# Plasma-sprayed non-PGM anodes and cathodes for alkaline water electrolysis

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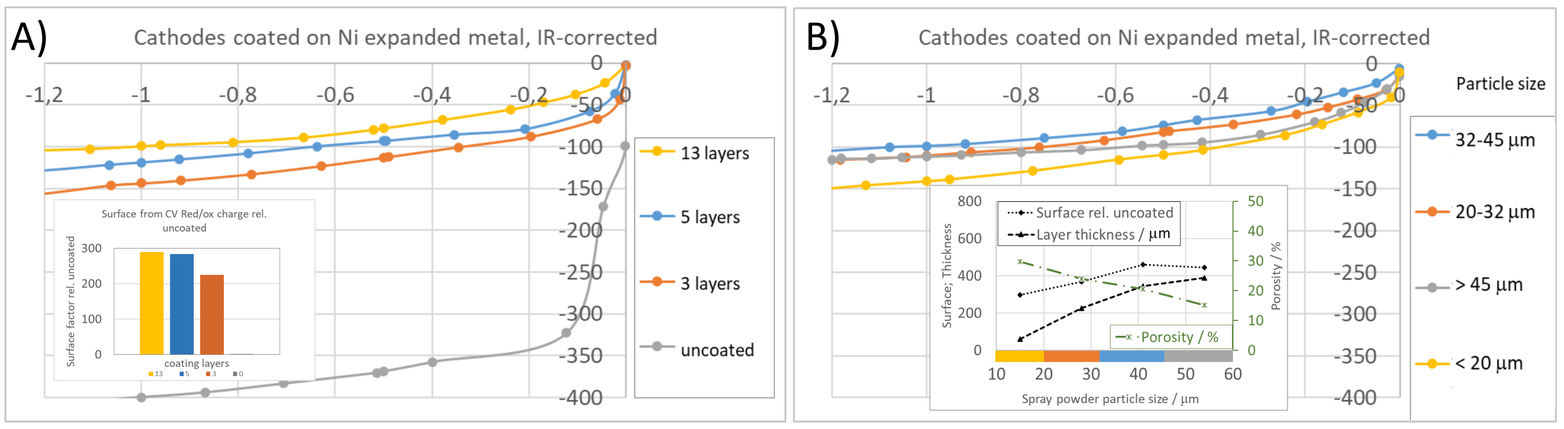



**Figure 1: Cathodes Raney-Nickel ($Ni_xAl_yMo_z$) with APS coating. A) Half cell polarisation curves and relative surfaces varying number of coating layers with RhM coating. B) Half cell polarisation curves, relative surfaces, thickness and porosity varying the coating powder particle size with DLR coating. C) Half cell pol curces of „best" electrode and electrode selected for stack. D) FIB-SEM structural analysis of coating at various scales, pores between coating particles, smaller pores by leaching of Raney-Nickel, smallest surface structure Ni-Hydroxide. Tests at 70°C, 30 wt% KOH, ambient pressure**

## Introduction

Low cost, PGM free, durable and efficient electrodes for alkaline water electrolysis that can operate at high current density and with fluctuating power input are prepared by using Atmospheric Plasma Spraying (APS). This production method can be scaled up for large production volumes.
Within the project E²NGEL, DLR, Rheinmetall (RhM) and McPhy address these challenges targeting for electrodes below 75 mV overpotential for the cathode and 220 mV overpotential for the anode at 0.5 A $cm^{-2}$ as well as a full cell voltage of 1.8 V at 1.2 A $cm^{-2}$.

## Cathodes

Based on previous DLR coating developments [1, 2] the APS method was further developed. New catalyst compositions were tested and process parameters were adjusted. After activation removing the leachable Al-rich phase the electrodes were tested at 70°C in 30 wt% KOH solution in a half-cell three electrodes setup and in a full cell of 8 $cm^2$. Phase distribution and structural analysis of the powders and the electrodes were performed by XRD, SEM and FIB-SEM (Focussed ion beam SEM). Electrodes were coated on nickel wire mesh, expanded metal or punched hole sheet, however with little difference in performance when changing the substrate. Spray powders from commercial sources and produced by RhM were used.

For the cathode the original $Ni_xAl_yMo_z$ composition was varied. Higher Mo content was investigated expecting an improved catalysis and possibly amorphous phases, yet al lower electrode stability was observed. Lower Al content was investigated expecting a better long-term stability due to higher mechanical strength of the coating, yet this was not observed.

The desired low overpotential can be reached due to the improved coating parameters, material composition, structural effects and high surfaces (Fig. 1). Selecting the electrode for stack test a trade-off between coating costs and low overpotential caused the selection of the cathode.

