37th Chemnitz Seminar
»Electronic Packaging and Applications«

Latest Progress of Plating Equipment for Al plating from ionic liquids

Chemnitz

14.06.2023

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consulting engineers

Outline

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- NBT introduction
- ENAS / NBT history of cooperation

- Motivation / applications
- Status of Al plating at ENAS / NBT

- Status of tooling solutions

- Roadmap

NBT Facts and Figures

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- **Ownership: 100% private, founded 2004**
  - Mike Becker, Dipl.-Ing. in Electrical Engineering,
    more than 25 years experience in R&D on electroplating,
    MEMS switches and medical devices, solar cell manufacture
  - Dr. Dietmar Lütke Notarp, Ph.D in Electrical Engineering,
    more than 30 years of experience in R&D on electroplating, MEMS, medical devices,
    tool engineering, solar cells manufacture, medical industry, mechanical engineering
- **Locations: 3 sites (Germany)**
  - Bremen: Headquarters, production chemical products, R&D center, lab & cleanroom
  - Frechen (Cologne): Production medical components
  - Marsdorf (Cologne): Office, Tool construction & manufacture, R&D
- **Staff**
  - ~19 employees incl. assistants
    + technical teams on demand (scientists & engineers)

NBT services and product fields

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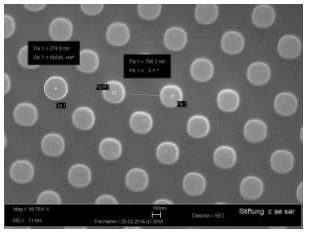
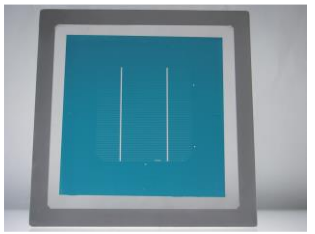
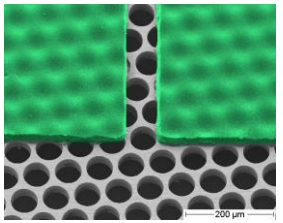
Consulting, prototyping, seminars

Screen printing & Nanoimprint stamps

- sunstence® uni
  (fine line, distortion-free, precision alignment)

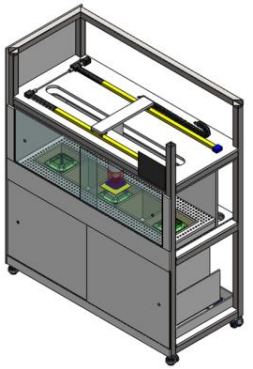






Plating tools

- suncup® (plating cell for lab and production)



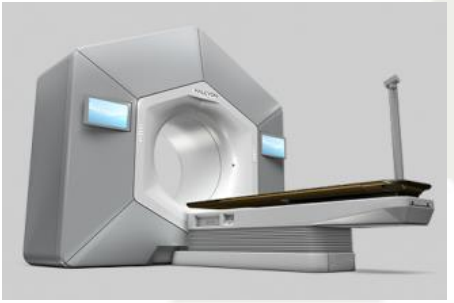
Plating solutions

- NB Semiplate series
  (Ni, **NiMn**, Au, Cu, Ag, Sn, In, Bi, AuPd,…)
- Distribution partner MicroChemicals GmbH

MicroChemicals

Etching solutions (seed layer etching)

- Cu etch, Au etch, TiW etch, Cr etch
- (least undercut, least dimension loss)



Medical Device Components

- Cancer treatment devices

Focus & Mission I

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As **manufacturer & vendor** we provide
(ISO 9001:2015 certified since 2017)

- components for medical therapy system
- consumables for plating and etching (solutions)
- electroplating tools for R&D and production
- screens and screen printing products (pastes, resists)

Screen manufacturing in China

Joint Venture: Frintrup NB SST (Kunshan)

FRINTRUP
nb technologies

Focus & Mission II

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As **engineering house** we provide
worldwide consultancy and support services

Your Vision – Our Mission !

**We help to “overcome barriers”
to achieve your business ideas.**

NBT is Entirety

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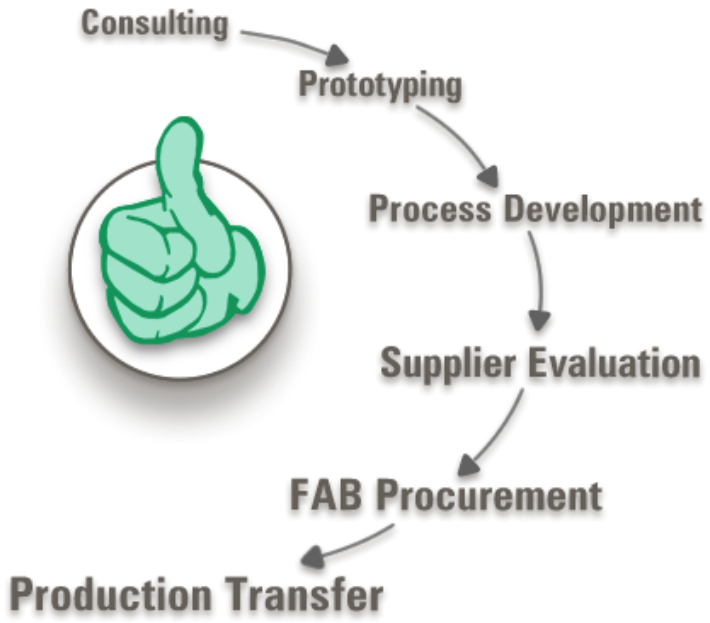
We find an overall solution - whatever the requirement is in the field of



- Semiconductor & Microsystem Technology
- Medical Microsystems
- Mechanical & Systems Engineering
- MEMS for Telecommunication
- Solar Energy / Photovoltaics / Hydrogen
- Nanobiotechnology
- Screen printing / Nanoimprint

We accompany the way from the first product idea up to the mass production.

