Low Cost Bipolar Plates for Large Scale PEM Electrolyzers

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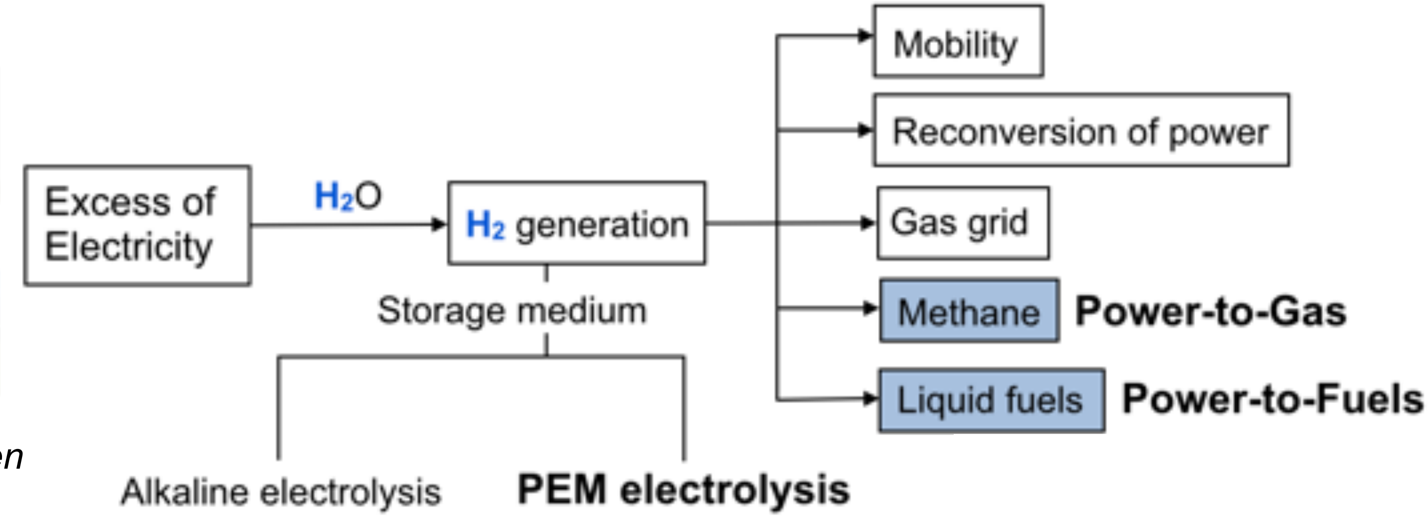
Outline

- Introduction: H_2 as energy vector
- Cost issue in PEM-electrolysis systems
- Strategy for producing the coatings for low cost bipolar plates
- Physical and electrochemical characterization of **Au/Ti** and **Pt/Ti** coatings
- Conclusions

Hydrogen as energy vector

Wind

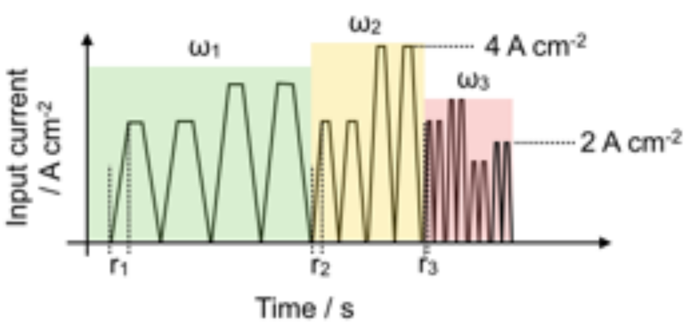
Solar



Erneuerbare Energien Gesetz – EEG

40% - 45% by 2025
55% - 60% by 2035
80% by 2050

AST protocol based on wind profile



- Uses only DI water
- No additional compressor is needed
- Current density > 6 A cm^{-2}
- Rapid response (dynamic operation)
- <u>Expensive</u>

Alcaline electrolyzer = 1,394 USD/kW
PEM electrolyzer = 2,648 USD/kW

"Study on development of water electrolysis in the EU"
Fuel Cells and Hydrogen Joint Undertaking

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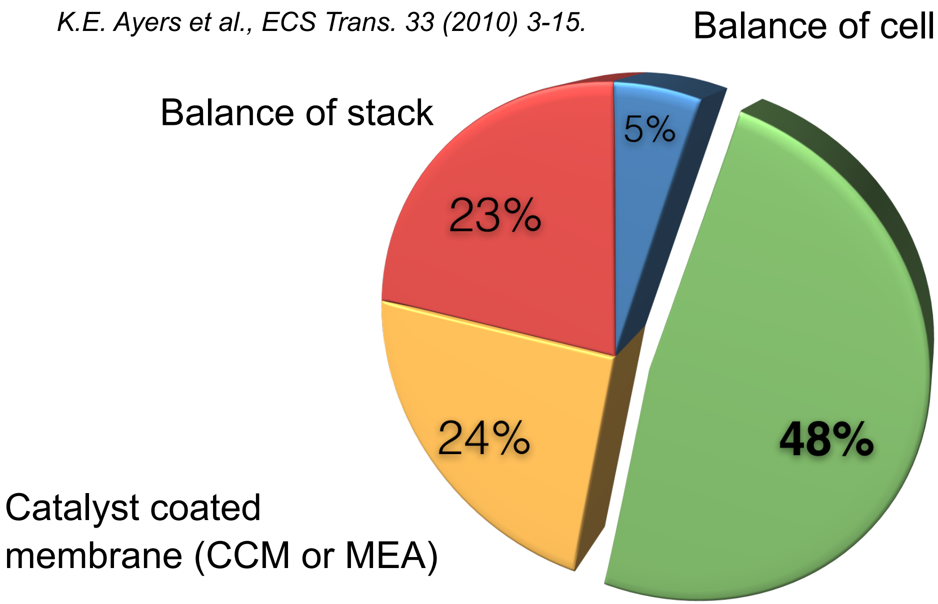
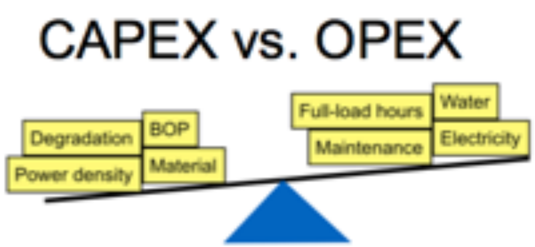
Cost of a PEM electrolysis stack

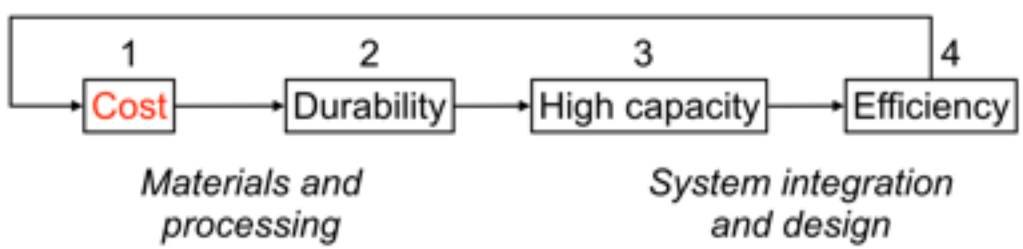
K.E. Ayers et al., ECS Trans. 33 (2010) 3-15.



Stainless steel in the PEM electrolysis stack?

