal Spray)**
  - For stainless steel (Ti-PVD + DOTs)
  - For Titanium (DOTs only)
  - Extreme Lifetime expectation (Trucks, Buses, Trains, ***Electrolyzers***)



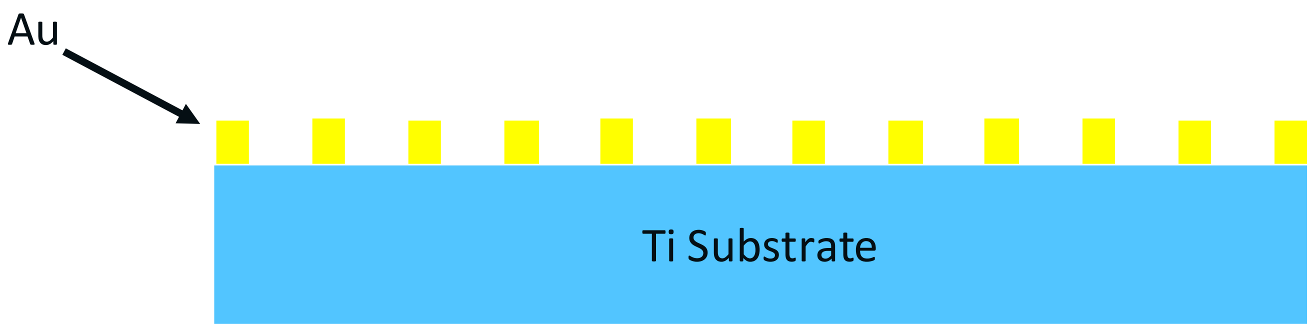
Carbon based Coatings by PVD

Batch load of Bipolar Plates

Coating Architecture of Carbon Coatings

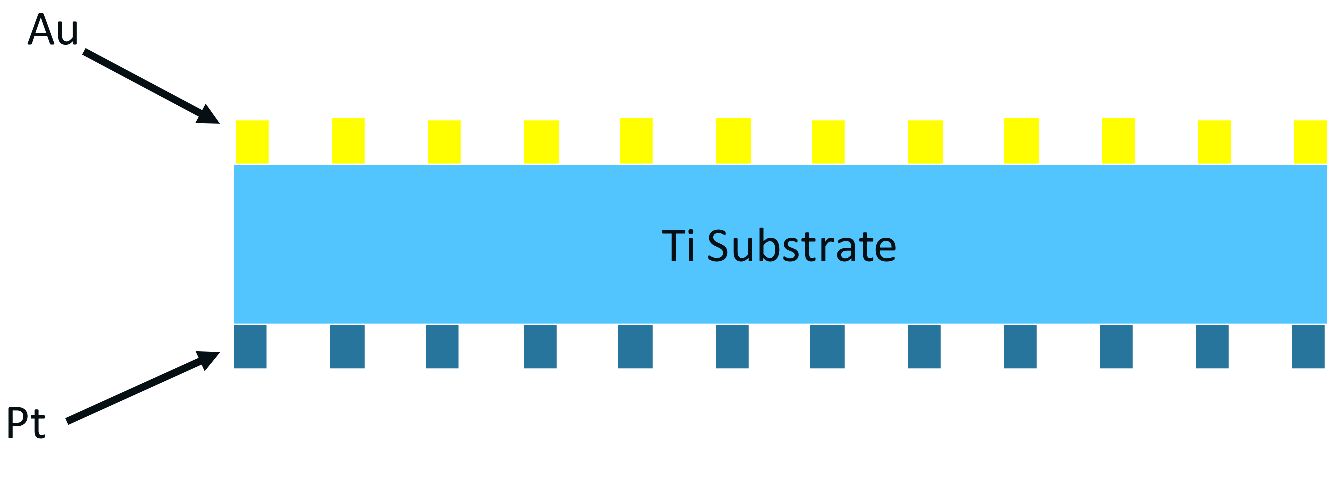
DOT Coating - electrolyzers

- 3 step process
  - Thermal spray of splashes/droplets of Au on cathode side



