CHALMERS

CORROSION CHALLENGES IN SOFC APPLICATIONS

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Introduction

What is a Fuel Cell?

Chemical Energy → Electrical Energy

Advantages and Usage of Solid Oxide Fuel Cell

- Efficient power generation (60 el%)
- Fuel flexible
- Low emissions
- Scalable

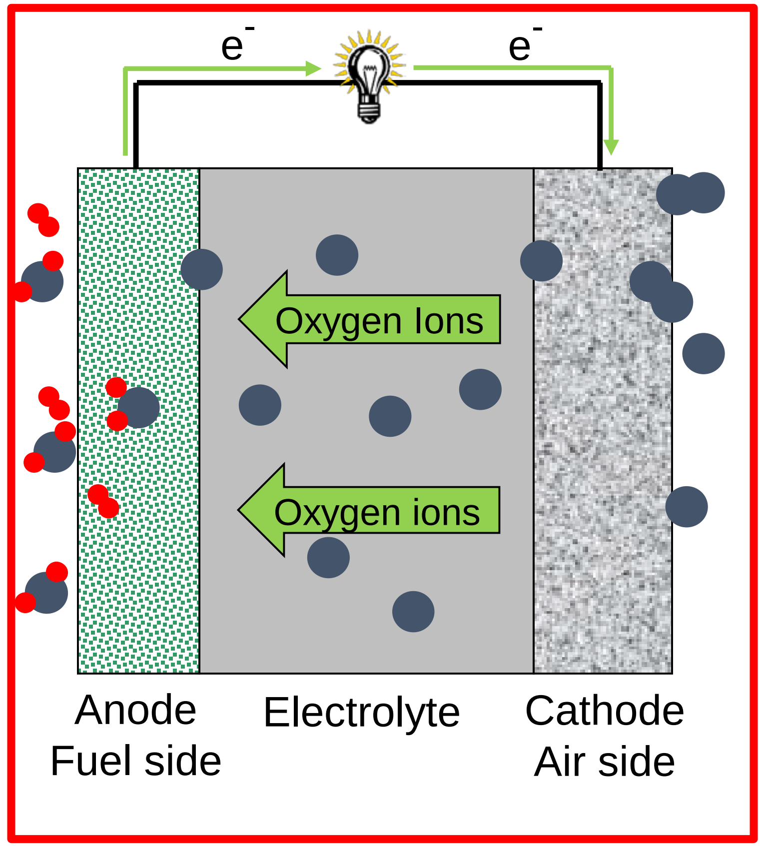
Truck or RV Auxilliary Power Units (APUs)

Combined Heat & Power (CHP)

Off-grid power generation

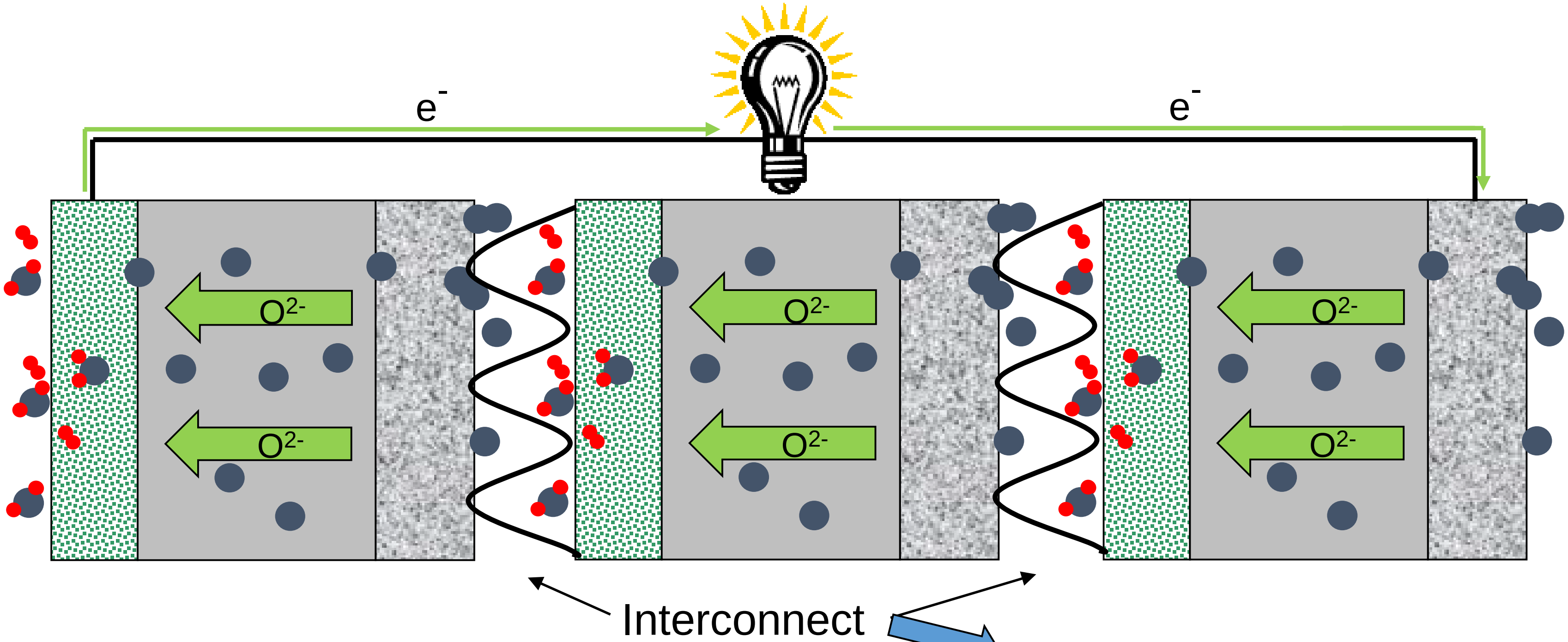
Solid Oxide Fuel Cell (SOFC)

Cathode: $O_2 + 4\ e^- \rightarrow 2\ O^{2-}$
Anode: $2\ O^{2-} + 2\ H_2 \rightarrow 2\ H_2O + 4\ e^-$
Total reaction: $O_2 + 2\ H_2 \rightarrow 2\ H_2O$