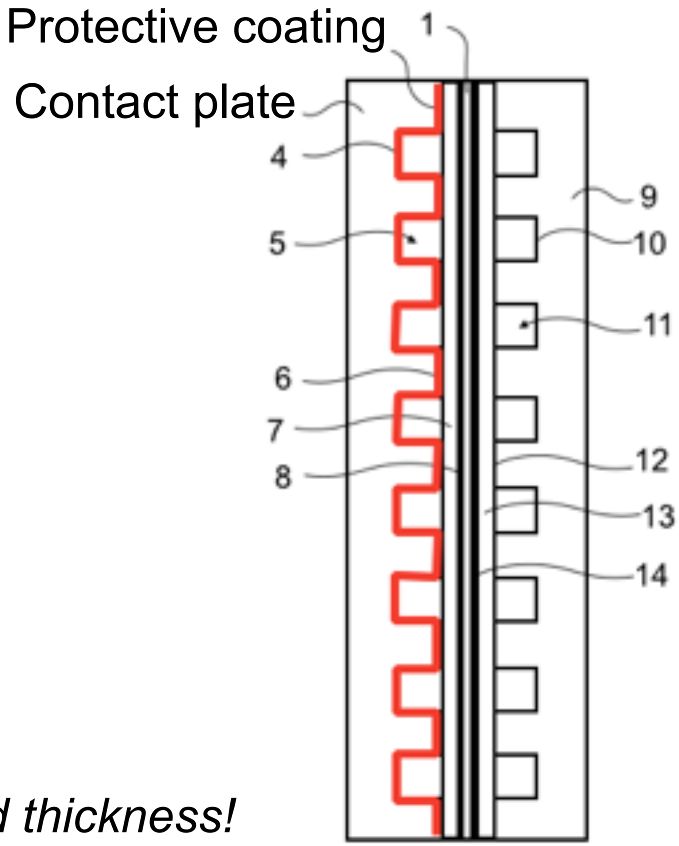
Bipolar plates (BPP) and current collectors made of **Titanium**





Requirements of the protective coating

1. **Resistant to corrosion**
2. **Low electrical resistivity / High electrical conductivity**
3. Strong adherence to the substrate
4. Low cost material, facile and scalable deposition technique
5. Withstand mechanical loads during operation
6. Minimal differences in the coefficient of thermal expansion
7. Resistant to H_2 embrittlement (cathode side)



No limitations in weight and thickness!

Strategy for coating stainless steel

Coatings for PEM fuel cells:

Standard approach:

Coating 1 **Coating 2**

Corrosion resistant and conductive coating on stainless steel

Pitting corrosion in PVD coatings

The released Fe^{2+} poison the CCM of the electrolyzer

S. Sun et al., J. Power Sources 267 (2014) 515.

Coatings for PEM electrolyzers:

Our approach:

Coating 1: Titanium coating by vacuum plasma spraying (VPS)

Coating 2: Surface modification of the Ti coating by electrodeposition or PVD magnetron sputtering

Cost reduction?

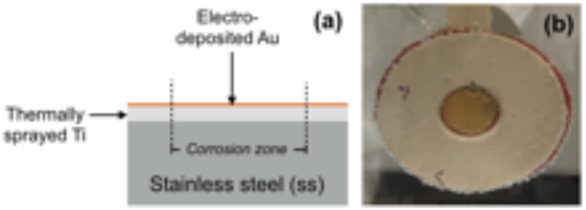
PEMFC: PVD coatings alone meet the DOE requirements.

PEM electrolyzers: current Ti bipolar plates have to be coated to reduce the passivation.

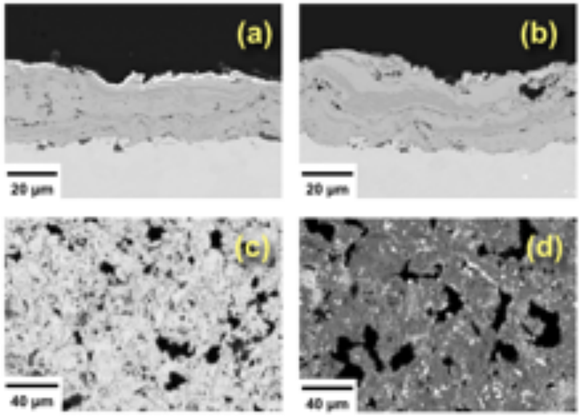
Dramatic cost reduction for **large area** bipolar plates → **Megawatt** scale

Physical characterization of Au/Ti coating

Optical and SEM images

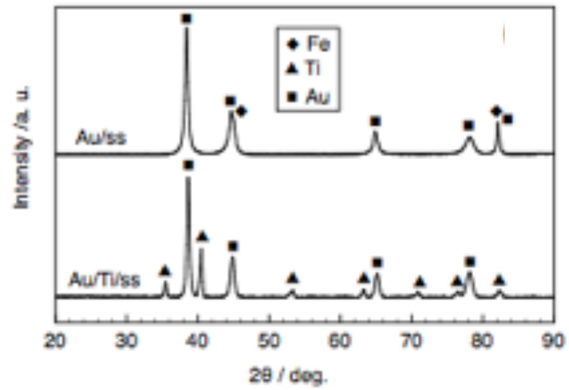


Thermally sprayed Ti coatings with a plasma enthalpy of 21.3 MJ kg^{-1} electroplated with Au afterwards