NBT / ENAS history of cooperation

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- **ENAS / TUC / NBT share a decade of history of joint (public funded) cooperation projects**
  - Plating of reactive multilayers (RMS) for packaging, silicon through vias (TSV)
  - 2015 first joint project on Al-plating
    AIOLI (BMBF funded project (FKZ16ES0331) (finished 2018)
  - Total 5 public funded projects finished/running, 3 more projects applied for

➢ **Over many years, ENAS has built up considerable expertise on Al-plating for different applications**

➢ **NBT's focus on equipment solutions**

Motivation aspects

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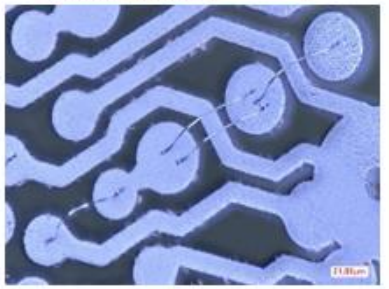
- Perspective on material cost & availability (Cu 3.5x more expensive, increasing demand)
- Al and Al alloys are common materials in microsystem technology / microelectronics
  - Conductive paths
  - Bonding material
  - Bonding pads
  - Optical layer
- PVD is usually limited in layer thickness

⇒ ECD

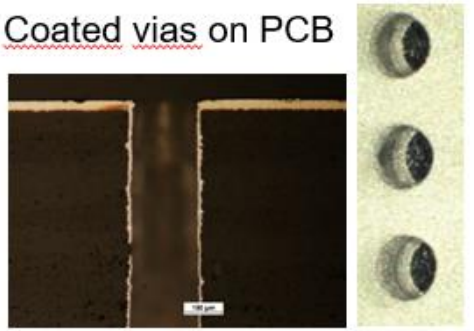
  - enables thick, dense and patterned layers
  - can be used for conformal coating (e.g. vias, grooves)

⇒ **New application fields for Al using ECD**

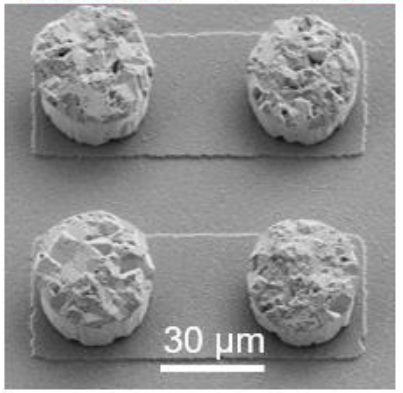
Al RDL on PCB with wire bonds



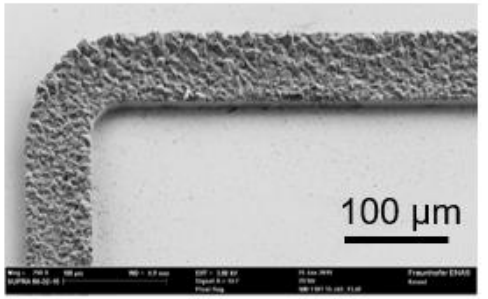
Coated vias on PCB



Al Pillars for Flip Chip bonding



Bonding frames for TCB



Source: ENAS
Work done by Silvia Braun, Imants Cirulis (ENAS)

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Fraunhofer ENAS

Basics of Al-ECD from ionic liquids

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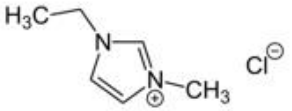
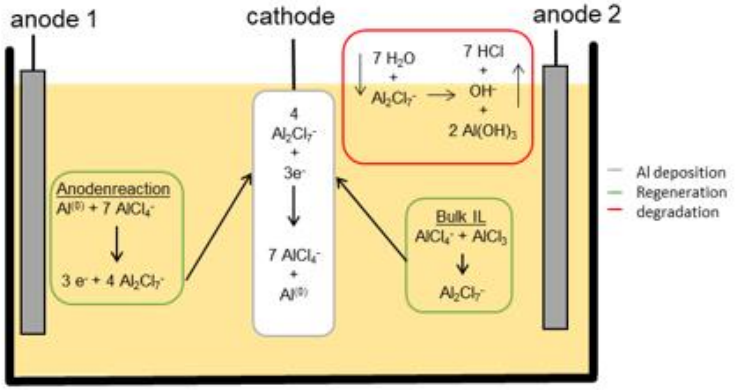
- E^0_{Al}= -1,67 V vs. NHE → deposition from aqueous solutions is not possible

