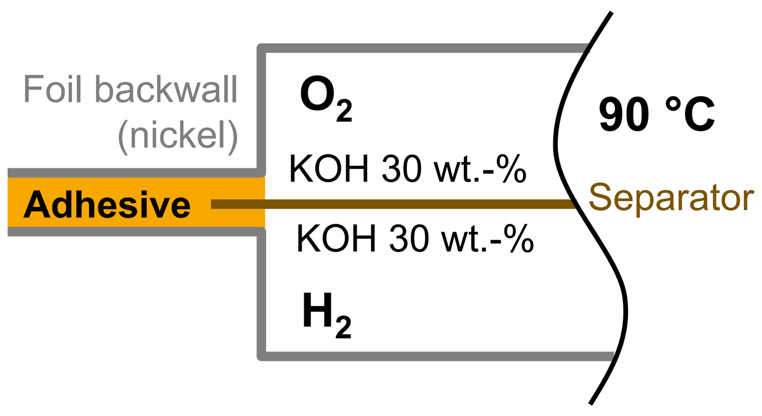
Femtosecond-pulsed Laser Pre-Treatment of Nickel Foil III: Influence of Atmosphere and Ambient Pressure on Adhesion

CJA Beier, M Schmitz, MK Heym, V Ginster, A Schiebahn, U Reisgen
RWTH Aachen University, ISF - Welding and Joining Institute,
Pontstraße 49, 52062 Aachen, Germany.

Introduction

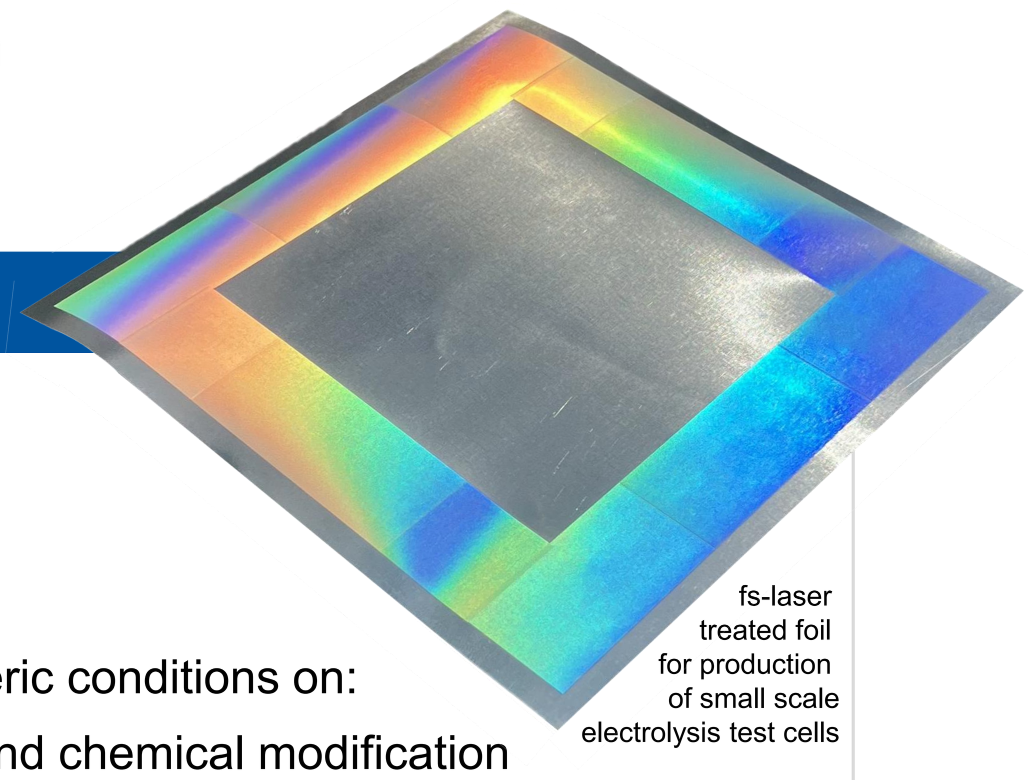
- Adhesive bonding enables cost efficient **foil design** for **alkaline water electrolysis** (AEL) cells
- Alkaline environment requires **strong adhesion** → **fs-laser pre-treatment** most suitable [2,3]
- Previous investigations only at normal atmosphere
- Atmospheric conditions **influence** laser plasma and process (particles, composition) [4]
- Influence of process atmospheres and pressure on adhesion properties still unexplored