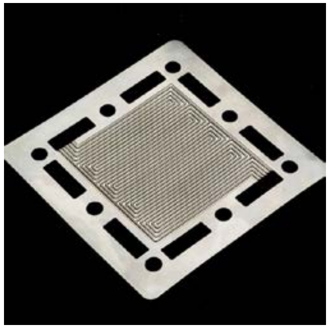


U < 1 V

Solid Oxide Fuel Cell Stack

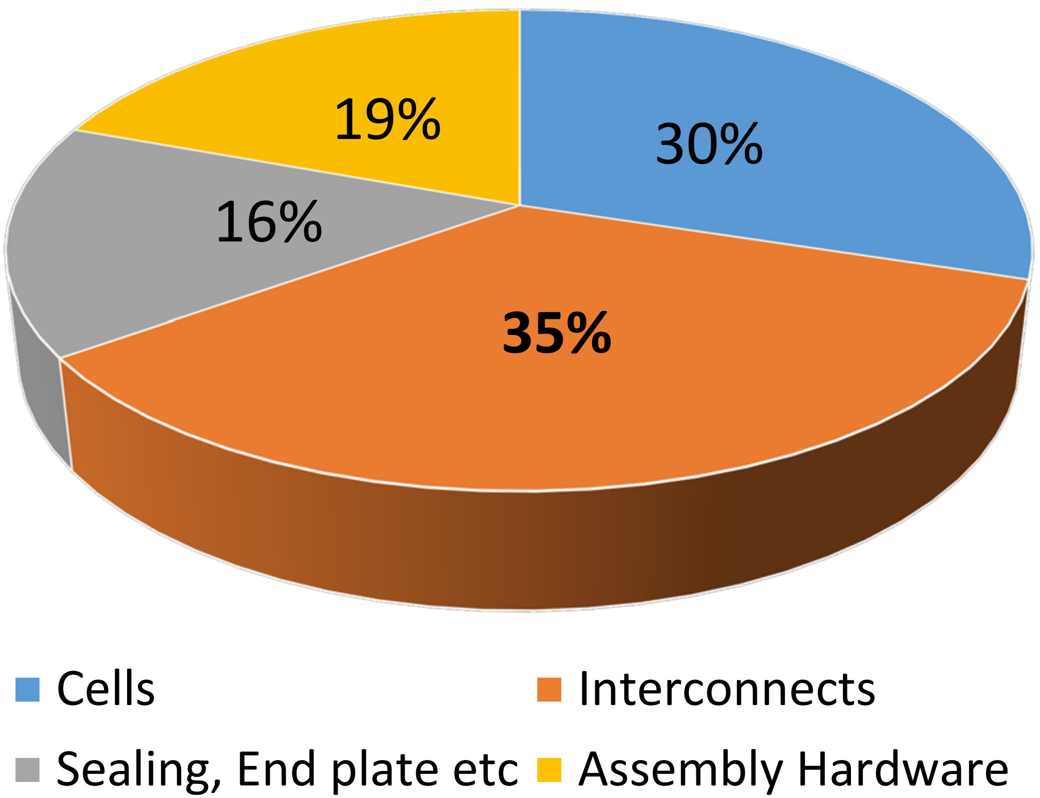


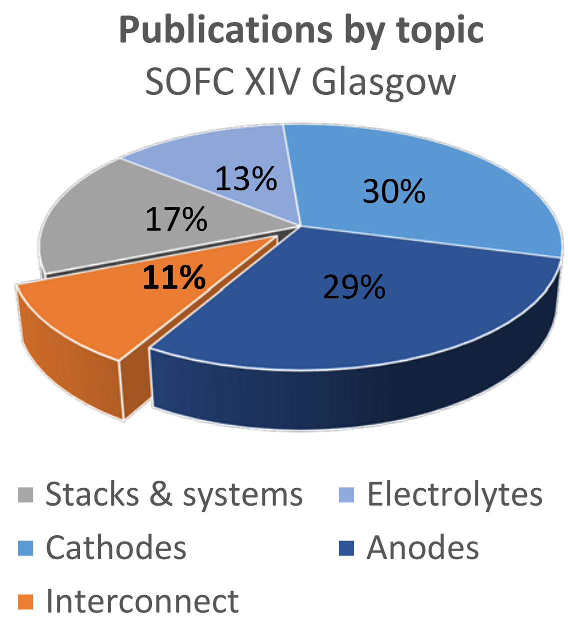
Ferritic Stainless Steel



- Similar thermal expansion as the ceramics used in SOFC
- Good electrical conductivity
- Formability
- Cheap to produce

Cost analysis 1 kW Stack
50 000 Units





Manufacturing cost analysis of 1 kW and 5kW solid oxide fuel cell (SOFC) for auxillary power applications. 2014, Battelle.

Problems at Interconnect level

Corrosion

poisoning the cathode!

- Chromium evaporation:

  $Cr_2O_3(s) + 2\ H_2O(g) + 1.5\ O_2(g) \longrightarrow 2\ CrO_2(OH)_2(g)$

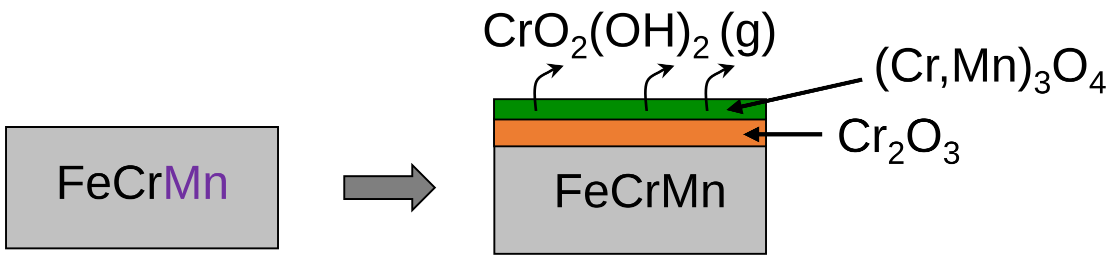
- Growing Cr_2O_3 layer
  → In combination of Chromium evaporation leads to increased Chromium consumption
  → Increase in electrical resistance

Solutions:

New alloys & Coatings

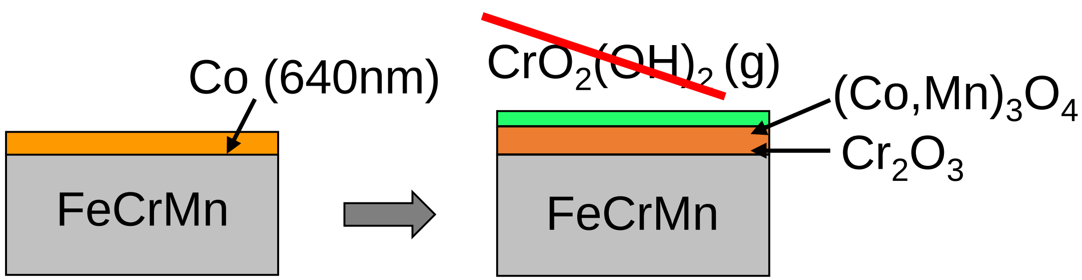
Possible ways to overcome Cr-evaporation

Change substrate composition:



Decreases Cr-evaporation, however, still too high!

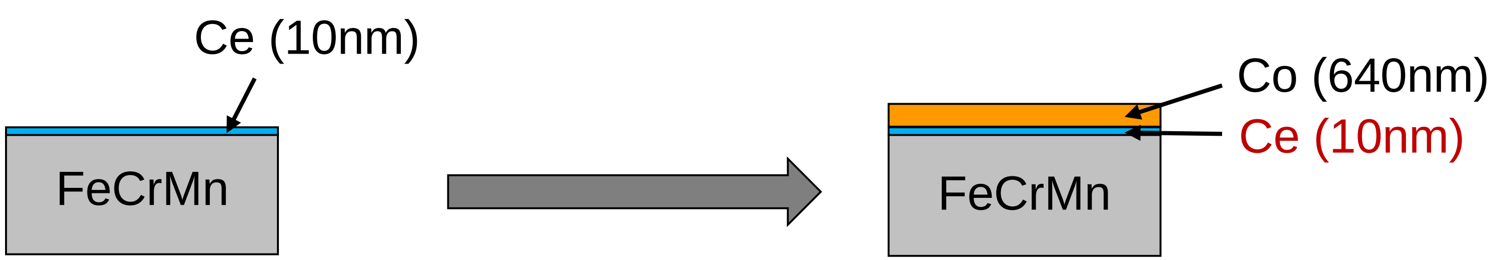
Apply Co coatings:



Minimize Cr evaporation by presence of $(Co,Mn)_3O_4$

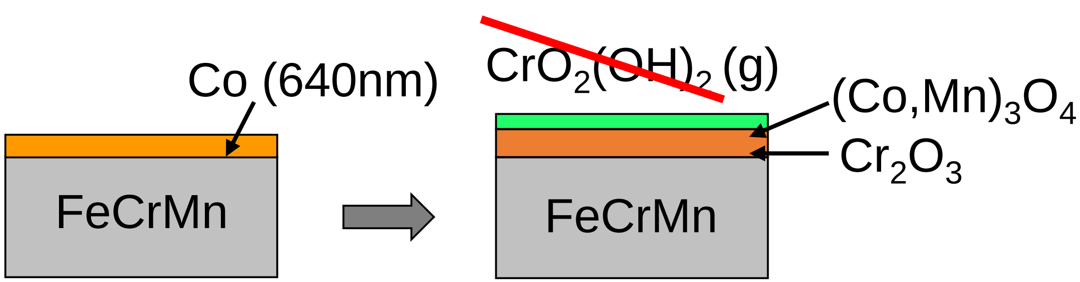
Possible ways to decrease oxide scale growth rate