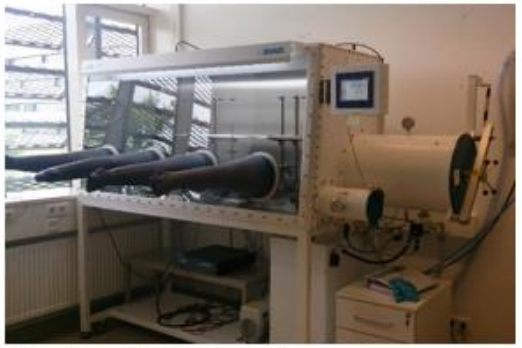
  → ionic liquids (Ils) are used
- ILs= organic salts with a melting temperature < 100 °C
  - Properties are tunable by varying the composition
  - Wide electrochemical window
- Use of EMImCl/$AlCl_3$ 1:1,5 (~150 g/l Al)
  (1-Ethyl-3-methylimidazolium chloride / Al chloride)



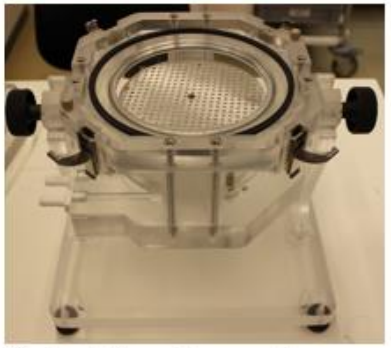
- Moisture sensitivity of IL
  - ➢ Degradation when exposed to moisture
  - ➢ HCl (gas) generation
  - ➢ Controlled humidity atmosphere required
  - ➢ Challenges for plating equipment



ECD process for double-side deposition and reaction equations



Glovebox with N_2 atmosphere



6 inch plating unit, manual deposition equipment

Source: ENAS
Work done by Silvia Braun, Imants Cirulis (ENAS)

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Facts & Figures

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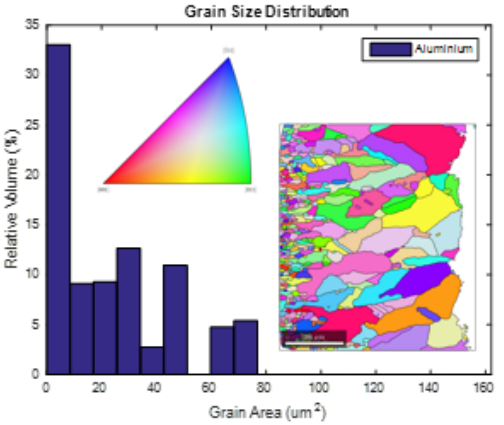
Deposition and layer properties

- Deposition of pure Al (EDX analysis with no contaminations)
- Deposition rate: 70 nm/min…300 nm/min depending on seed layer and deposition parameters
- Thickness: up to 40 µm (thicker possible but not tested yet)
- Deposition inhomogeneity < ± 15 % (deposition process and equipment can still be optimized)
- No specific grain orientation
- Grain boundaries are thermally active → merging of grains possible
- Layer stress ~ 38 MPa
- Thermal conductivity ~230 W/(m*K)
- Roughness increases with layer thickness
  - CMP treatment or electro polishing possible
  - Additives for electrolyte under investigation
- Smallest structure until now:
  8 µm width, 10-15 µm height (in resist)

Material	Spec. electrical resistance [10^{-8} Ωm]
ECD-Al	3,03
PVD-Al	3,44
Bulk Al	2,65

FIB preparation of 30 µm thick Al layer on highly doped Si



EBSD measurement of grain size and grain orientation

Source: ENAS
Work done by Silvia Braun, Imants Cirulis (ENAS)

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ENAS Roadmap (I)

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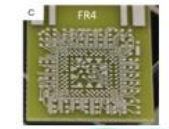
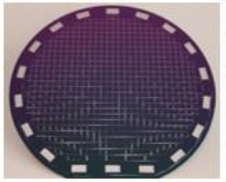
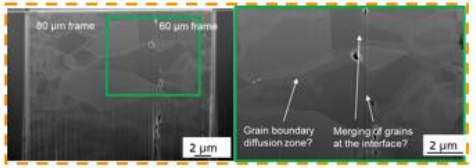
Roadmap for ECD-Al

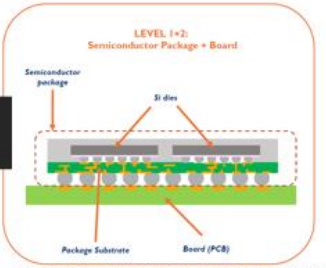




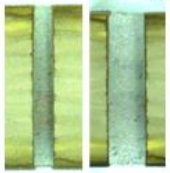


Thermo compression bond with grain diffusion

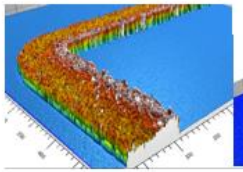
Scheme of different topographies to be coated



source: Yole Report 2017: Status of Advanced Packaging

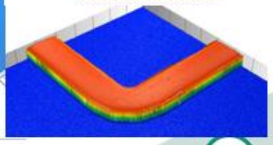


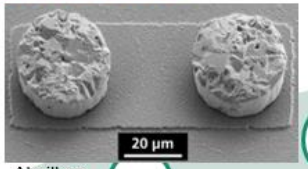
Al in PCBs



Al for wafer bonding

CMP/ electropolishing





Al pillars

Al-TSVs for MEMS applications and hybride wafer bonding with Al

Scaling to 8 inch + development of additives

Advanced Packaging of all components with homogeneous material system of Al

Al-Pillars for Flip Chip assembly resulting in an homogeneous package between MEMS, ASIC and PCB

Al on ceramic, Si, glass etc.