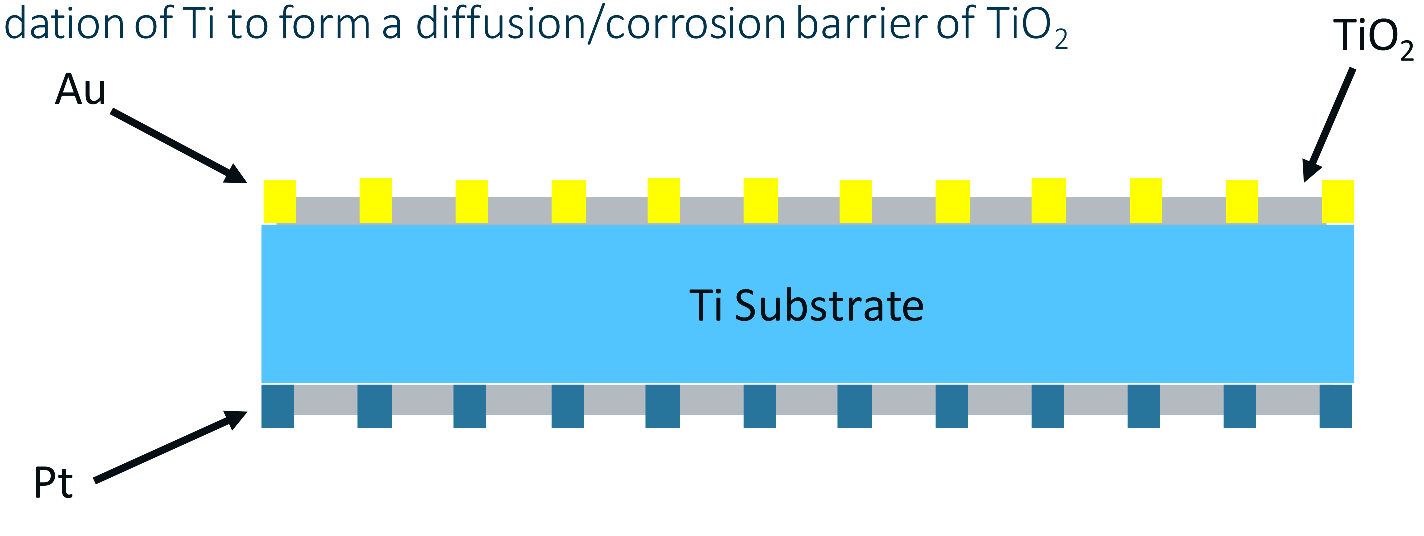
DOT Coating - electrolyzers

- 3 step process
  - Thermal spray of splashes/droplets of Au on cathode side
  - Thermal spray of splashes/droplets of Pt on anode side



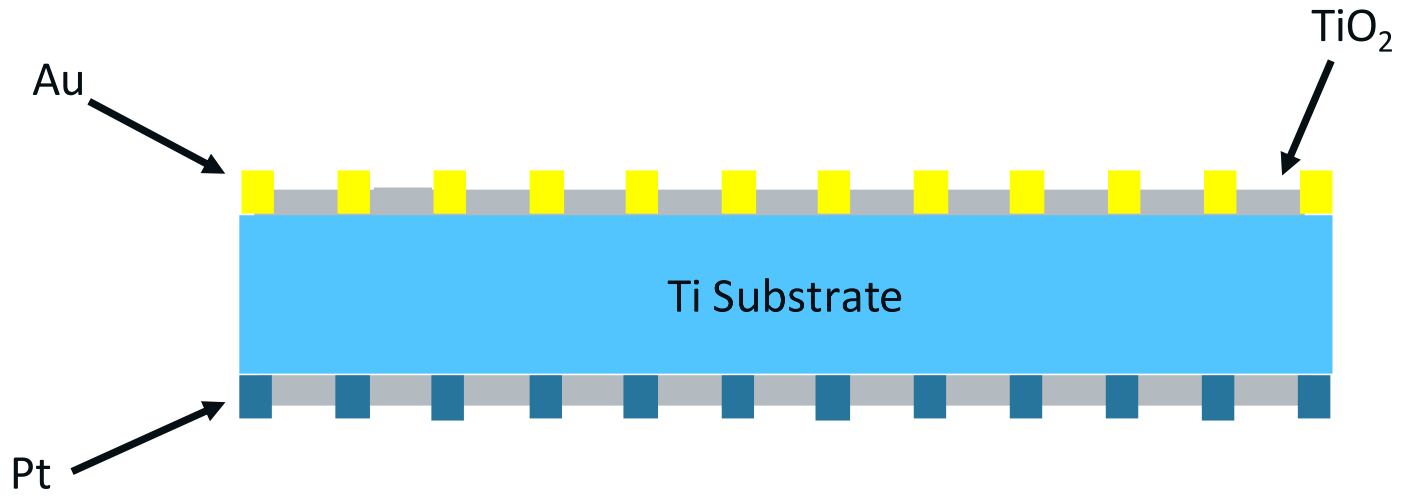
DOT Coating - electrolyzers

- 3 step process
  - Thermal spray of splashes/droplets of Au on cathode side
  - Thermal spray of splashes/droplets of Pt on anode side
  - Post-oxidation of Ti to form a diffusion/corrosion barrier of TiO_2