Foil design of water electrolysis cell with adhesive seal [1]

Research goals

- Integration of a process chamber in a fs-laser for generating
- Influence of atmospheric conditions on:
  - ➢ Surface structure and chemical modification
  - ➢ Initial adhesive strength and fracture behavior
  - ➢ Resistance of the interface against the conditions in a water electrolysis cell



fs-laser treated foil for production of small scale electrolysis test cells

Materials & Methods

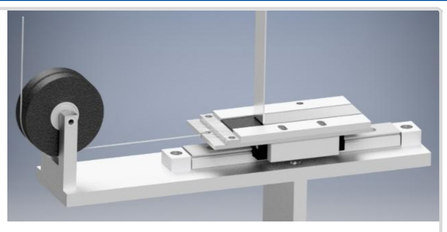
Adherent

- Nickel 201 (> 99 % nickel)
- Foil: < 75 µm thickness
- Bright annealed

Adhesive

- 2-C epoxy adhesive

Testing

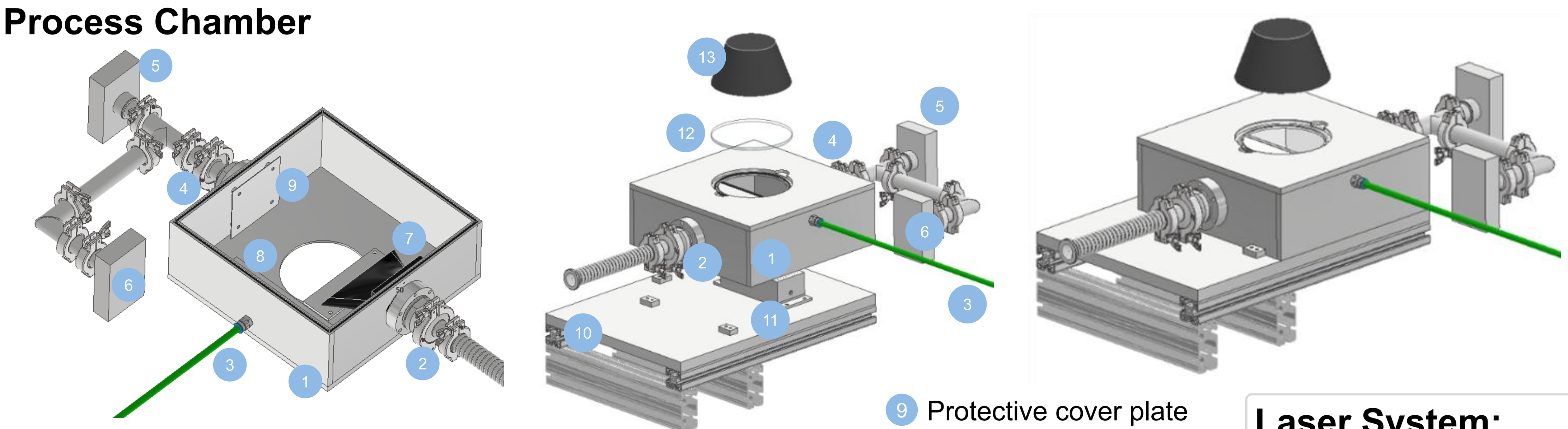


- 90° peel test (EN ISO 29862)
- Surface & fracture analysis: SEM, EDX
- Aging tests: 30 days @90 °C in
  - 35 wt.-% potassium hydroxide (KOH)
  - deionized water (**H2O**)