Apply Ce coating:



Decrease in oxide scale growth

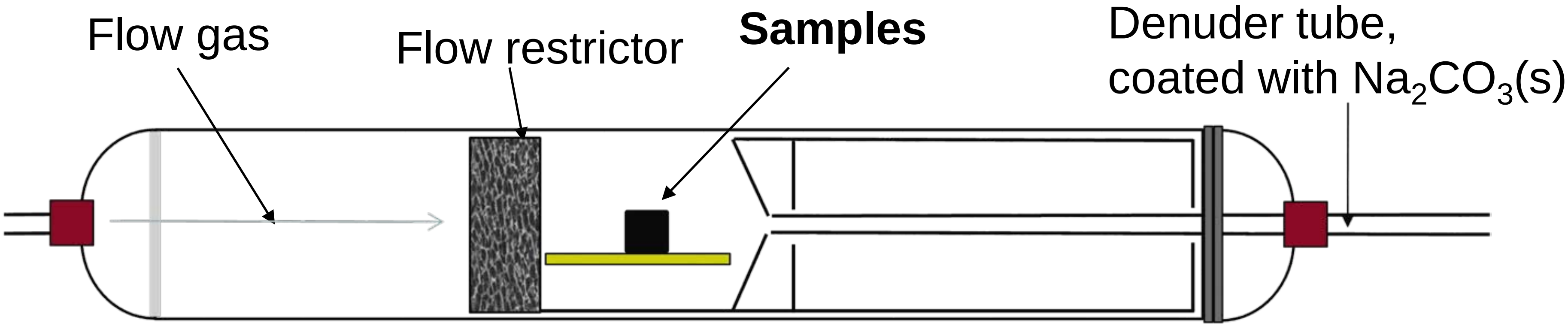
Apply Co coatings:



Minimize Cr evaporation by presence of $(Co,Mn)_3O_4$

Measurement Procedures

Cr-evaporation
Experimental Setup



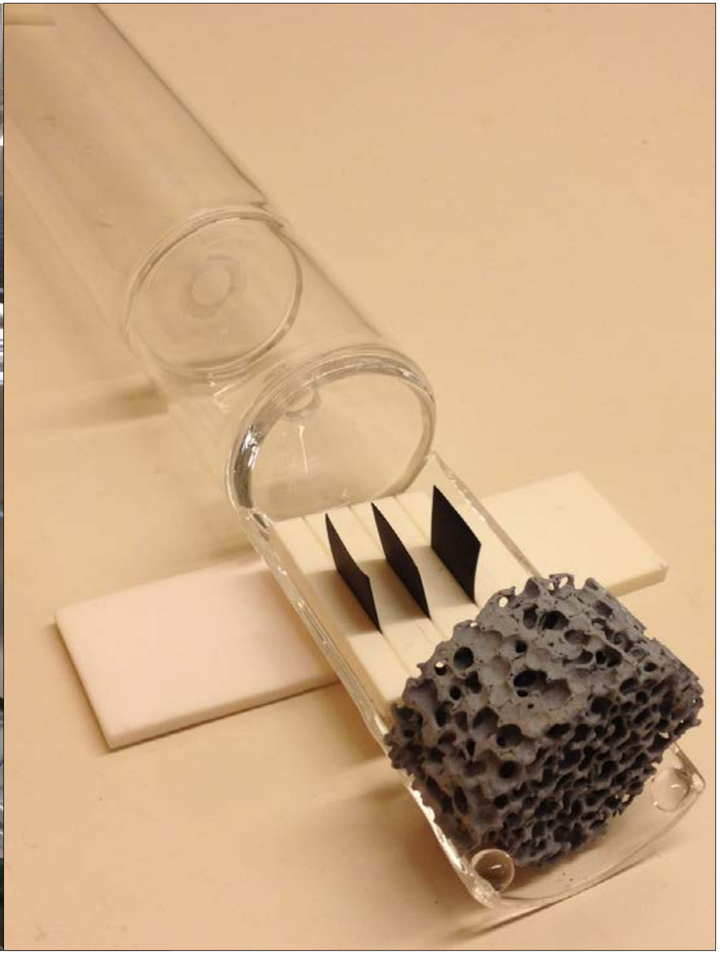
$$CrO_2(OH)_2(g) + Na_2CO_3(s) \rightarrow Na_2CrO_4(s) + H_2O(g) + CO_2(g)$$

After removing the denuder tube it is washed with deionized water and the water is analyzed for chromate by spectrophotometry.

Froitzheim et al. Journal of The Electrochemical Society, **157 (**2010)