DOT Coating - electrolyzers

- **Final Result – Split in functionality through the coating architecture**
  - High corrosion resistance through TiO_2
  - Virtually no H_2 uptake on cathode side as it is blocked by TiO_2
  - Low electrical resistance through the Au and Pt contact points, i.e. electrically conductive pathways



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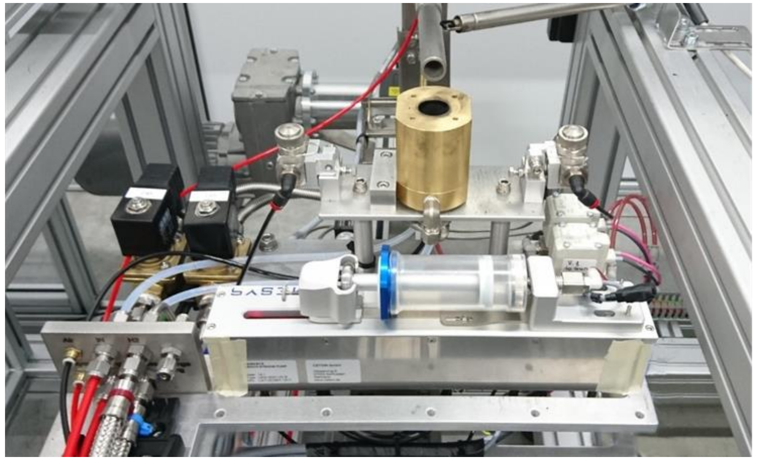
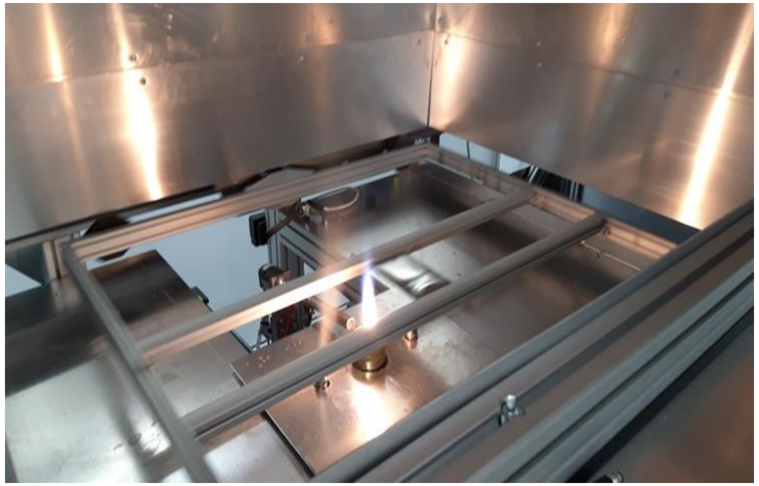
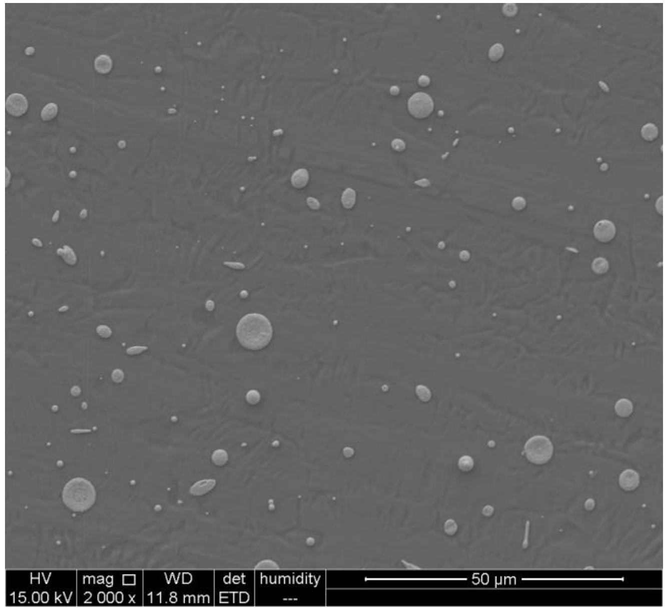
Droplet spray unit