Al coated mulilayer PCBs incl. via technology and soldering on Al surfaces

Investigation of the bonding behavior of ECD-Al in Al-Al-Thermo-compression bonding

Basics of Al-ECD on various substrate evaluated within public funded project

Research ongoing within different projects

Source: ENAS
Work done by Silvia Braun, Imants Cirulis (ENAS)

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ENAS Roadmap (II)

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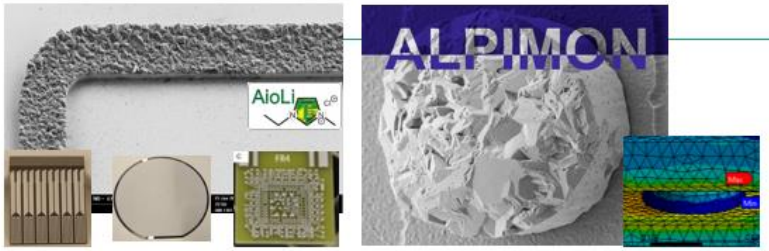
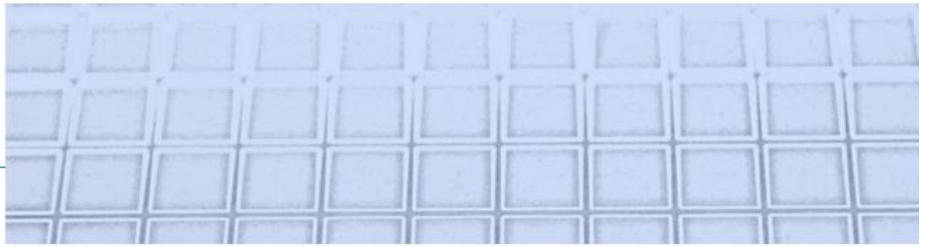
Aluminum ECD
Technology Roadmap





Thick Al layers > 70 µm (power electronics, X-ray, thermal management)

Al-TSV/TGV TBD
Al für TSVs und TGVs

ALMA ZIM
Al-Vias für Leiterplatte

Al-Coat4Industry
Weiterentwicklung der Anlagentechnik hin zu I4.0 (Sensorik, KI, Closed Loop)

ALEKTRO TBD
Fügetechnologien für Al PCB- bzw. Wafersubstrate (DB, Löten, Kleben)

AioLi KMU-Innovativ IKT
Waferlevel-Prozess zur Abscheidung dicker Aluminium-Schichten für die Aufbau- und Verbindungstechnik

ALPIMON SME
Al-Pillar Bondtechnologie

AlPacka (DVS / AiF)
Al- Pillars + Simulation Bonden/ECD

EF ENAS
Untersuchung des ECD-Al für das Al-Al-TKB auf Waferebene

AlLess (EF SP)
E-less Alu zur Seed layer Herstellung

Alox TBD
Al als Viamaterial in der Keramikleiterplatte

2018 2020 2021 2022 2023 2024 2025 2026

Source: ENAS
Work done by Silvia Braun, Imants Cirulis (ENAS)

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History - NBT & Aluminum Plating Tool

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Supported by:

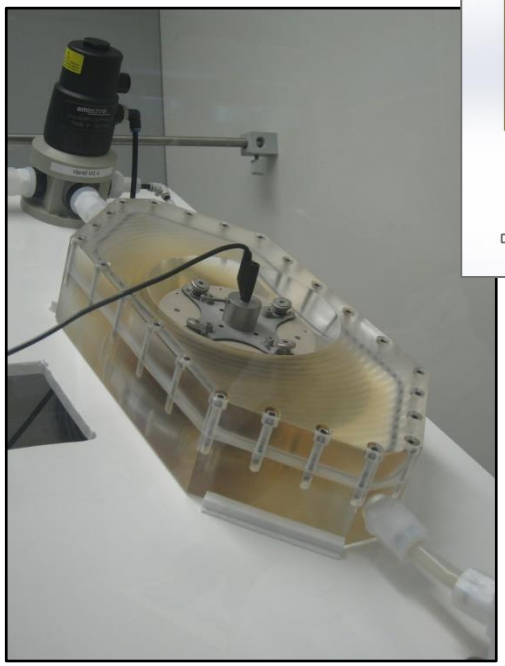
Federal Ministry
for Economic Affairs
and Climate Action