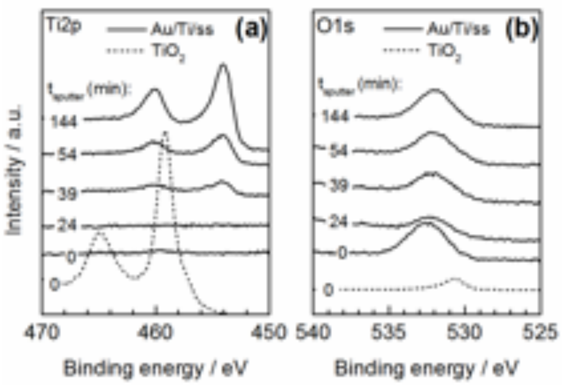


Before After

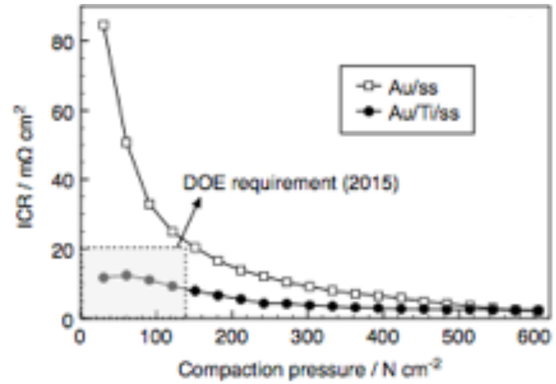
XRD



XPS



ICR



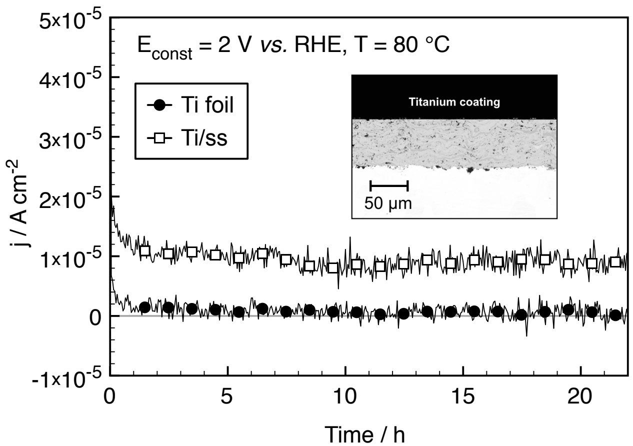
Au/Ti coating

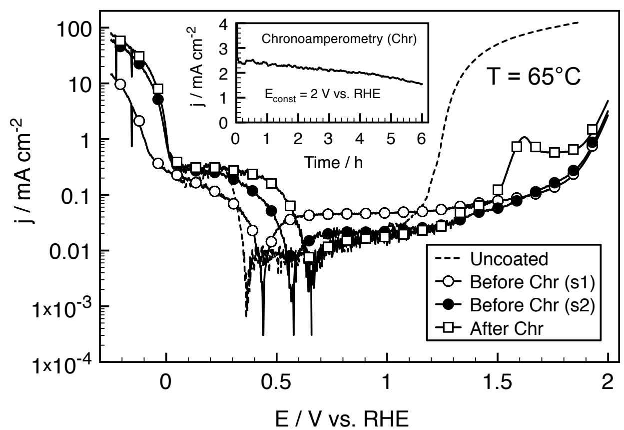
- Deposited by successive steps of VPS and electrodeposition
- It has a roughness factor of 0.62. This property allows the adherence of Au on Ti.
- The presence of TiO_2 between Ti and Au is below the detection limit.
- Meets the DOE requirements of IRC.