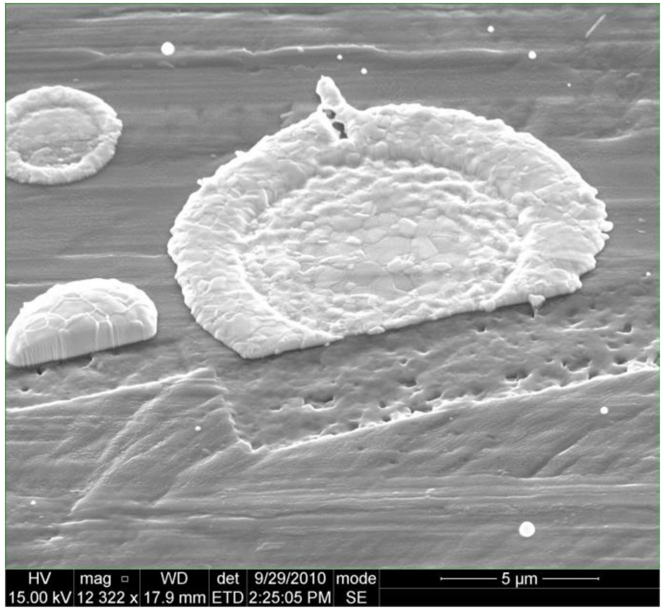




DOT Coating – SEM Images

- Gold droplets are deposited with thermal Spray onto the surface and form splats with diameter from 1 – 5 µm
- The cross section shows that the thickness is in the range 0.1 – 0.3 µm





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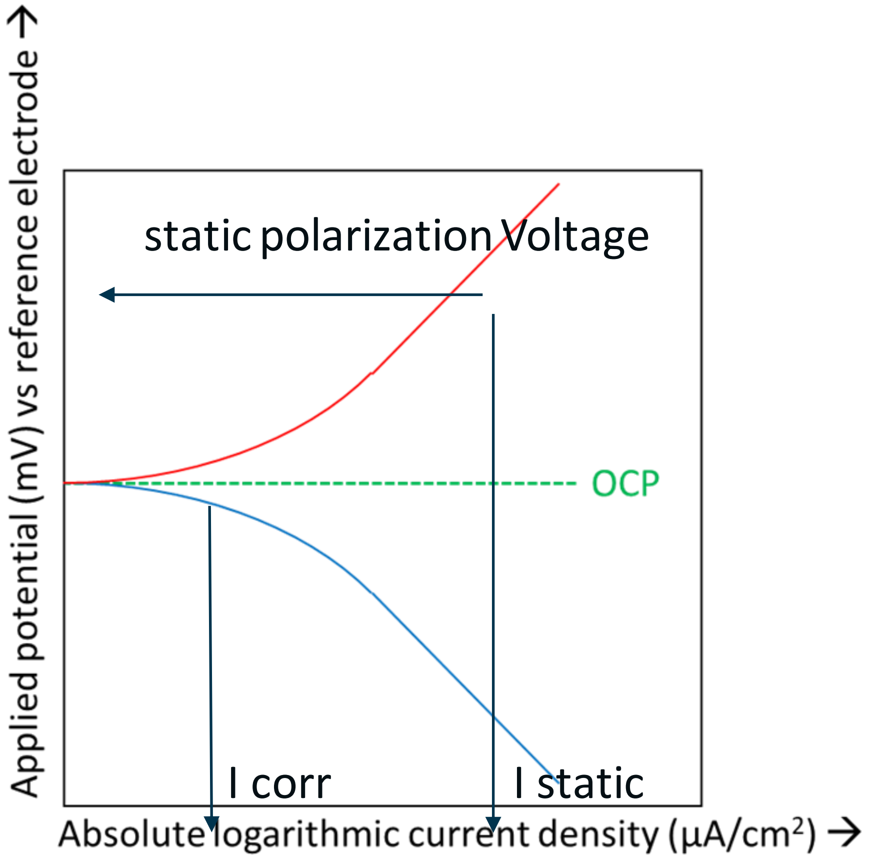
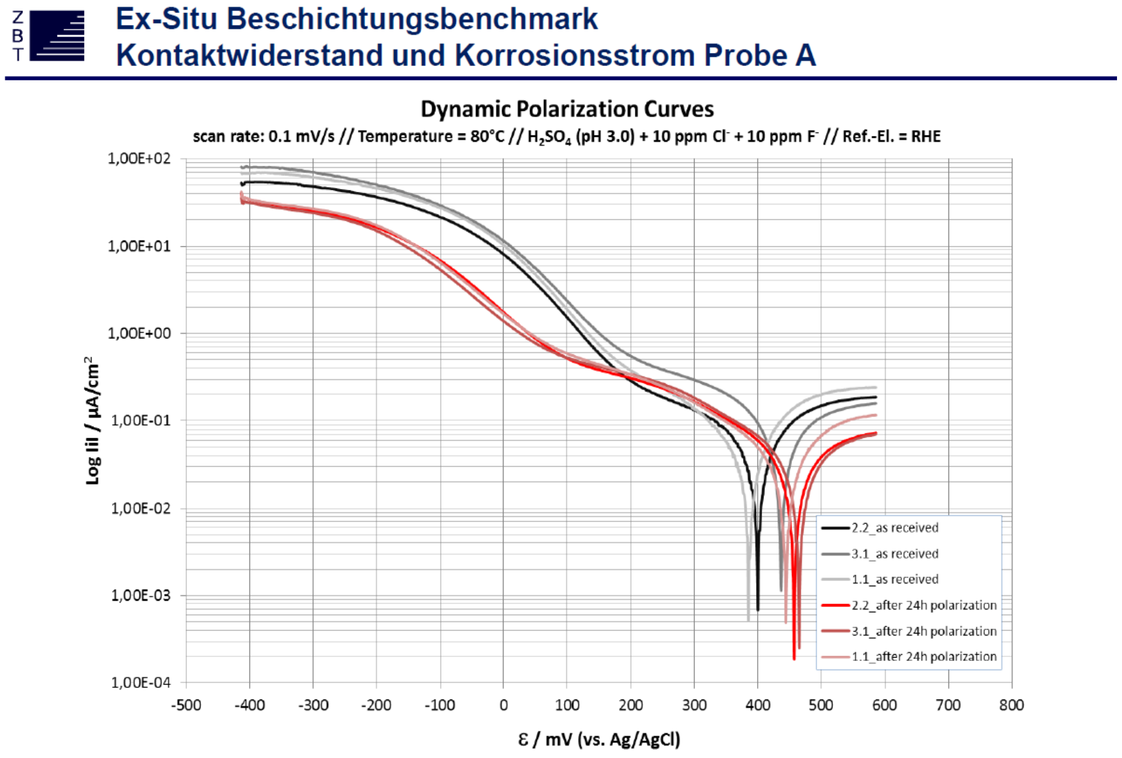
Corrosion test overview

- Medium H_2SO_4; pH 3
- 20 ppm Cl^-
- 10 ppm F^-
- Reference electrode Ag/AgCl (0.2 V shift)
- Dynamic polarization
    - from -0.4 to +0.6 V
    - OCP; open circuit potential
    - Icorr; corrosion current at OCP
- Static polarization
    - 24 hr at 0.6 V
    - DOE; I_{static} below 1 µA



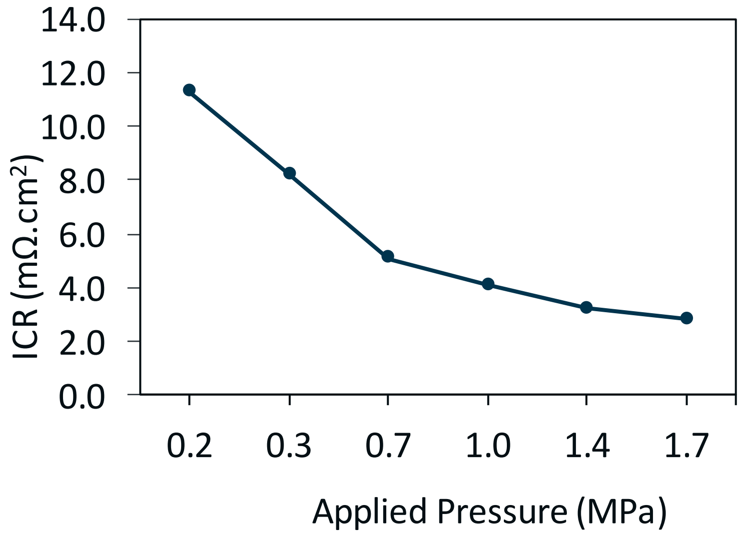
Polarization curves Au DOT’s coating

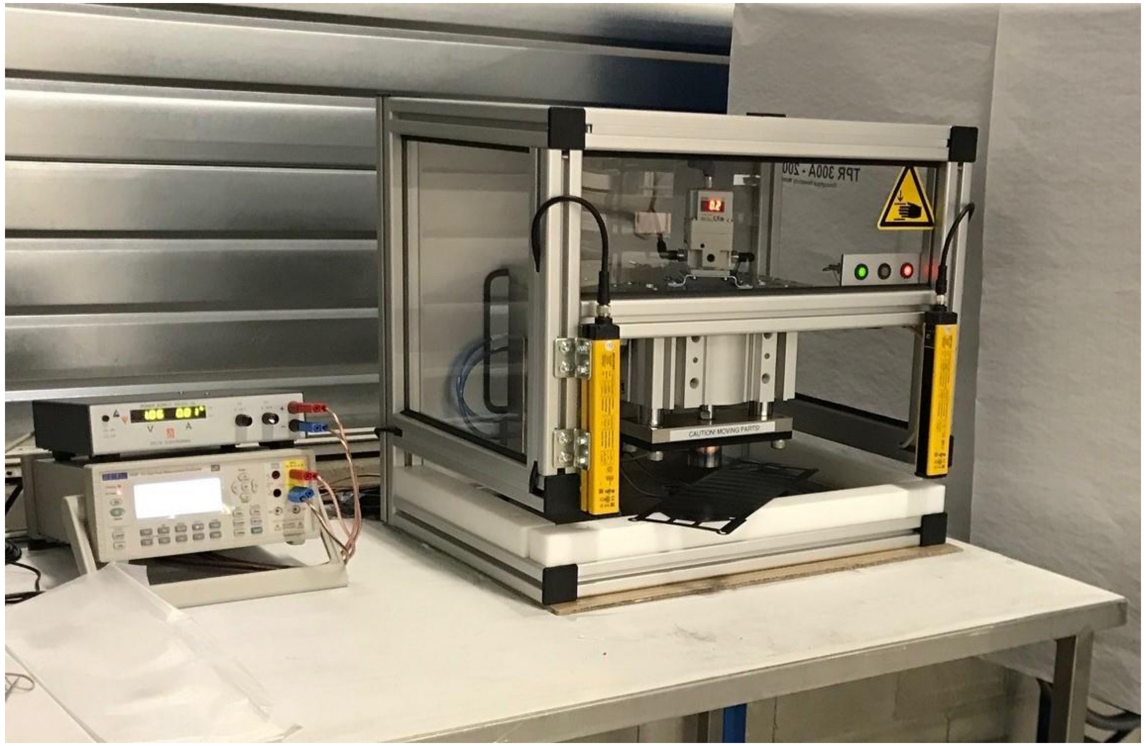
- DOT Samples were produced with Ti base layer on Stainless Steel 316.
- Thicknesses applied were 50 nm, 100 nm and 200 nm Ti.
- Dynamic polarization curves were very similar for all three Ti thicknesses:
  - OCP around 400 mV
  - Icorr around 0.05 µA/cm^2
- Dynamic polarization curves at least as good after static polarization



ICR unit developed at Ionbond

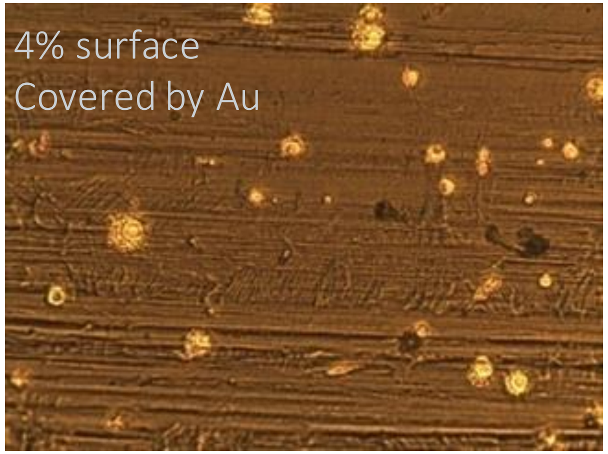
- The unit is suitable to measure complete Bipolar Plates, also very large ones
- It can measure ICR at 2 sides
- it can measure ICR at only one side