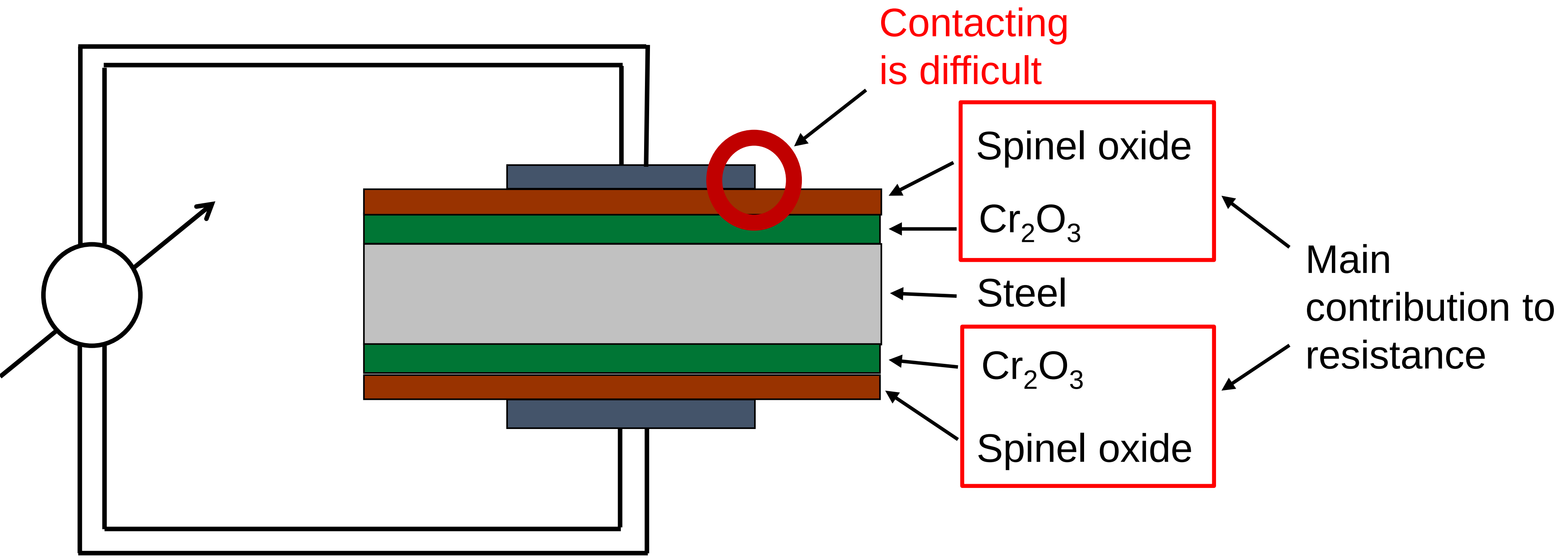
Cr-evaporation

Experimental Setup

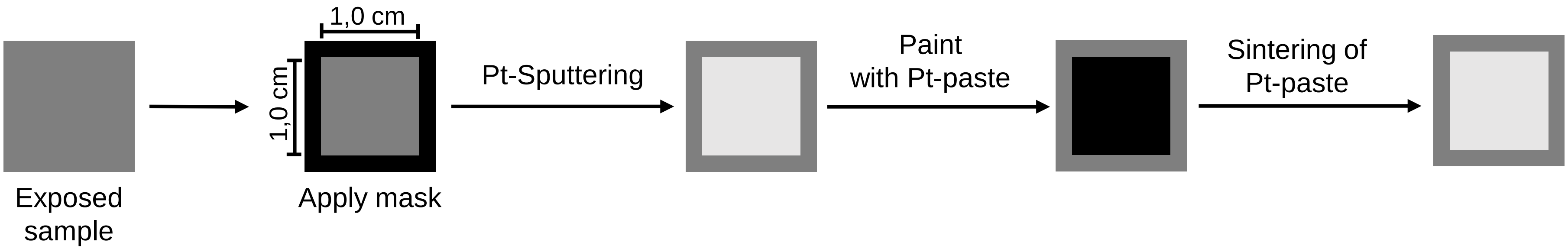


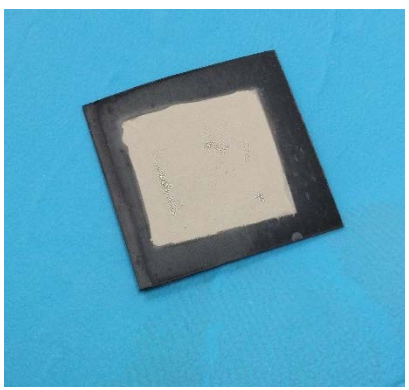
ASR Measurement

Basic Idea

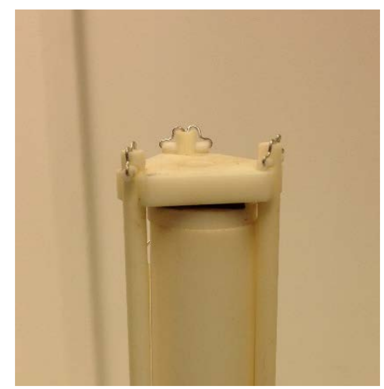


ASR Measurement
Electrode Preparation





Prepared sample



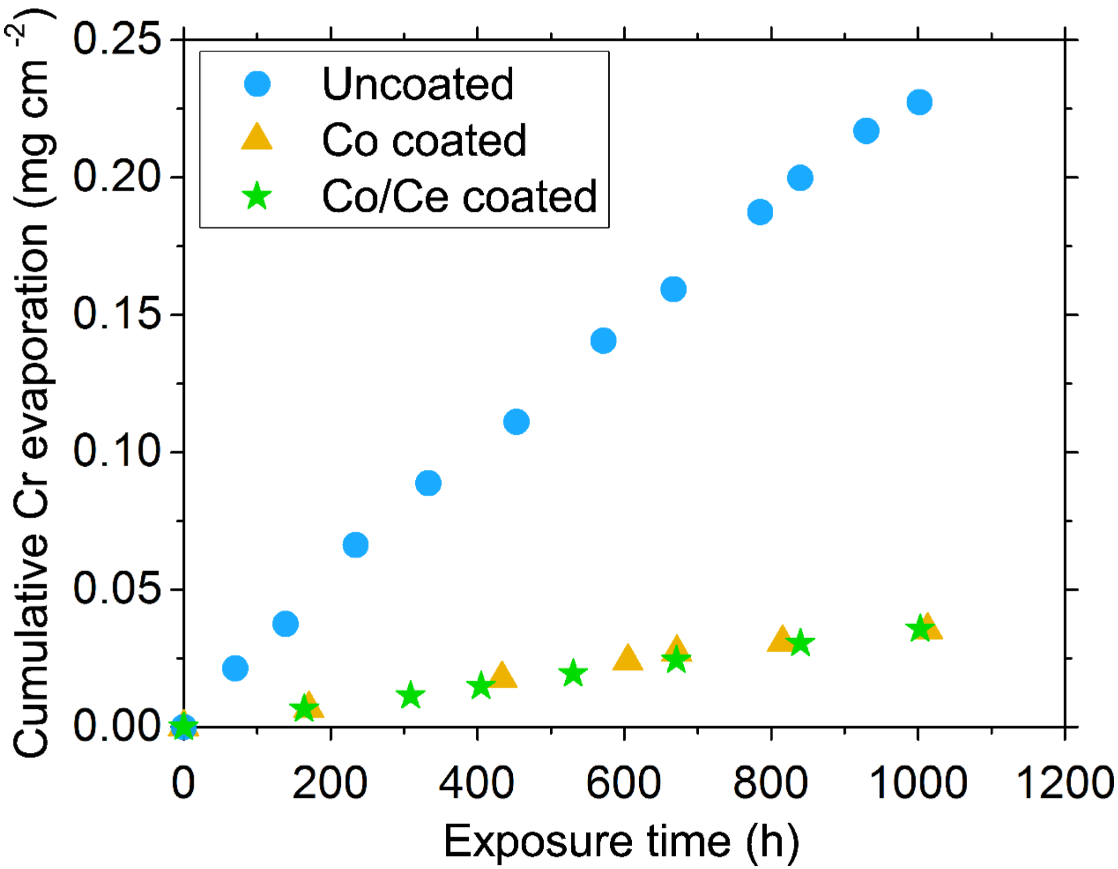
Sample mounted on Probostat, inclusive Pt-electrode

Coatings

A mean to mitigate Cr-evaporation and decrease oxide scale growth.