Electrochemical characterization of Au/Ti coating

Corrosion tests (half-cell)

O_2-saturated 0.5 M H_2SO_4



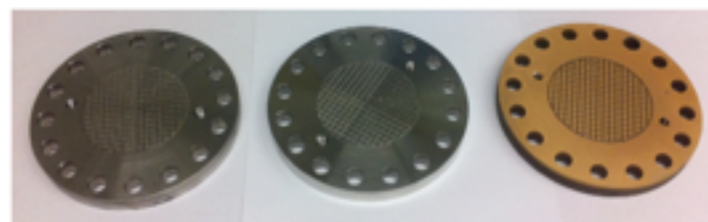


Electrochemical parameters

$$R_p = \frac{\beta_a \beta_c}{2.3 j_{corr}(\beta_a + \beta_c)}$$

Corrosion potential (E_{corr}); corrosion current (i_{corr}); anode (β_a) and cathode (β_c) Tafel slopes and polarization resistance (R_p) of the coated stainless steel before (scan 1 and 2) and after the chronoamperometric (chr) test.

Au/Ti/ss	E_{corr} / V vs. RHE	j_{corr} / µA cm^{-2}	β_a / mV dec^{-1}	β_c / mV dec^{-1}	R_p / x 10^3 Ω	[Fe^{2+}] / ppm
Before chr (s1)	0,44	4,76	63	91	3,40	–
Before chr (s2)	0,57	1,52	36	35	5,08	–
After chr	0,66	3,82	148	61	4,92	**0**



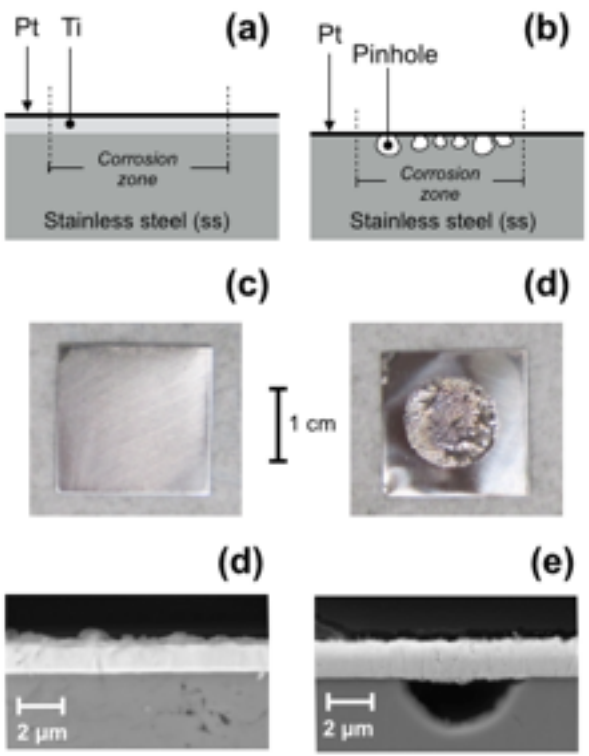
Ti ss Au/Ti/ss

Au/Ti coating

- The i_{corr} of the coated sample is 270 times lower that than the uncoated one.
- It improves the contact between GDL / CC and the BPP.
- The Au modification detached after 6 h of being constantly polarized at 2 V vs. RHE.

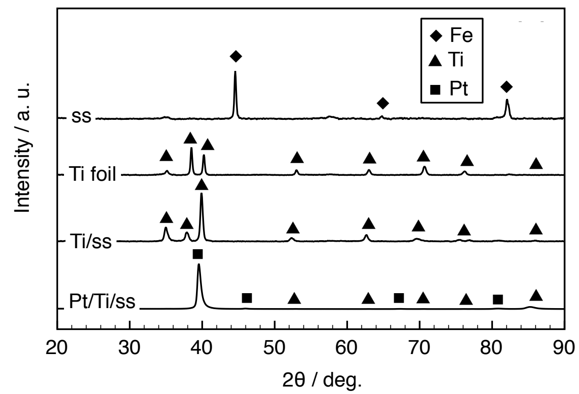
Physical characterization of Pt/Ti coating (< 4 wt% PMG)