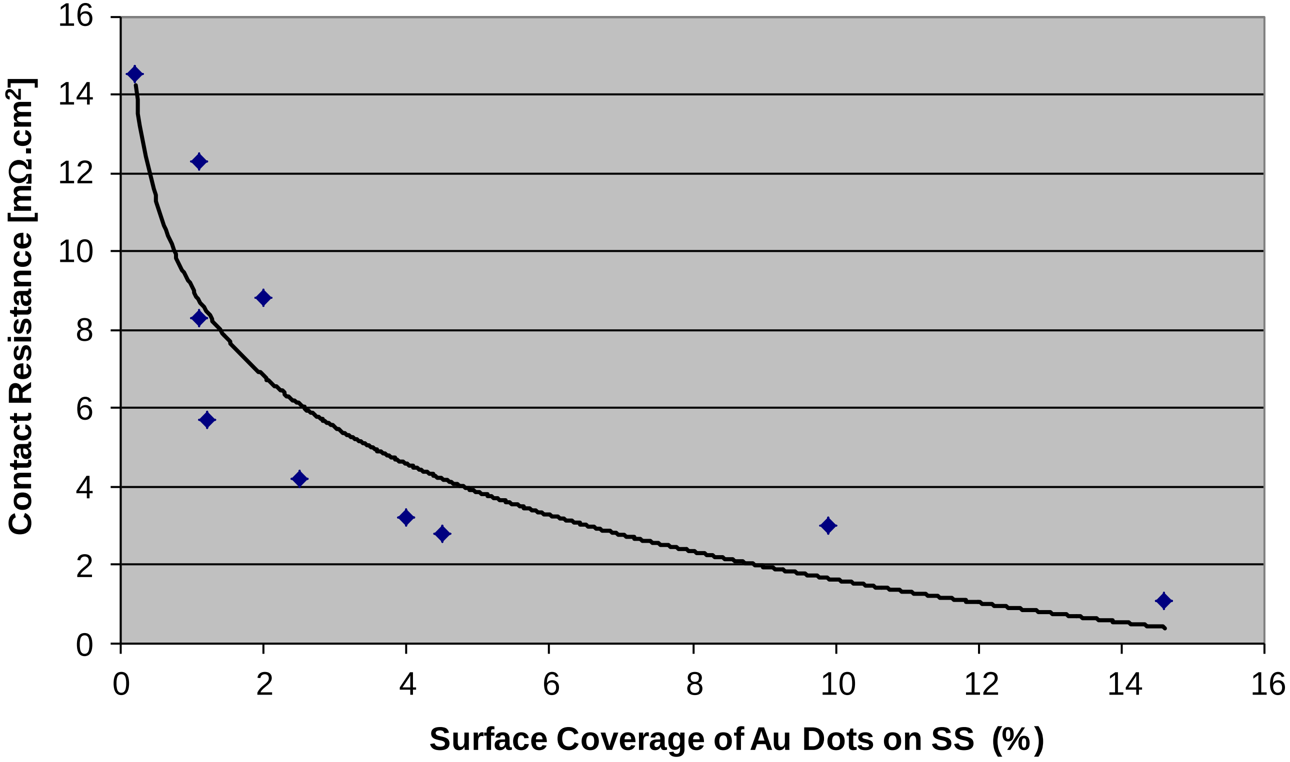




ICR dependence on Au surface coverage

- Interface contact resistance ICR is at acceptable level already at Au surface coverage of 2%





Chapter 4

What to expect next? DOE Focus/opportunities

Opportunities going forward

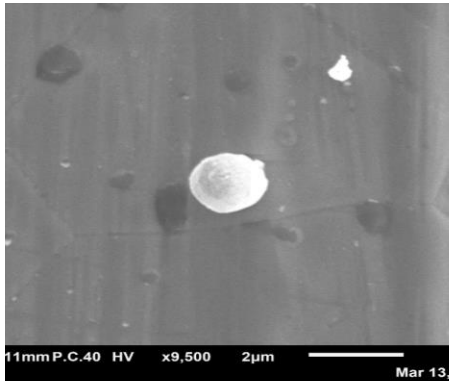
- Ongoing pressure on
  - Higher electrical current densities
  - Longer lifetime of stacks
  - Cost reductions

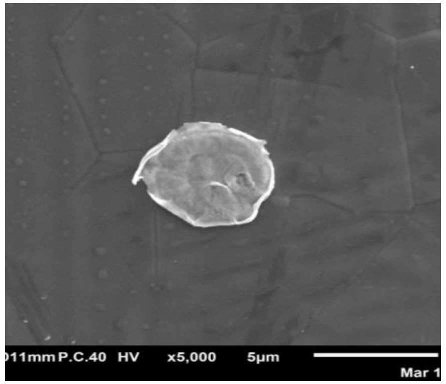
Opportunities going forward – Vacuum Deposition

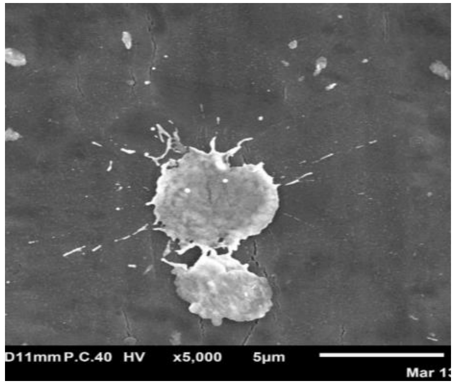
- PVD, CVD, and PACVD based coatings:
  - Precious metals free solutions
  - Solve the natural conflict between high electrical currents and no electrochemical corrosion
  - Withstand the high electrical operating voltages in electrolyzers
    - Coatings should not be dissolved ("stripped")
    - Shift in polarization curves, accelerating pitting corrosion, which can also lead to coating adhesion failures
  - Further voids reductions of deposited coatings
    - reduced dust while processing (creating spots with missing coating)
    - no droplets (= larger metal clusters embedded in the coating system)
    - pinholes elimination, because they are an easy path for pitting corrosion
  - Self-healing systems ("voids repair themselves through oxidation and seal again")

Opportunities going forward – DOT's Thermal Spray

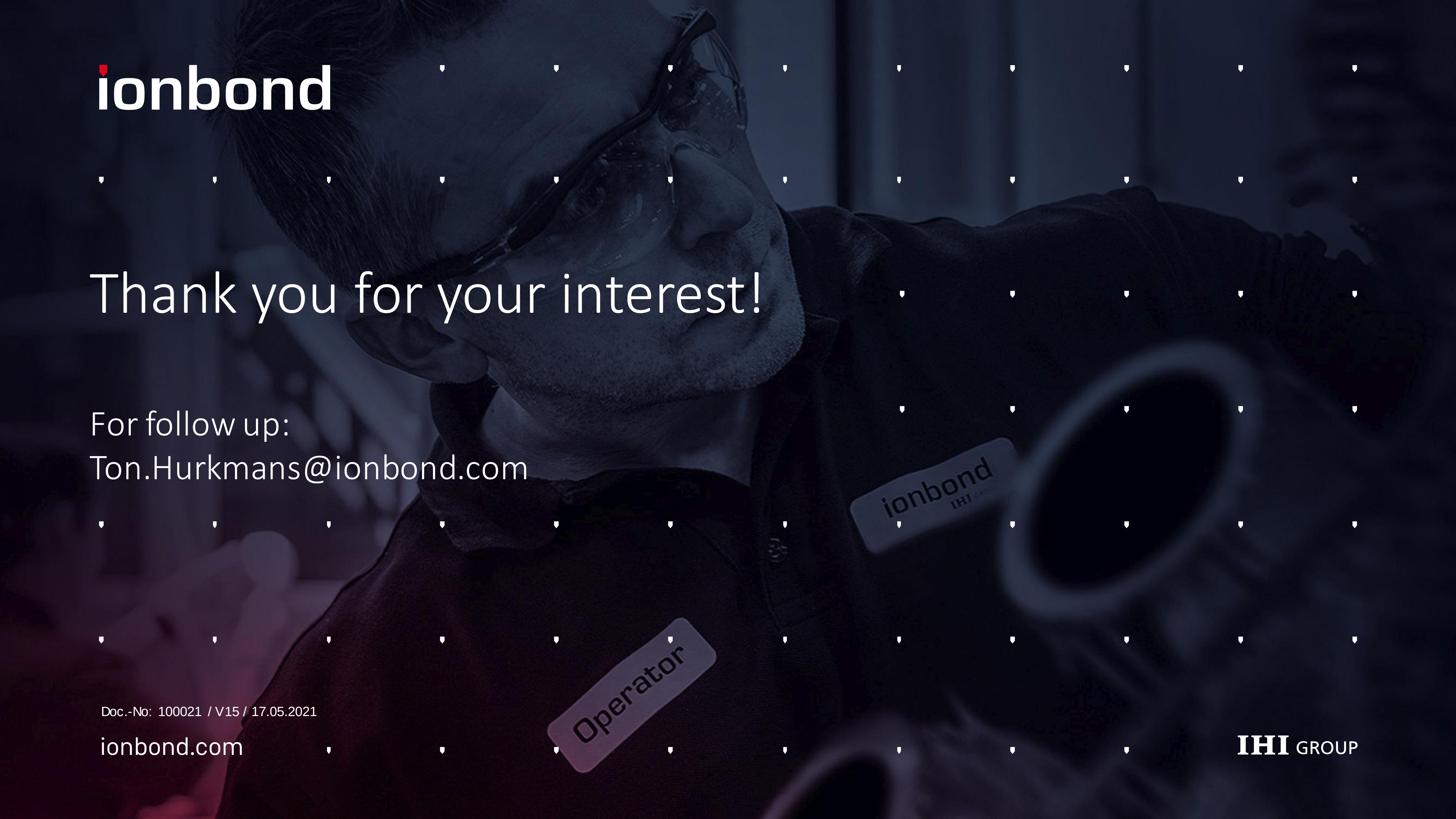
- DOT's thermal spray
  - Ongoing precious metal transfer efficiency improvements (equals cost reductions):
    - Sticking factor of incoming particles
    - Minimizing over-spray outside the active area of the bipolar plate
  - Optimization of droplet shapes to have maximum performance







  - Upscaling to higher throughputs



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Thank you for your interest!

For follow up:
Ton.Hurkmans@ionbond.com

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