Process atmospheres

- Gas atmospheres:
  - Argon (**Ar**)
  - Nitrogen (**N**)
  - Oxygen (**O**)
- Low pressure: **60 mbar** (Protective gas for optics: Ar)

Process Chamber

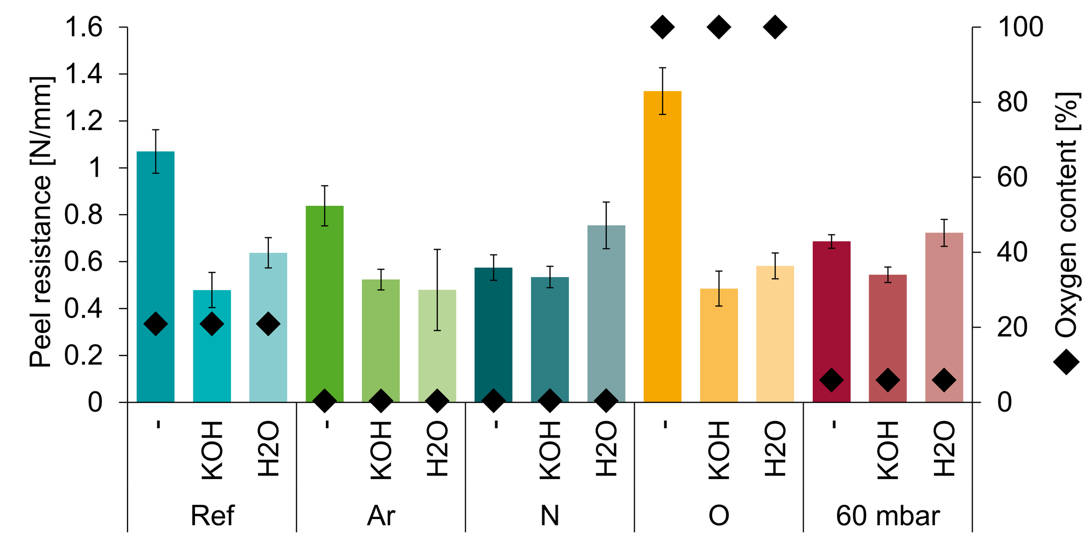


1. Process chamber
2. Vacuum pump connection
3. Process gas connection
4. Connection sensor technology
5. Oxygen meter
6. Pressure sensor
7. Extraction system
8. Gas distribution sytsem
9. Protective cover plate
10. Base with substructure
11. Suction fixture
12. Laser glass
13. F-Theta Lense

Laser System:

- IR-Laser, 780 fs
- 60 µJ, 100 kHz

Results: Mechanical Analysis



Initial adhesion strength (-):

- ➢ Presence of oxygen seems to increase initial peel resistance (highest for O, Ref)

Aged in KOH:

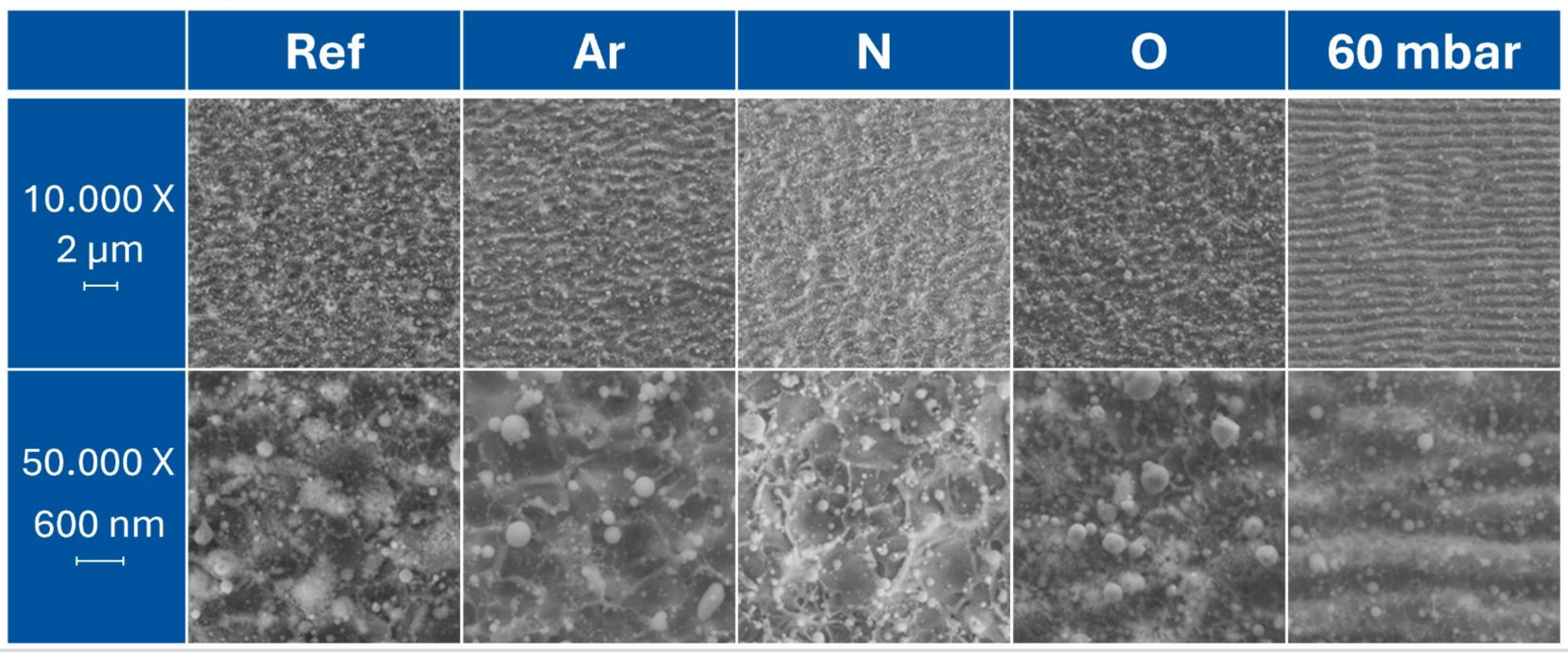
- ➢ Peel resistance decreases, especially for atmospheres with oxygen
- ➢ No decrease for N, small decrease at 60 mbar

Aged in H_2O:

- ➢ Strong decrease for atmospheres with oxygen
- ➢ Increase for N and 60 mbar → plasticizing effect of water absorbed into the adhesive