Optical and SEM images
after corrosion measurements

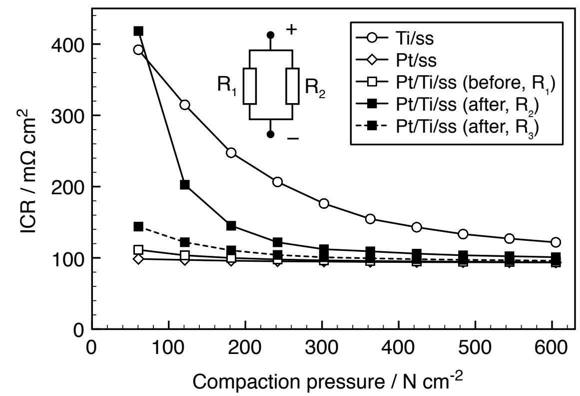


Pt/Ti/ss
Pt/ss

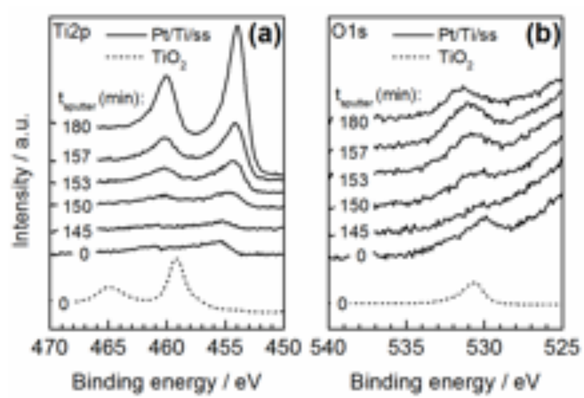
XRD



ICR



XPS



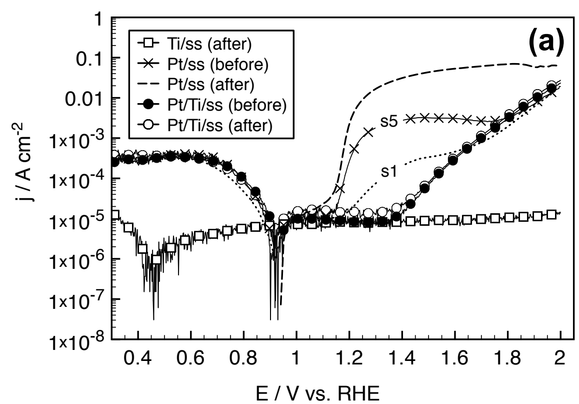
Pt/Ti coating

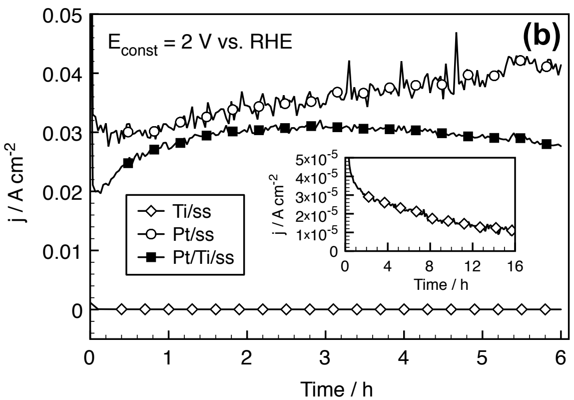
- Deposited by successive steps of VPS and PVD magnetron sputtering techniques.
- The presence of TiO_2 between Ti and Pt could not be detected
- The IRC @ 240 N cm^{-2} of Pt/Ti coating increased 6% after corrosion measurements.

Electrochemical characterization of Pt/Ti coating

Corrosion tests (half-cell)

O_2-saturated 0.5 M H_2SO_4, T = 65°C

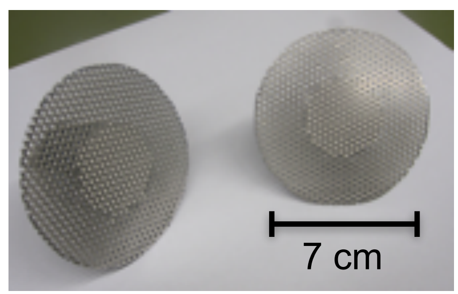




Electrochemical parameters

	E_{corr} / V vs. RHE		i_{corr} / μA cm^{-2}		β_a / mV dec^{-1}		β_c / mV dec^{-1}		R_p / x 10^3 Ω		$[Fe^{2+}]$ / ppm
Sample	Before	After	Before	After	Before	After	Before	After	Before	After	After
Stainless steel (ss)	0.36	0.54	1,7	0,6	50	56	20	34	3,7	15,3	100.8
Ti/ss	0.22	0.46	0,71	0,44	99	102	92	73	29,2	42,0	**0**
Pt/ss	0.91	0.94	1,22	0,66	53	17	19	21	5,0	6,2	27.73
Pt/Ti/ss	0.93	0.92	0,73	0,56	29	13	22	15	7,5	5,4	**0**