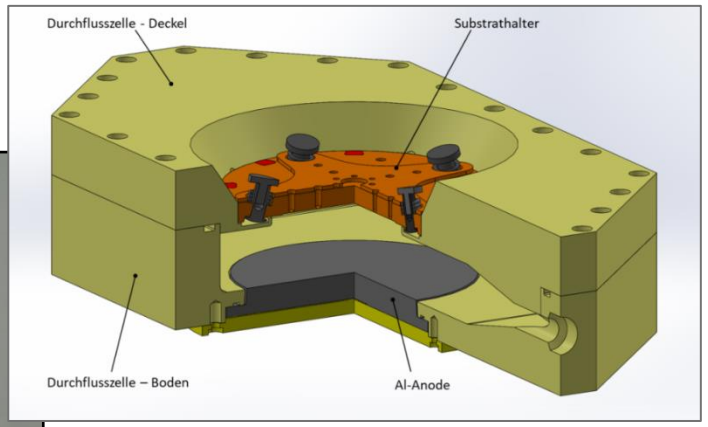
on the basis of a decision
by the German Bundestag

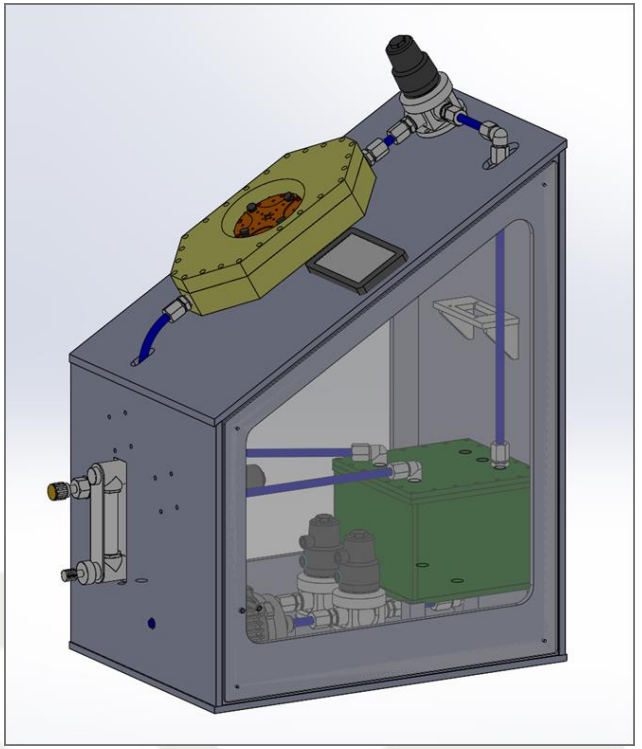
Project AIOLI (BMBF funded project AIOLI (FKZ16ES0331) (finished 2018)

- Motivation: Plating Al for Printed Circuit Boards and semiconductor wafers
- Bench top tool for plating (SFC) on 100 wafer substrate realized

Safe Flow Cell (SFC)







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Present Aluminum Plating Tools (I)

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Project ALMA
(2021 – 2023)
(FKZ KK5092601FF0)

SPONSORED BY THE
Federal Ministry
of Education
and Research

Motivation:

- Plating Al for Printed Circuit Boards
- Realize tooling solution close to commercialisation for replacing Cu in next generation PCB technology
- Status: under construction
  to be finished middle of 2023

Partners:

- NB Technologies GmbH
- Jenaer Leiterplatten GmbH
- Ionic Liquid Technologies GmbH
- ICA Analytik GbR
- Fraunhofer ENAS
- TU Chemnitz

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Present Aluminum Plating Tools (II)

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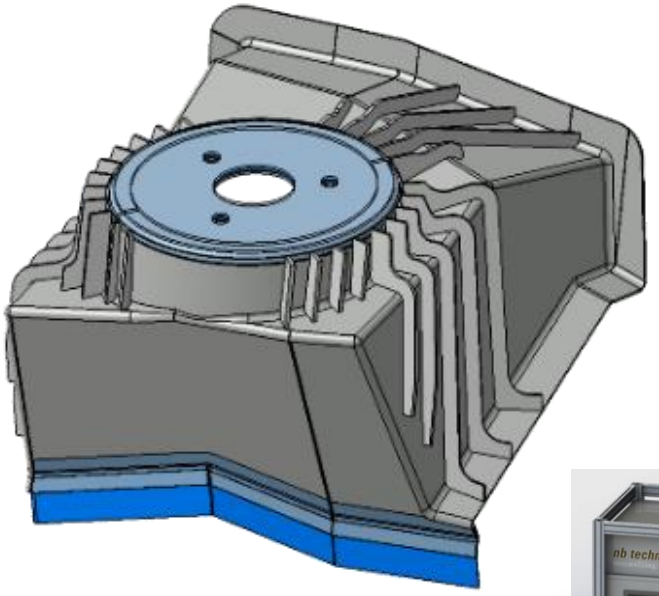
Project CastCo (2022 – 2025)

(FKZ 03LB2046D)

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag



Motivation:

- Plating of AlSi alloys for lightweight diecast components in car bodies
  - CO_2 and weight reduction (process & operation)
- Realize plating tool for reproducible deposition of AlSi for 3D components
- Challenges: 3D, alloy with Si
- Status: under construction, tool to be finished middle of 2024

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Tool overview & main features