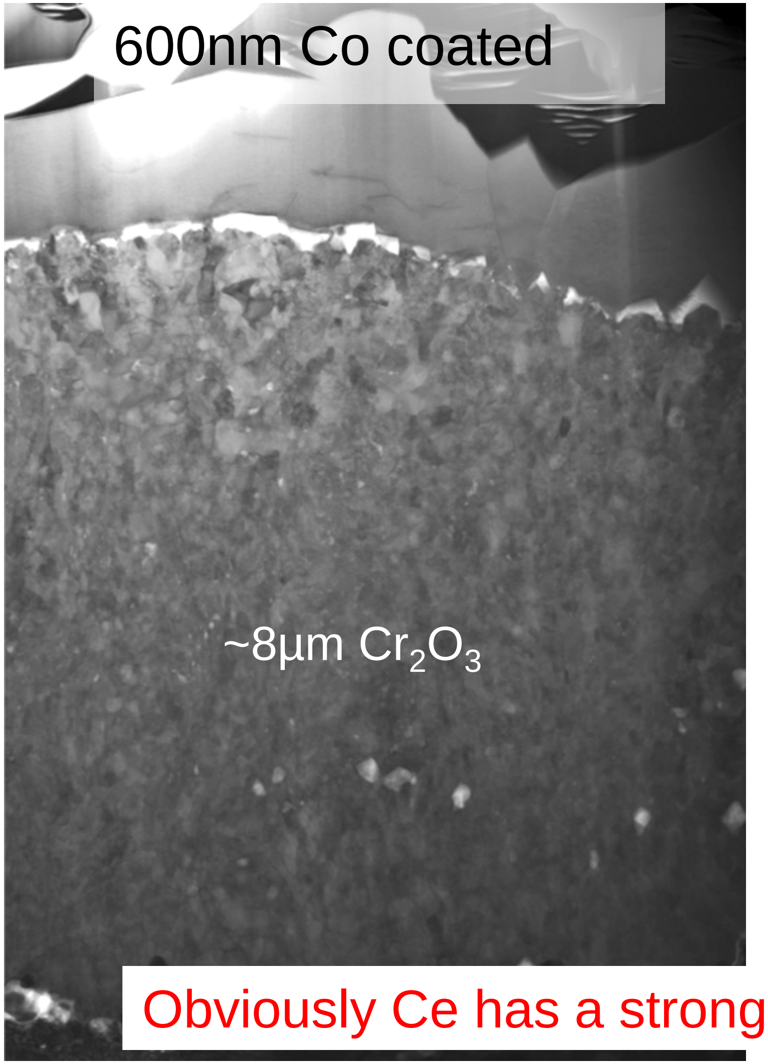
Cr-evaporation

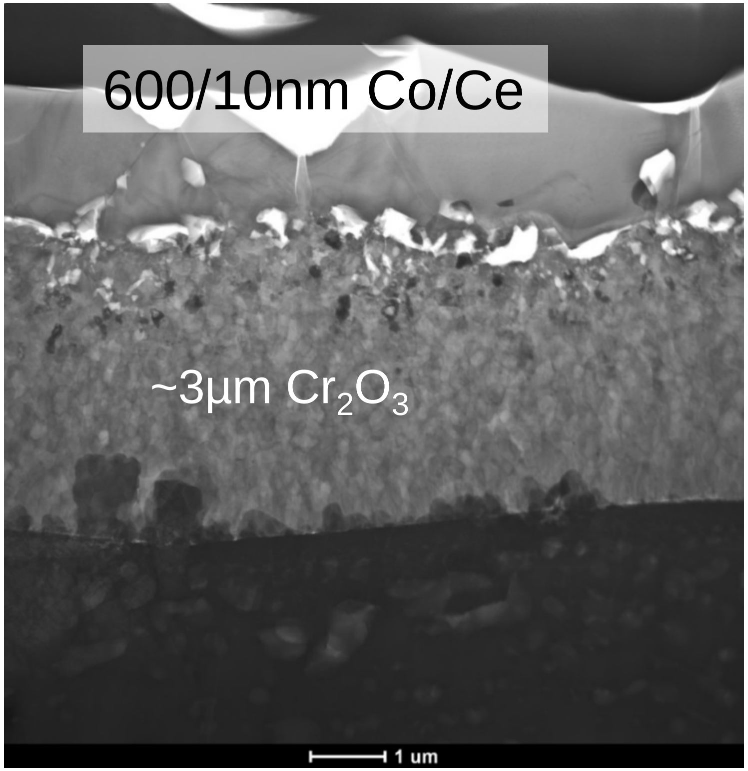
1000 hours exposure



Co+Ce coating perform as good as Co coating with regard to Cr-evaporation

Sanergy HT, 850°C, 6000ml/min

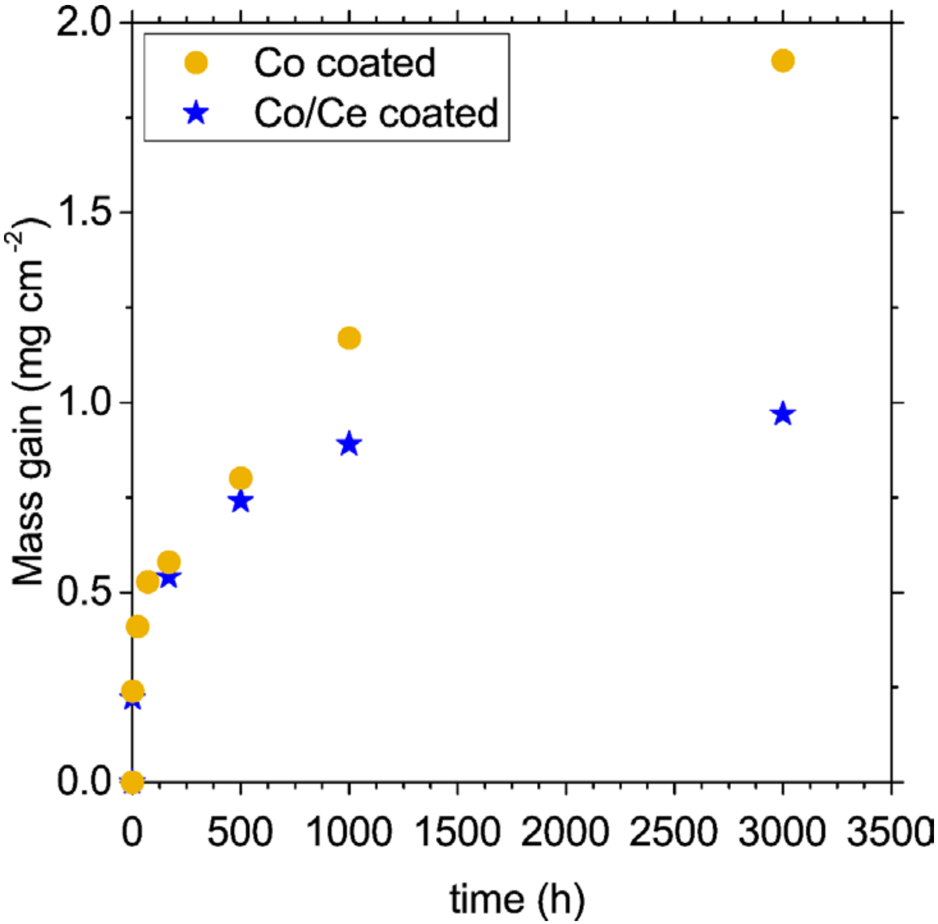




Obviously Ce has a strong effect on oxide scale growth

Sanergy HT 3000h, 850°C, air 3% H_2O

Mass gain



Co+Ce has lower mass gain than Co

Sanergy HT 3000h, 850°C, air 3% H_2O

The long-term stability of Co/Ce coatings

LONG-TERM EXPOSURES
37 000 h

Exposures

AISI 441

wt%	Fe	Cr	Si	Nb	Mn	Ni	Ti	P	C	S	N	RE
Batch 1	Bal.	17.83	0.55	0.48	0.26	0.1318	0.139	0.024	0.012	0.002	0.0157	no
Batch 2	Bal.	17.74	0.55	0.37	0.30	0.1922	0.1480	0.027	0.015	0.002	-	no

Thickness: 0.2 mm

Coating: 10 nm Ce + 600 nm Co

Geometry: 3 x 4 cm (cut down to 3 x 2 cm for Cr-evaporation and 1.5 x 1.5 cm for ASR measurements)

Exposures:

800 ° C in a **box furnace** at Sandvik Materials Technology for up to **37 000 h**

Analytical methods:

Cr- evaporation (in tube furnace)