Contact plates



Long term tests in real conditions are currently being carried out by the industry

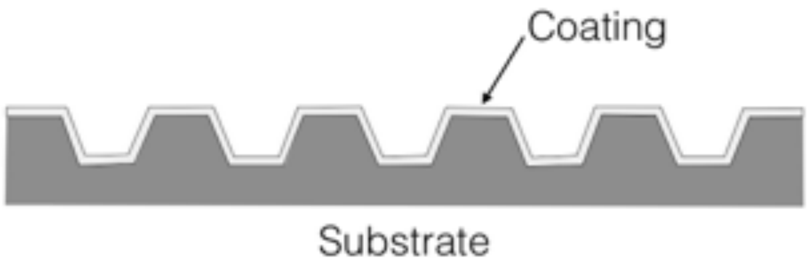
Pt/Ti coating

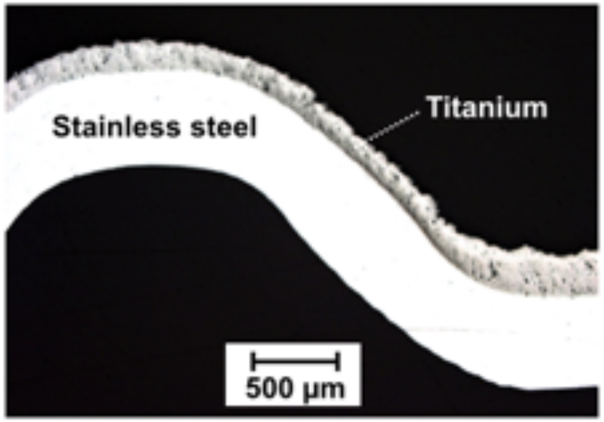
- It successfully protected the stainless steel substrate from corrosion and remained highly conductive at the end of the electrochemical experiments.
- In contrast the Pt coating on ss failed dramatically and the Fe^{2+} and Cr^{3+} heavily polluted the electrolyte as result of corrosion of the substrate.

Cost of the thermally sprayed Ti coating

Cost of coating BPPs for **1 MW** PEM electrolyzer:

(2 V @ 2 A cm^{-2})





250 x 1000 cm^2

= **2.9 USD** / bipolar plate (considering only consumables, feedstock powder and working hours)

Cost of possible stack base materials and their respective electrical conductivities

Metal	**Cost (30 x 30 x 0,3 cm3) / USD[1]**	**Electrical conductivity (S/m) at 20 °C**
Titanium (99.6+)	614	2.38×10^6
Fe/Cr18/Ni10 (ss 304)	268	1.45×10^6
Copper (99.9%)	242	5.96×10^7
Aluminium (99%)	161	3.5×10^7

[1] http://www.goodfellow.com/catalogue/GFCatalogue.php?Language=E

Conclusions

- There is an urgent need to reduce the cost of PEM electrolysers for large scale storage of surplus electricity. The bipolar plates are very expensive.
- Dense Ti coatings were produced by vacuum plasma spraying (with high enthalpy) on stainless steel substrates.
- The coatings were evaluated in simulated conditions: O_2-saturated 0.5 M H_2SO_4, 65 - 80 ºC, E_{const} = 2 V.
- Further surface modification resulted in low ICR and full protection of the substrate over extended periods of time.
- The cost of coating stainless steel bipolar plates of 1000 cm^2 with Ti, for the Megawatt range, is estimated in 2.9 USD per piece.
- Cheaper materials as Cu and Al can be used as substrate. The developed coatings are currently being tested in commercial electrolyzers.

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Acknowledgments

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