MaxPhase™ coatings on bipolar plates deposited by magnetron sputtering techniques in a high throughput industrial coating system

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Linköping, Sweden

Technoport 2012, Trondheim
Monday 16 April
Impact Coatings

- PVD coating systems for mass production of individual parts
- Functional and decorative coatings for connectors, mobile phone shells, frames for glasses, decorative coatings for car interior, surgical devices, EMI shielding, etc.
- Unique architecture provides short cycle times (1-2 min) that match continuous production flows
Impact Coatings

“New and revolutionary technique for metalizing plastic parts”

“But most of all, it cuts production time by close to 70%”

Industriverktøy AS in Leksvik, 30 km from Trondheim
PVD - Physical Vapor Deposition
Magnetron sputtering
Bipolar plates (BPP)
Bipolar plates

Graphite, polymer, graphite+polymer, metallic
The challenge is the surface.
Can we enhance the surface properties with a coating?
Coating Design Strategy

Including, but not limited to

<table>
<thead>
<tr>
<th>Group</th>
<th>Period</th>
<th>Elements</th>
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<td>Li, Be</td>
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<td>Fr, Ra, Rf, Db, Sg, Bh, Hs,Mt, Ds, Rg, Cn, Uut, Uuo</td>
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Lanthanides: La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu

Actinides: Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr
Coating Design Strategy

**MAX phases**

- **M** = Early transition element
- **A** = Group A element
- **X** = C or N

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Lanthanides
- 57 La
- 58 Ce
- 59 Pr
- 60 Nd
- 61 Pm
- 62 Sm
- 63 Eu
- 64 Gd
- 65 Tb
- 66 Dy
- 67 Ho
- 68 Er
- 69 Tm
- 70 Yb
- 71 Lu

Actinides
- 89 Ac
- 90 Th
- 91 Pa
- 92 U
- 93 Np
- 94 Pu
- 95 Am
- 96 Cm
- 97 Bk
- 98 Cf
- 99 Es
- 100 Fm
- 101 Md
- 102 No
- 103 Lr
Introducing MaxPhase™ coatings for stainless steel bipolar plates

The coating is

- a ceramic alloy producible by PVD
- corrosion resistant
- electrically conductive
- economic and environmentally sound

1. Uncoated
2. Etch
3. Grow coating
Introducing MaxPhase™ coatings for stainless steel bipolar plates

Corrosive attacks are blocked

MaxPhase™

Substrate

500 nm

e−, high electrical conductivity
Ex Situ Corrosion Resistance

- 1 hour test
  SS316L + 300 nm MaxPhase
  SS316L + 150 nm MaxPhase

- Low corrosion currents and no detectable levels of substrate metal ions in the electrolyte

Very thin coatings work well!

Potentiostatic 1 hour experiments
(80 °C, 1 mM H₂SO₄, 0.643 V vs Ag/AgCl)
Ex Situ Electric Contact Resistance

- The oxide layer grows thick on uncoated SS316L and the contact resistance increases as a result.
- The electrical properties of the gold and MaxPhase™ coatings are unaffected by the corrosion tests.

![Contact resistance graph](image)
**In Situ Stack test**

- Performance after 1500 hours: 93%
- The MaxPhase coated BPP provide similar performance as the gold coated BPP
In Situ Stack Test: 2000 hours

- Test performed by PowerCell Sweden AB
- S1-series short stack with MaxPhase coated BPP
- Stable performance for 2000 hours

- Reformate fuel with 25 ppm CO
- Galvanostatic 500 mA/cm² operation
- 70 °C operating temperature
- 80% RH
Post-analysis of metals in membrane

- No detectable difference in Fe and Cr content in the membrane between a fresh one and one used for 1500 hours.

![Graph showing Fe and Cr content comparison between fresh and used MEA, 1500 hours.]

ICP-AES, 6 samples, 95 cm²
Lean Production

Traditional PVD
Out-source the coating step
Lead time: **Weeks**
Produce to storage

Inline PVD
Do it yourself
Lead time: **Minutes**
Produce to order
Two systems

**InlineCoater™**

Post-coating of formed BPP

**ReelCoater™**

Pre-coating steel reel to reel
Production and cost analysis

Detailed cost analysis for different coating scenarios:

- Initial investment
- Personnel (Swedish salary)
- Taxes
- Operation
- Service
- Materials
- Interest
- ..

Let’s highlight the results!
Post-coating of formed BPP today

Maximum capacity*

<table>
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<th>BPP per year**</th>
<th>Euro</th>
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<td>750 000</td>
<td>12</td>
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<td>1 000 000</td>
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<td>1 250 000</td>
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Production cost

<table>
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<tr>
<th>Material</th>
<th>Investment</th>
<th>Operation</th>
<th>Total cost</th>
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<tbody>
<tr>
<td>Green</td>
<td>MaxPhase™ post-coating</td>
<td>Gold post-coating</td>
<td>Blue</td>
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<tr>
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Au: 12 EUR/BPP
MaxPhase: 2 EUR/BPP

* Capacity of 1 InlineCoater™ 500
** 1 BPP = 700 cm²
A future outlook
Reduced coating thickness & pre-coating reel-to-reel

Maximum capacity*

<table>
<thead>
<tr>
<th>BPP per year**</th>
<th>0</th>
<th>2,500,000</th>
<th>5,000,000</th>
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<tbody>
<tr>
<td>Production cost</td>
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<table>
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<th>Material</th>
<th>Investment</th>
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<th>Total cost</th>
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<tbody>
<tr>
<td>0.1 EUR/BPP</td>
<td>0.3 EUR/BPP</td>
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<td>0.4 EUR/BPP</td>
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<tr>
<td>0.1 EUR/BPP</td>
<td>0.3 EUR/BPP</td>
<td>0.2 EUR/BPP</td>
<td>0.4 EUR/BPP</td>
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</table>

Post-coat: 0.5 EUR/BPP
Pre-coat: 0.2 EUR/BPP

* Capacity of InlineCoater™ 500 and modified ReelCoater™
** 1 BPP = 700 cm²
Conclusions

- **MaxPhase™ coatings perform as gold coatings**
  2,000 hours in stack test

- **Coating costs: 2 EUR/BPP** (700 cm²/BPP, volume production)
  Further cost reduction up to 90 % possible

- We offer job coatings and entire PVD systems for integrated production lines
Acknowledgments