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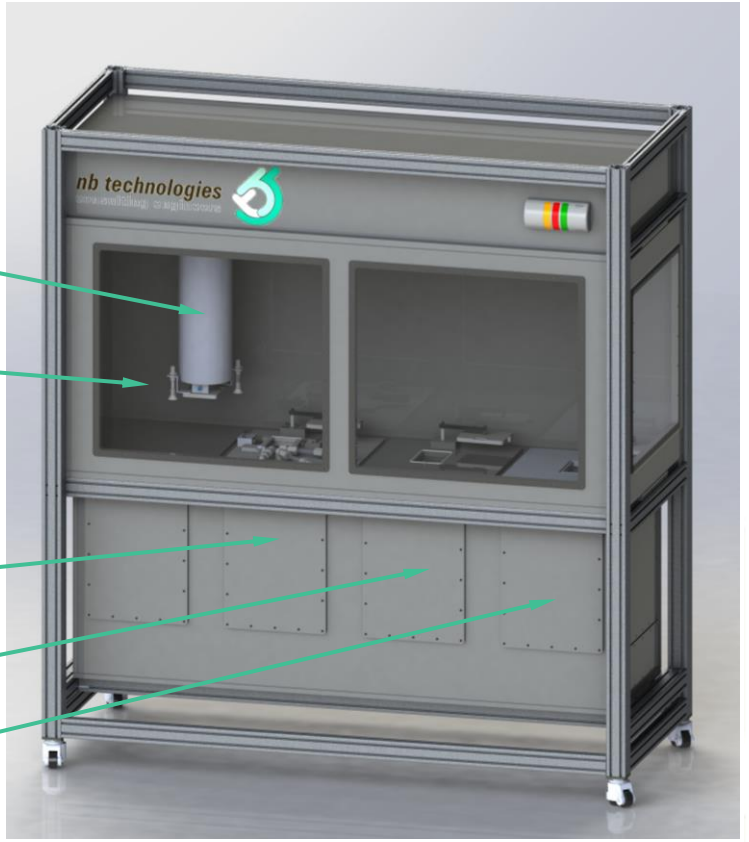
- Double side plating for substrates up to 160mm x 160mm
  - PCB, semiconductor wafer, ceramic, glass
- Controlled atmosphere in handling chamber
  - HCl sensor, humidity sensor (humidity <50ppm)
  - load lock
  - exhaust
- Process chamber for ionic liquid
  - 15 to 20 liters
  - indirect heating up to 50°C
  - circulation & filtration
  - workpiece agitation (x-direction)
- Rinsing chamber (rinsing ionic liquid)
- xz handling system
  - anode extraction handling



Material challenges:

Usable: PTFE, PMMA, PEEK, titanium, glass, PFA

Not usable: stainless steel, PP, PVC, PE, PA, PVDF, FKM, EPDM, FPM, silicone

Tool dimensions & media

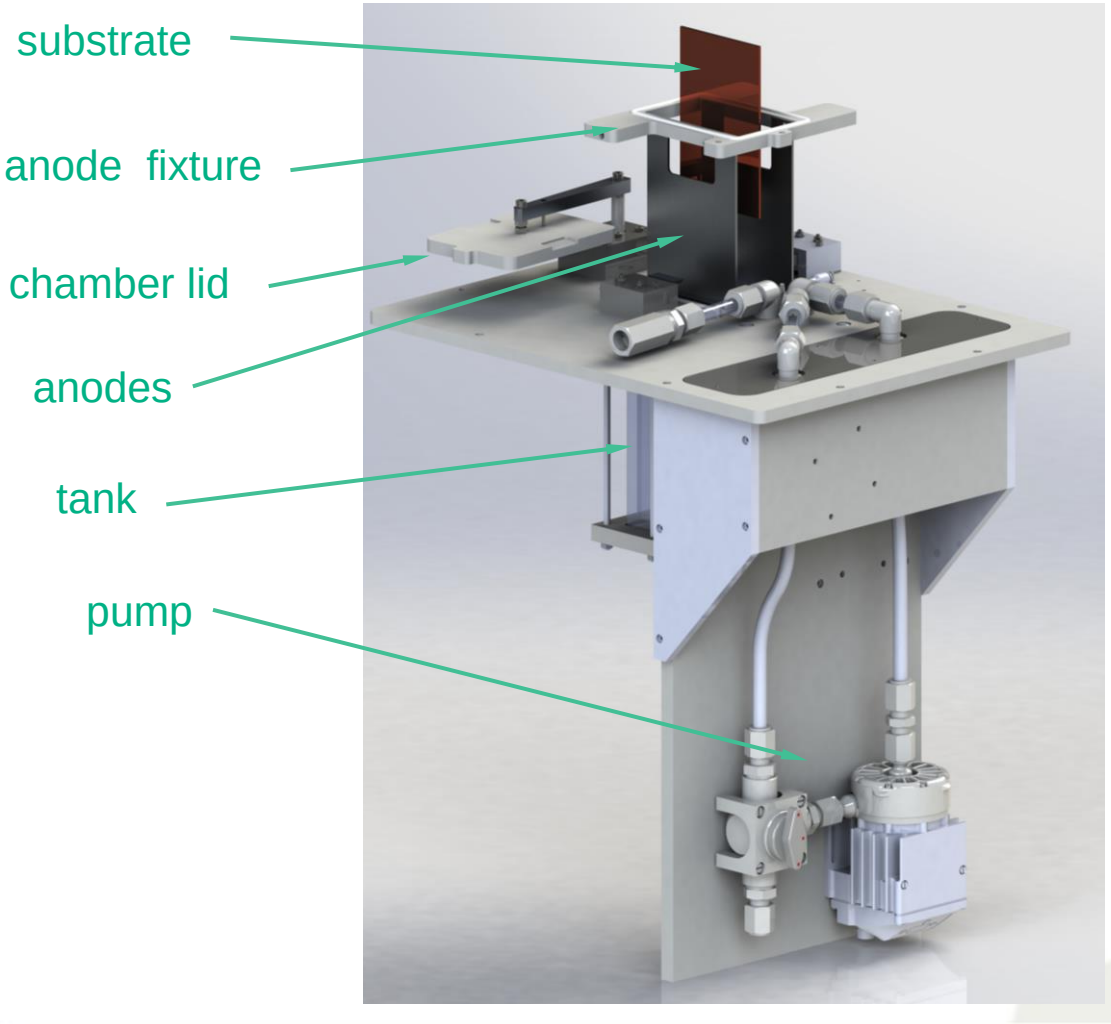
Dimensions

- width: 1,80 m
- height: 1,95 m
- depth: 0,80 m

Media & connections

- power
- compressed air
- nitrogen
- rinse liquid
- waste connection
- fill & drain
- offline analytic tap

Plating process chamber



- Anode fixture/anodes:
  removable by robot in idle time
- Agitation:
  substrate agitation possible
  in x- and z- direction by robot arm
- Lids:
  pneumatic closure
  (extra closure-lid for process
  attached to handling unit)
  (not shown)
- Heating:
  indirect heating by jacket heating
- Circulation pump:
  flow rate electronically controlled
  via rotation rate

xz-handling unit

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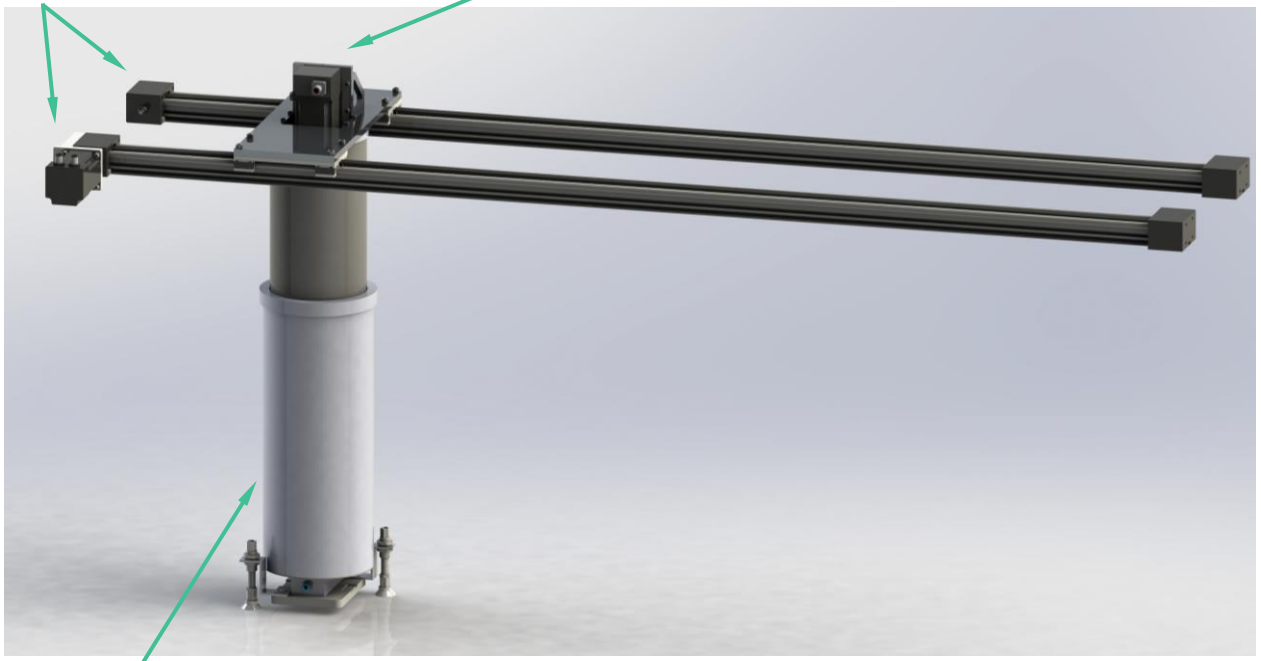
x-axis handling unit