Area Specific Resistance Measurements

SEM/EDX

Different Furnaces

Box Furnace

+ high throughput
- Stagnant not controllable air flow

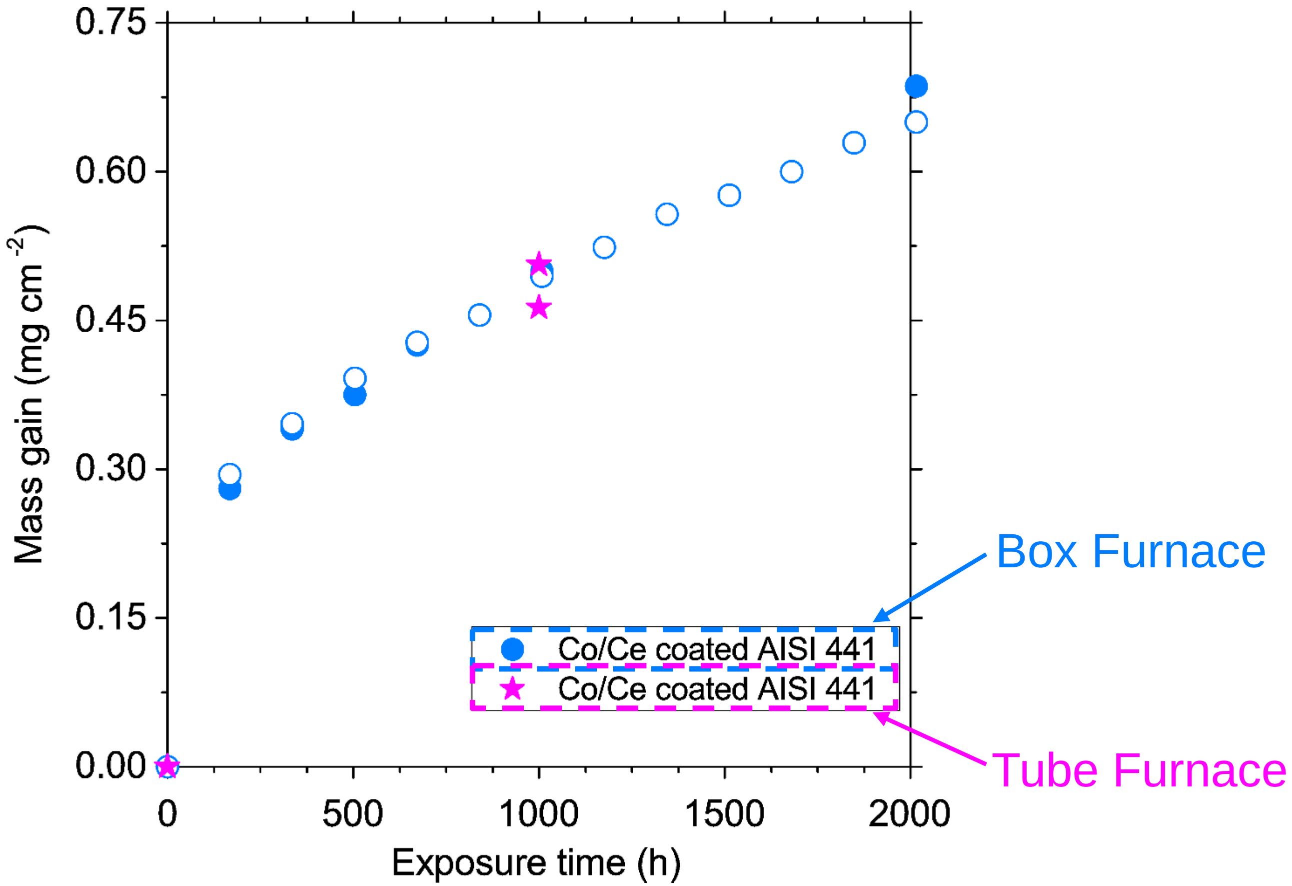
Tube Furnace

closer to stack conditions

+ controlled atmosphere (with adjustable humidity levels)
+ controlled flow rate
- Expensive
- Limited throughput