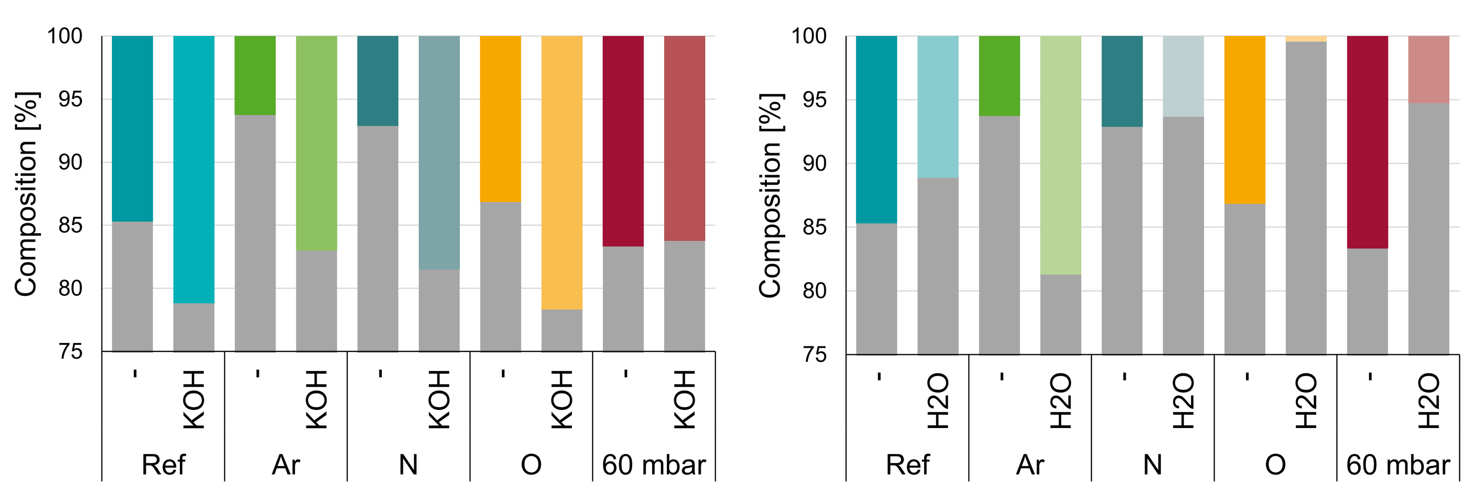
Results: Surface & Fracture Analysis

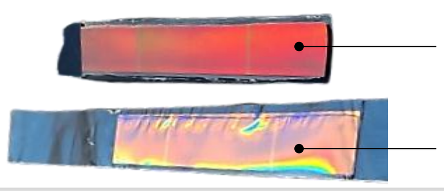
SEM images of laser treated surfaces



- ➢ Major depositions at normal pressure
- ➢ LIPSS structures at low pressure with minor depositions
- ➢ Smaller nano-particles in N and 60 mbar
- ➢ Major condensation in oxygen-rich atmospheres (Ref, O)

Fracture analysis of the adhesive layer with EDX





KOH:

- ➢ Nickel content increases
  → Increased cohesive failure of the laser structures
  → Process deposits (nano-particles) possibly susceptible to KOH attack

H_2O:

- ➢ Nickel content mostly decreases → plasticizing effect on adhesive

Conclusions

Adhesion strength

- ➢ Presence of oxygen strengthens initial peel resistance (Ref, O)
- ➢ Inert gas does not contribute to high peel resistance or aging resistance (Ar)
- ➢ Low oxygen and presence of nitrogen produce aging-resistant interfaces (N, 60 mbar)

Fracture analysis

- ➢ Process depositions are a possible point of attack for alkaline media

Outlook

- ➢ Analysis of atmosphere on formation of functional groups (XPS, TOFSIMS)
- ➢ Transfer of laser pre-treatment in aging-resistant atmospheres to electrolysis test cells

[1] Lüke, W., WEW GmbH, EP4294965A1
[2] Beier et al., Journal of Laser Applications 36 (2024), DOI: 10.2351/7.0001558
[3] Beier et al., The Journal of Adhesion 101 (2023) DOI:10.1080/00218464.2024.2304606
[4] Frey et al., Vacuum 233 (2025), DOI: 10.1016/j.vacuum.2024.113964

/bond-with-christoph
Christoph Beier, M. Sc., EAE
Tel: +49 241 80 96301
Mail: beier@isf.rwth-aachen.de
RWTH Aachen University
Welding and Joining Institute

Flagship Project H_2Giga
With funding from the:
Federal Ministry of Research, Technology and Space
Funded by the European Union
NextGenerationEU
Funded by the German Federal Ministry of Research, Technology and Space within the Framework Concept "H_2Giga" under the grant no. 03HY102

RWTH Aachen University
Welding and Joining Institute
Univ.-Prof. Dr.-Ing. Uwe Reisgen
Pontstraße 49, 52062 Aachen, Germany
www.isf.rwth-aachen.de