z-axis handling unit



cover for z-axis handling unit

anode extraction unit

lid with substrate holder

Rinsing chamber & load lock

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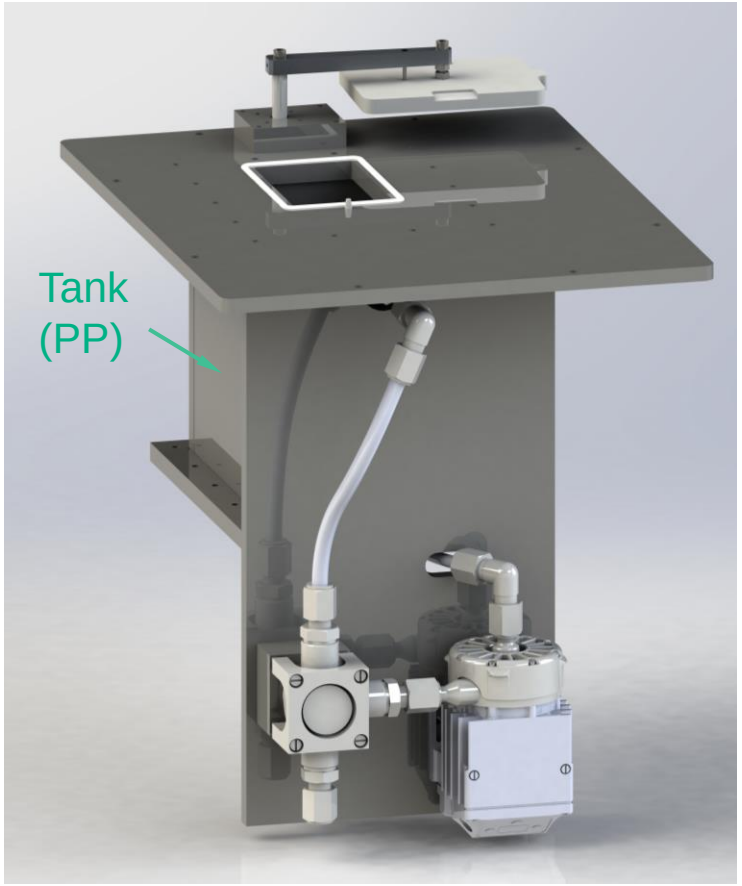
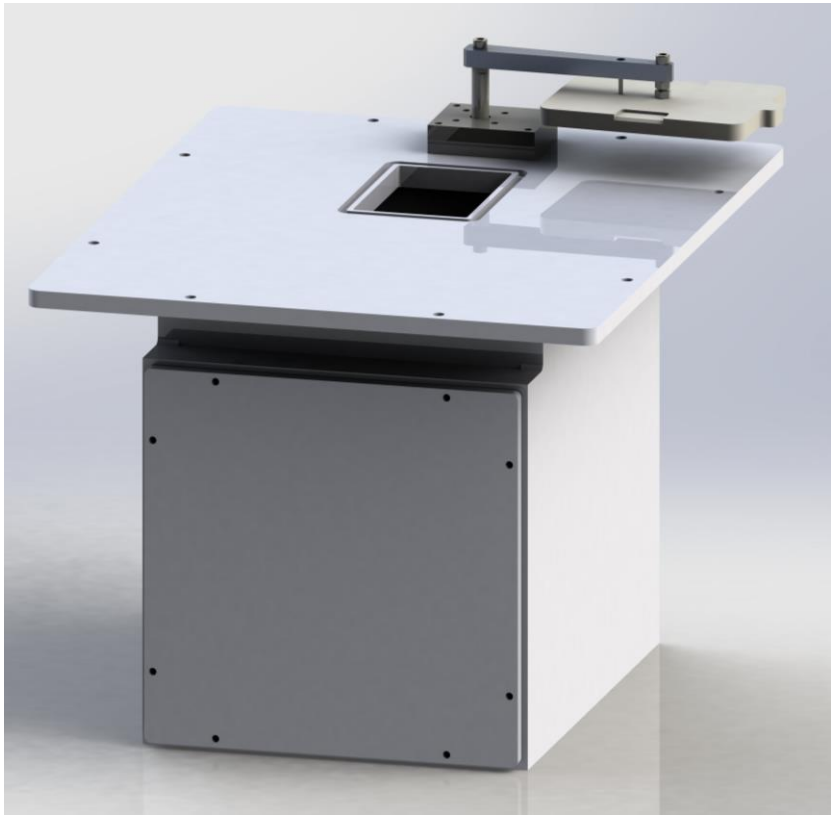
Rinsing chamber



Load lock



Outlook - Aluminum Plating Tool (III)

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Commercialisation - Automated Plating Tool (planned for end of 2024)

Motivation: Provide commercially available solution for R&D and production purpose

- Solve „chicken and egg“ situation
  - Facilitate considerating new technologies and application by involving Al-plating
- Enable introduction of Al plating for market participants
- Enlarge user community

Platform:

- Use existing industry-accepted platform, e.g. ClassOne Soltice® S4
- Extent/modify platform for Al-plating features
- **Fully automated, dry in / dry out**

Status: Design phase
(available for end of 2024)

ClassOne Soltice® S4

(source https://classone.com/plating-surface-preparation-systems/solstice-s4solstice-s4-automated-electroplating-systems/)

NBT Equipment Roadmap

nb technologies
consulting engineers

Continuous advancements of equipment
up to production capabilities

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

SPONSORED BY THE
Federal Ministry of Education and Research

AioLi
Al for packaging

basic manual lab tool
flow cell
wafer level plating

ALMA
Al-Vias for PCB

IL analytics (ICA GbR)
tool enhancements
semi-automation

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

CastCo
AlSi alloy for diecast

alloy plating
advanced handling & rinsing
(substrate / IL / atmosphere)
IL recycling (IOLITEC)

„Almight one“
Al plating for wafer

200mm substrates
fully automated
dry in / dry out

„Almight 3D“
AlSi plating for diecast

AlSi plating for 3D components

2018 2021 2022 2023 2024 2025 2026 2027