Mass gains

Exposure

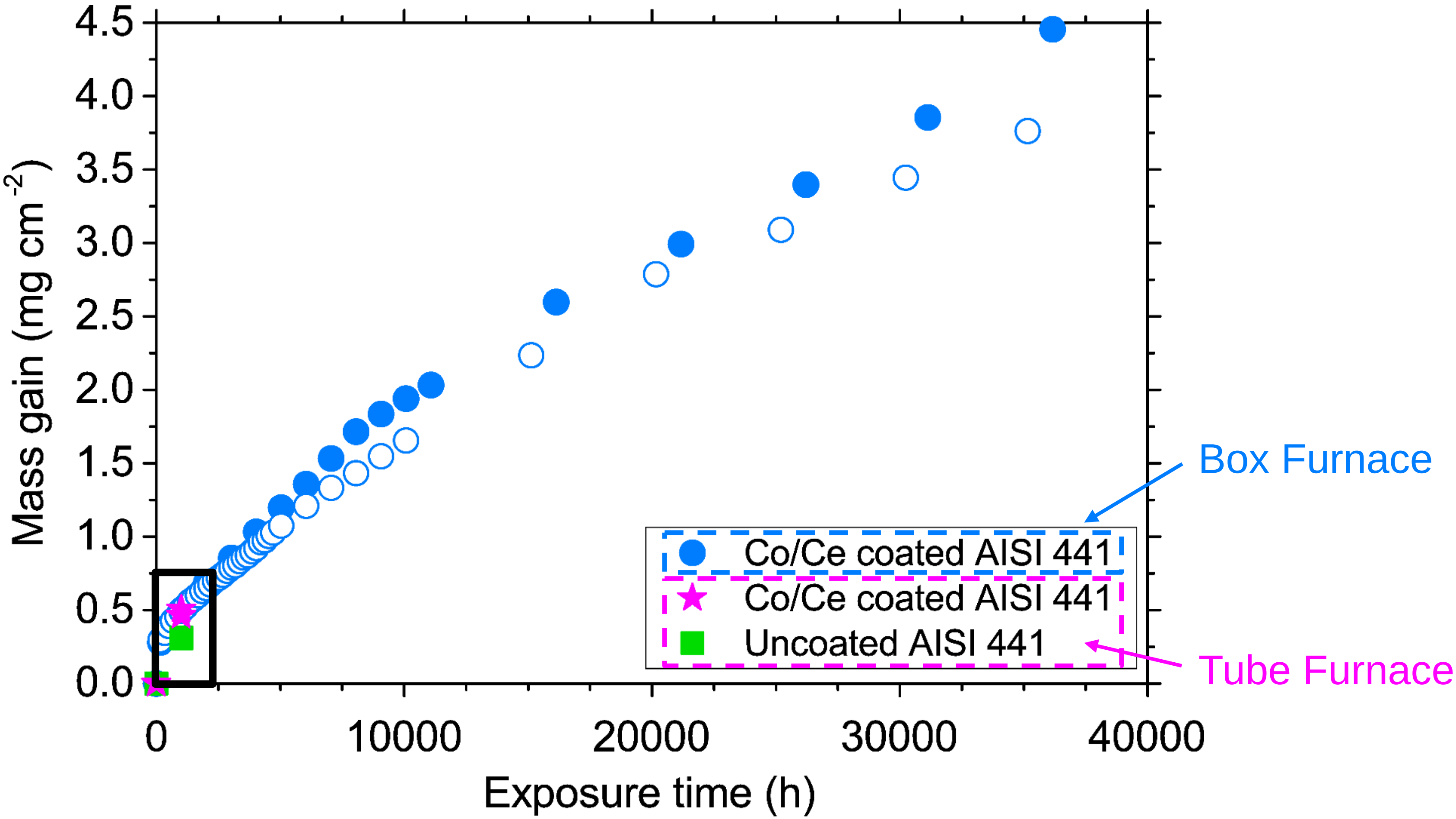


Initial increase of 0.21 mg/cm^2 can be attributed to the oxidation of Co

AISI 441, 800°C

Mass gains

Exposure

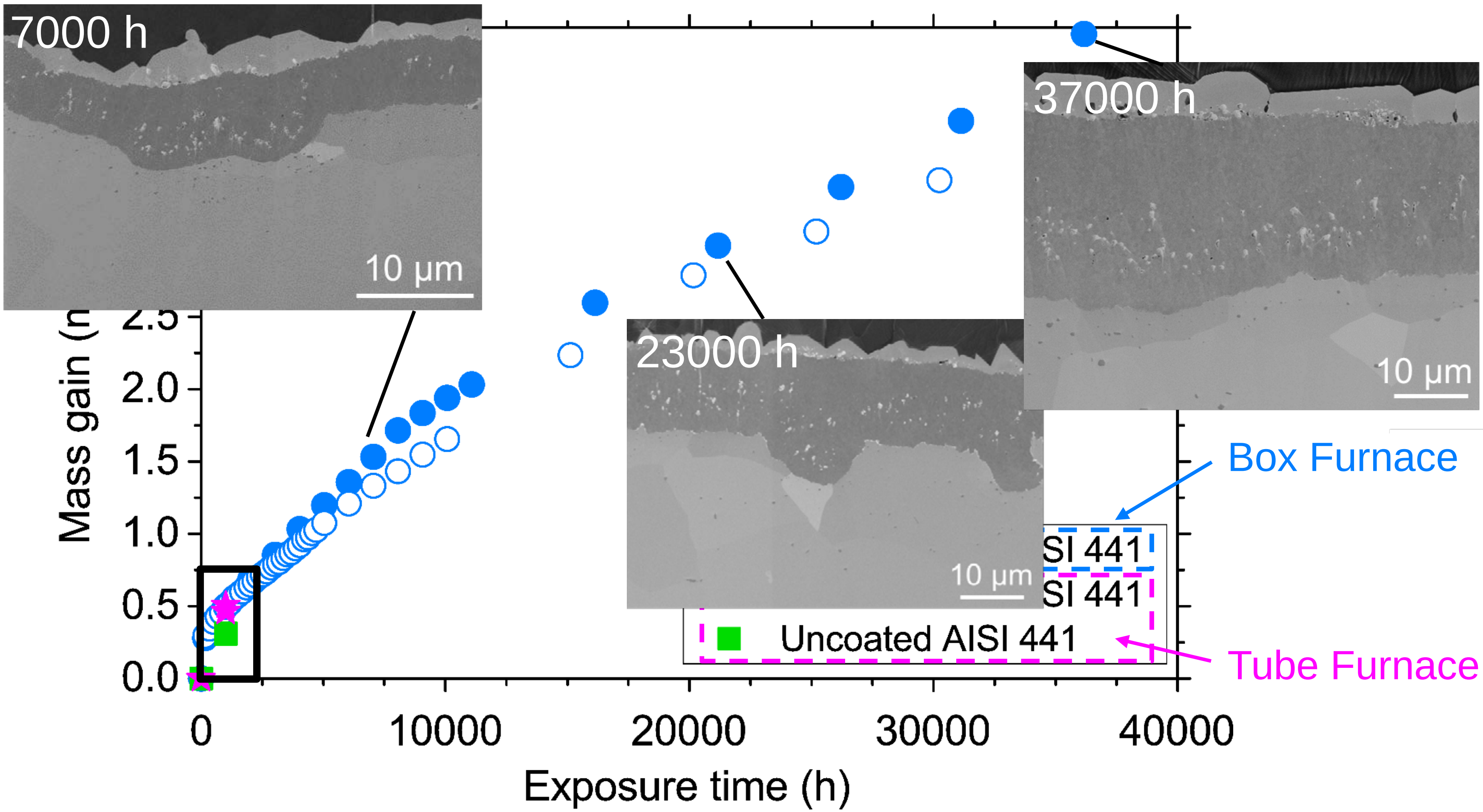


near parabolic growth

AISI 441, 800°C

Mass gains

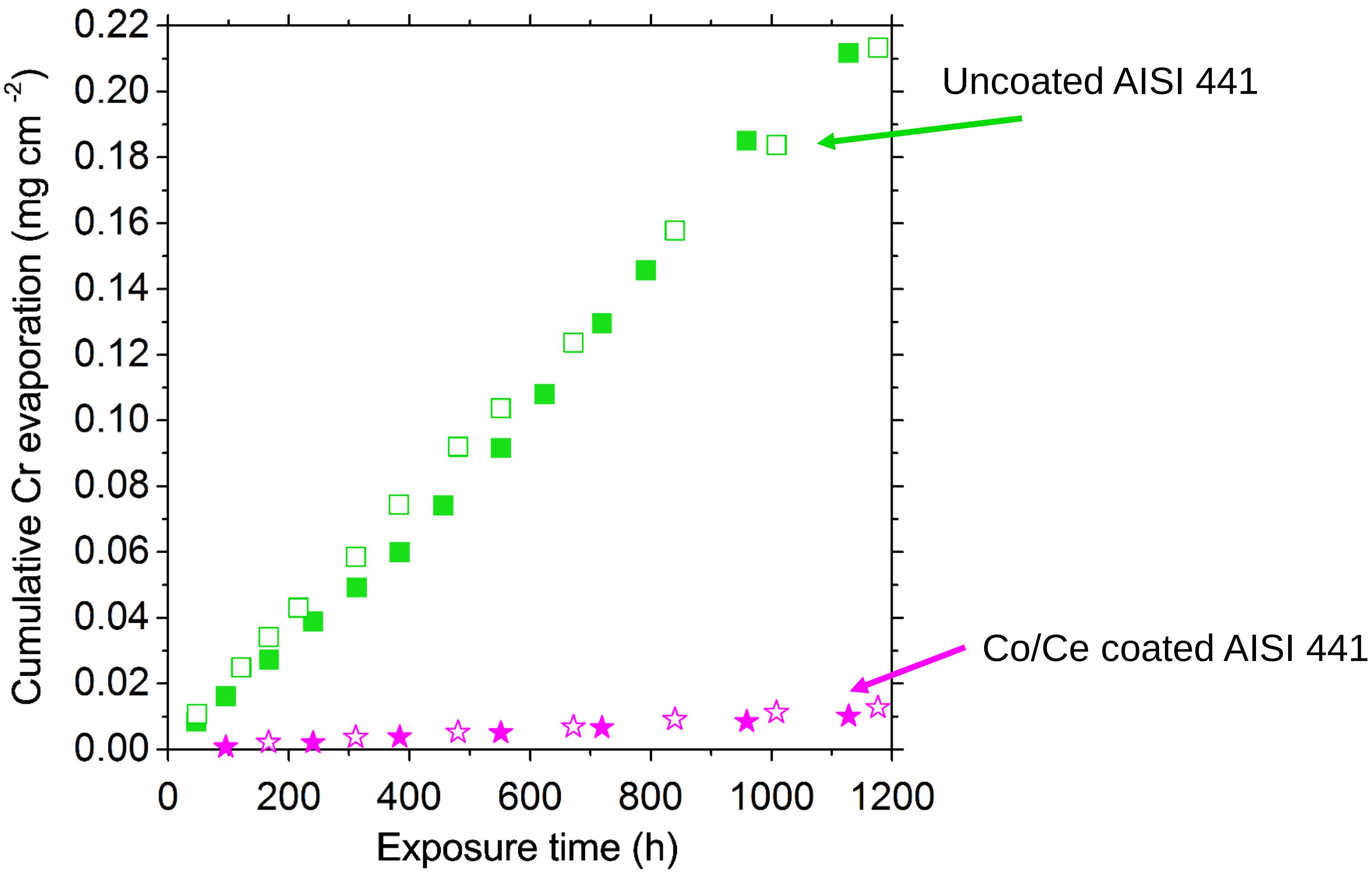
Exposure



near parabolic growth

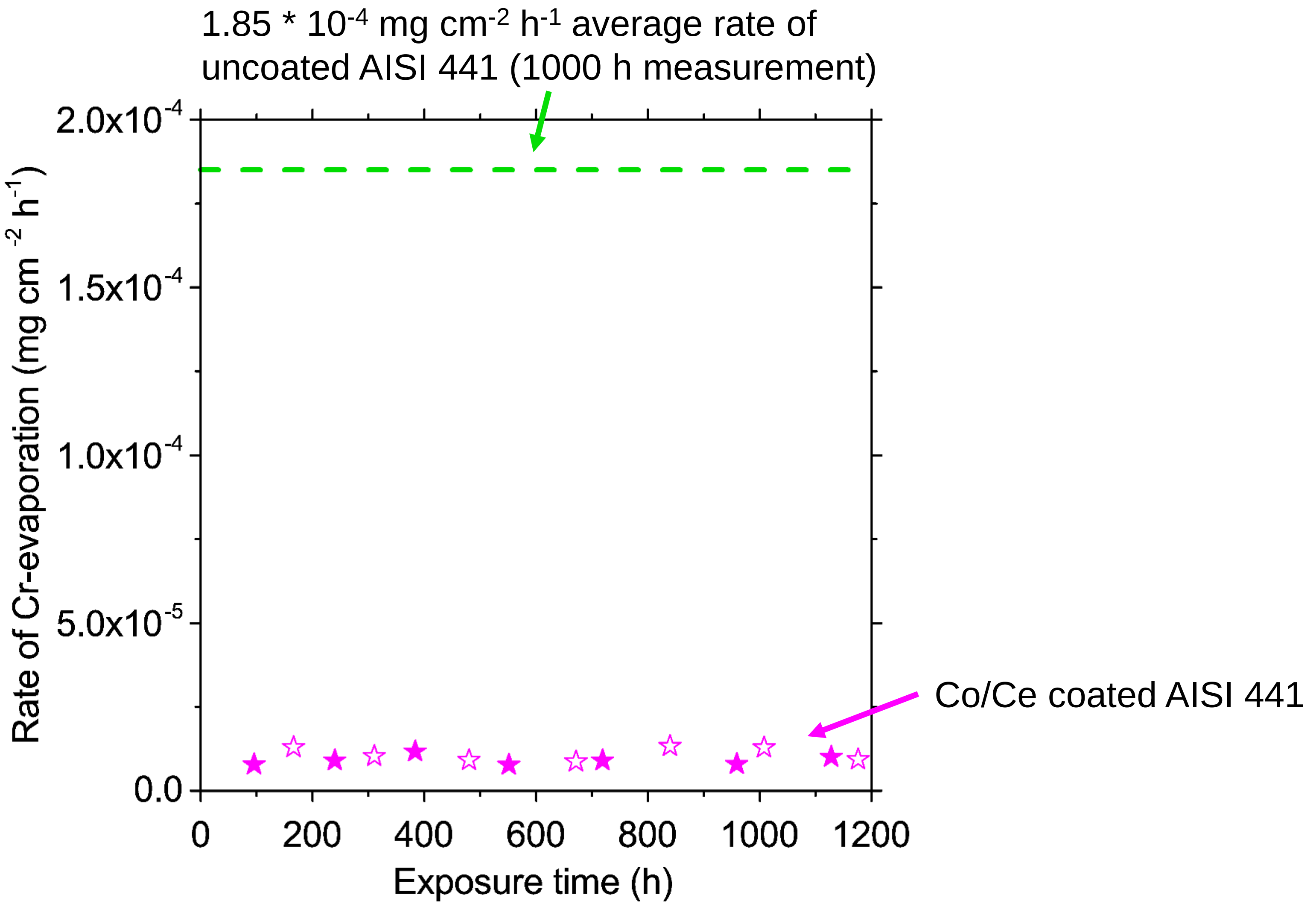
AISI 441, 800°C

Cumulative Cr-evaporation



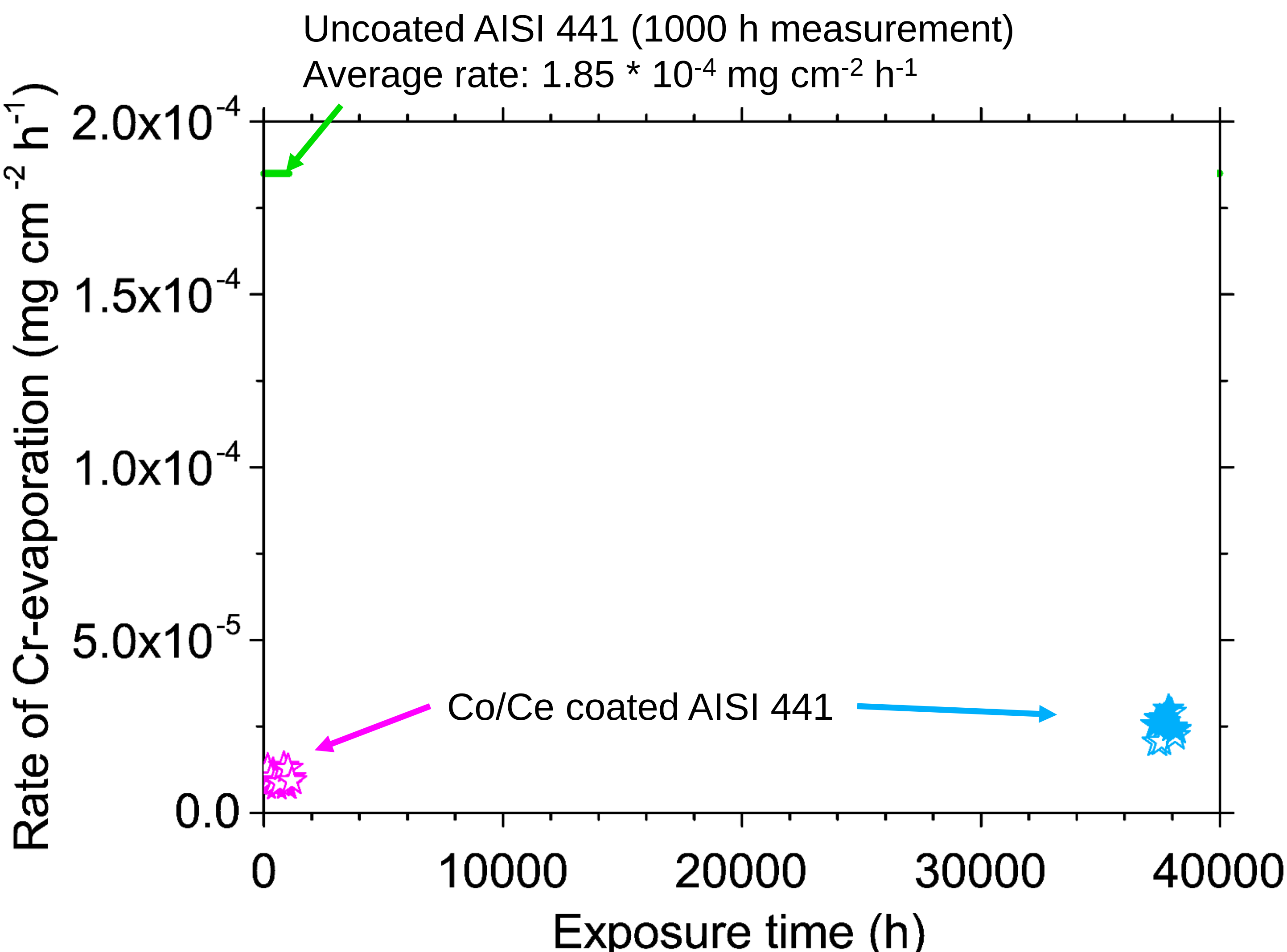
AISI 441, 800°C, 6000ml/min air

Cr-evaporation rate



AISI 441, 800°C, 6000ml/min air

Cr-evaporation rate



AISI 441, 800°C, 6000ml/min air

Conclusions

Conclusions - Long-term stability of Co/Ce coatings

- Co/Ce coatings are highly effective against Cr-evaporation and oxide scale growth

- After 37 000 h Co/Ce coated AISI 441 exhibits:
  - Cr-evaporation rates comparable to initial rates
  - ASR values well below 100 mΩ cm^2
  - Approximately 17 – 20 µm thick Cr_2O_3 layer

→ Co/Ce coated AISI 441 shows promising long-term stability in air at 800 °C