37th Chemnitz Seminar
»Electronic Packaging and Applications«

Latest Progress of Plating Equipment for
Al plating from ionic liquids

Chemnitz
14.06.2023
Outline

- NBT introduction
- ENAS / NBT history of cooperation
- Motivation / applications
- Status of Al plating at ENAS / NBT
- Status of tooling solutions
- Roadmap
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

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

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

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

Your Vision – Our Mission!

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

- 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

Source: ENAS
Work done by Silvia Braun, Imants Cirulis (ENAS)
Basics of Al-ECD from ionic liquids

- $E_{\text{Al}}^0 = -1.67 \text{ V vs. NHE} \rightarrow \text{deposition from aqueous solutions is not possible}$
  - Ionic liquids (ILs) are used
- ILs = organic salts with a melting temperature $< 100 \degree \text{C}$
  - Properties are tunable by varying the composition
  - Wide electrochemical window
- Use of EMIImCl/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

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

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)

<table>
<thead>
<tr>
<th>Material</th>
<th>Spec. electrical resistance [10^-6 Ωm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECD-Al</td>
<td>3.03</td>
</tr>
<tr>
<td>PVD-Al</td>
<td>3.44</td>
</tr>
<tr>
<td>Bulk Al</td>
<td>2.65</td>
</tr>
</tbody>
</table>

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

EBSD measurement of grain size and grain orientation

FIB preparation of 30 µm thick Al layer on highly doped Si
ENAS Roadmap (I)

Roadmap for ECD-AI

- Basics of Al-ECD on various substrates evaluated within public funded project
- Al coated multilayer PCBs incl. via technology and soldering on Al surfaces
- Investigation of the bonding behavior of ECD-Al in Al-Al-Thermo-compression bonding
- Thermo-compression bond with grain diffusion
- CMP/electropolishing
- AI pillars
- AI pillars for Flip Chip assembly resulting in an homogeneous package between MEMS, ASIC and PCB
- Scaling to 8 inch + development of additives
- AI-TSVs for MEMS applications and hybrid wafer bonding with Al

Advanced Packaging of all components with homogeneous material system of Al

Research ongoing within different projects
ENAS Roadmap (II)

Aluminum ECD
Technology Roadmap

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

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

AlMA ZIM
Al-Vias für Leiterplatte

ALPIMON SME
Al-Piller Bondtechnologie

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

AiCoat4Industry
Weiterentwicklung der Anlagentechnik hin zu 4.0 (Sensorik, KI, Closed Loop)

AIPacka (DVS / AiE)
Al-Pillars + Simulation Bonden/ECD

AI-TSV/TGV TBD
AI für TSVs und TGVs

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

2015 2020 2021 2022 2023 2024 2025 2026

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

Source: ENAS
Work done by Silvia Braun, Imants Cirulis (ENAS)
History - NBT & Aluminum Plating Tool

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)
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
Project CastCo (2022 – 2025) (FKZ 03LB2046D)

Motivation:
- Plating of AlSi alloys for lightweight diecast components in car bodies
  - CO₂ 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
Tool overview & main features

- 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

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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
Rinsing chamber & load lock

Rinsing chamber

Load lock

Tank (PP)
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 considering 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)

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

Continuous advancements of equipment up to production capabilities

AioLi
AI for packaging
basic manual lab tool
flow cell
wafer level plating

ALMA
Al-Vias for PCB
IL analytics (ICA GbR)
tool enhancements
semi-automation

CastCo
AISi alloy for diecast
alloy plating
advanced handling & rinsing
(substrate / IL / atmosphere)
IL recycling (IOLITEC)

„Almight one“
AI plating for wafer
200mm substrates
continuously automated
dry in / dry out

„Almight 3D“
AISi plating for diecast
AISi plating for 3D
components

2018  2021  2022  2023  2024  2025  2026  2027