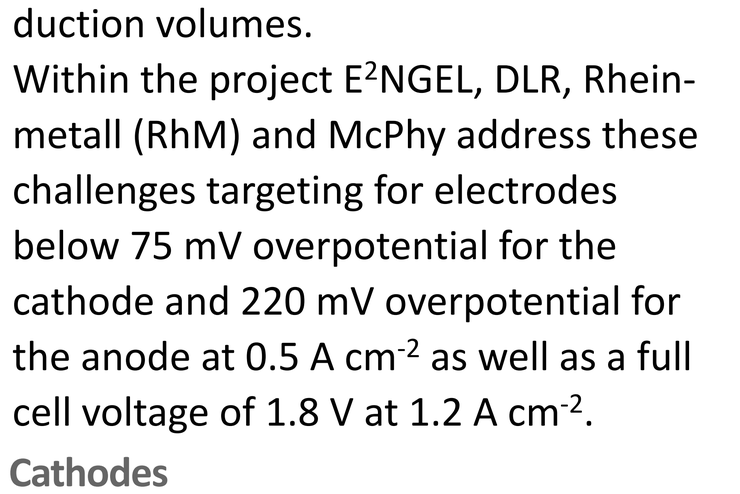


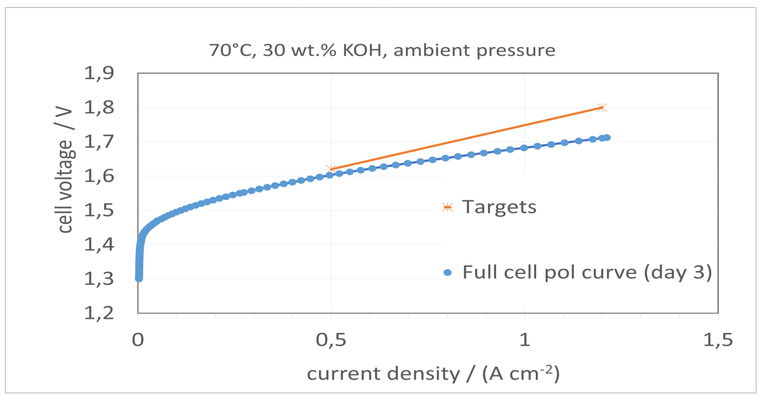

**Figure 2: Anode development varying coating material and coating parameters. Half cell test results at 70°C, 30% KOH and ambient pressure. Uncoated electrodes vary in a wide range. $Ni_xFe_y$ and $Ni_xAl_yFe_z$ electrodes have a lower overpotential. Lowest overpotential for Raney-$Ni_xAl_yFe_z$ electrode with optimized Al-content**

## Anodes

For the anodes $Ni_xAl_yFe_z$ coatings were APS sprayed and tested. To further adjust the porosity the addition of pore forming agents was studied. The desired overpotentials could be achieved due to high surfaces, adjusted pore structures and optimized Fe- and Al-content. (Fig. 2)

## Full cell

In full cell tests a very low cell voltage, exceeding state of the art for alkaline electrolysis, was demonstrated (Figure 3), as well as sufficient stability. The work continues with enlarged cells of 100$cm^2$ active area. In McPhy's 1000$cm^2$ 25 cell stack a similar performance is achieved and cell stability demonstrated in still continuing long-term test.



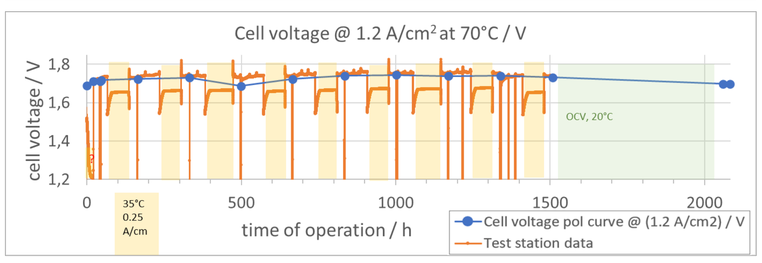




**Figure 3: Full cell measurement at 70°C, 30% KOH and ambient pressure, 8 $cm^2$ cell. Cathode $Ni_xAl_yMo_z$ coated, Separator Zirfon 220, anode $Ni_xAl_yFe_z$ coated. Long-term test at 1.2 A $cm^{-2}$ and 0.25 A $cm^{-2}$ and OCV.**

## Conclusion

Plasma-sprayed optimized Nickel-alloy electrodes can achieve a cell voltage of 1.7 V at 1.2 A $cm^{-2}$ giving a perspective for high current density operation of alkaline water electrolysis without PGM electrodes. The electrode production is possible at large size (5600$cm^2$ is demonstrated) and will allow scale-up for gigawatt electrolyser rollout. High surfaces, optimized catalyst composition and improved gas/liquid transport contribute to the low overpotentials and the sprayed layers show a good long-term stability.

References:[1] G. Schiller, R. Henne, G. Mohr, V. Peinecke, Int. J. Hydrogen Energy 23 (1998) 761; [2] F. Razmjooei, T. Liu, D. Aguiar Azevedo, E. Hadjixenophontos, R. Reissner, G. Schiller, S. Asif Ansar, K. A. Friedrich, NatureResearch (2020) 10:10948, https://doi.org/10.1038/s41598-020-67954-y

Funding:
BMWE
Verbundvorhaben
E2NGEL
Edelmetallfreie Elektroden für die nächste Generation der alkalischen Elektrolyse
(project No03EI3068B )

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag