Spherolyte® Cu UF 5

Next generation copper pillar plating

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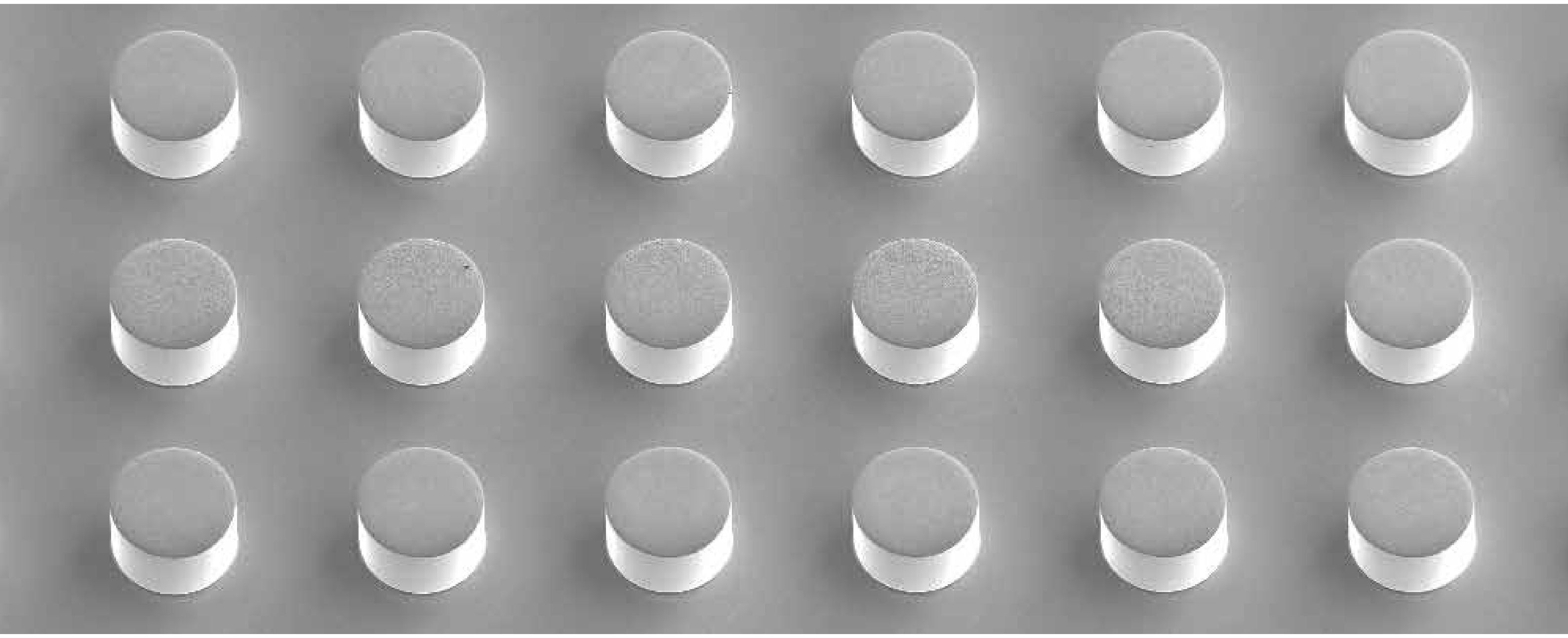

Pure and uniform copper deposits at high deposition speed

High speed pillar plating for advanced packaging

Advanced packaging technologies using copper pillars have emerged as enablers of further miniaturization and enhanced performance. Driven by the increasing demand for faster and better performance, the industry is focused on technologies that provide higher throughput, exceptional reliability performance, and optimal yield. Atotech's Spherolyte® Cu UF 5 process satisfies these requirements with pure and uniform Cu pillar deposits at high deposition speed.

The process is designed for standard pillars for flip chip application as well as new technological requirements such as mega pillar (tall pillar) plating.

Features and benefits

- Purest copper deposit due to lower additive incorporation
- Excellent non-uniformity of < 5% at high speed plating
- Elimination of Ni diffusion barrier
- Excellent adjustable profile shape
- Fully analyzable additive system
- High speed plating capability up to 25 ASD

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Spherolyte® Cu UF 5 – Next generation copper pillar plating

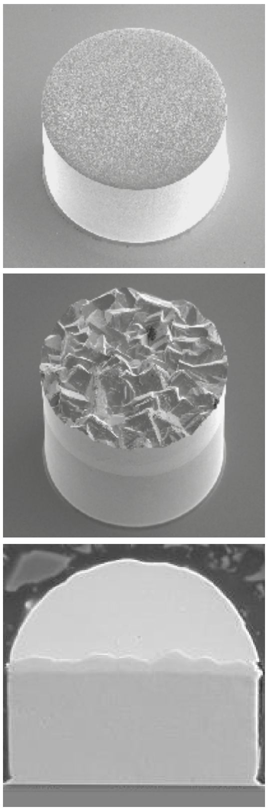

Figure 1-3:
Cu pillar 1) before and 2) after SnAg deposition; 3) cross section of Cu/ SnAg pillar after remelting.

Highest purity, void free copper deposition without a nickel diffusion barrier

The primary feature of the Spherolyte® Cu UF 5 process is the pure copper deposition, which is achieved through a lower incorporation of organic impurities of the additive system. Impurities (e.g. S, Cl) are found to be vastly below impurities of similar processes. Pure copper leads to lower void formation at the intermetallic phase after high temperature storage, and enables the elimination of the nickel-plating step, which is typically used as diffusion barrier to prohibit migration and voiding.

Excellent profile shape – adjustable via additive settings

Spherolyte® Cu UF 5 is designed to meet the toughest uniformity requirements at highest plating speed. It shows excellent coplanarity at high-speed plating conditions (< 5% within profile NU).
Additionally, the pillar shape can be adjusted through plating parameters to either flat, concave or convex surface structures – whichever you like and need.

Adjustable shape via additive control

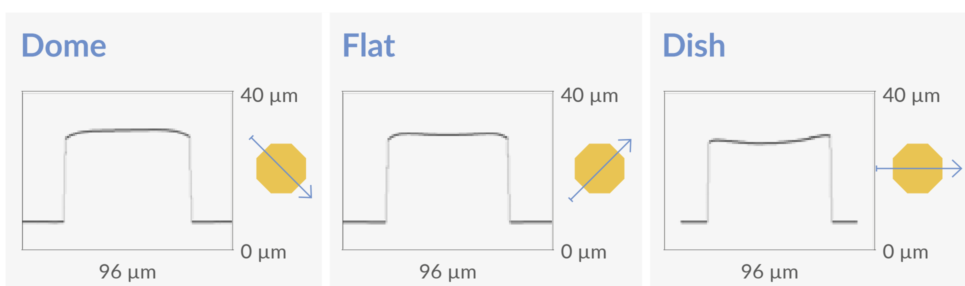

Figure 4-6:
Confocal measurements of 1) dome-shaped 2) flat and 3) dish-shaped Cu pillars.

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Spherolyte® Cu UF 3

Next generation RDL plating

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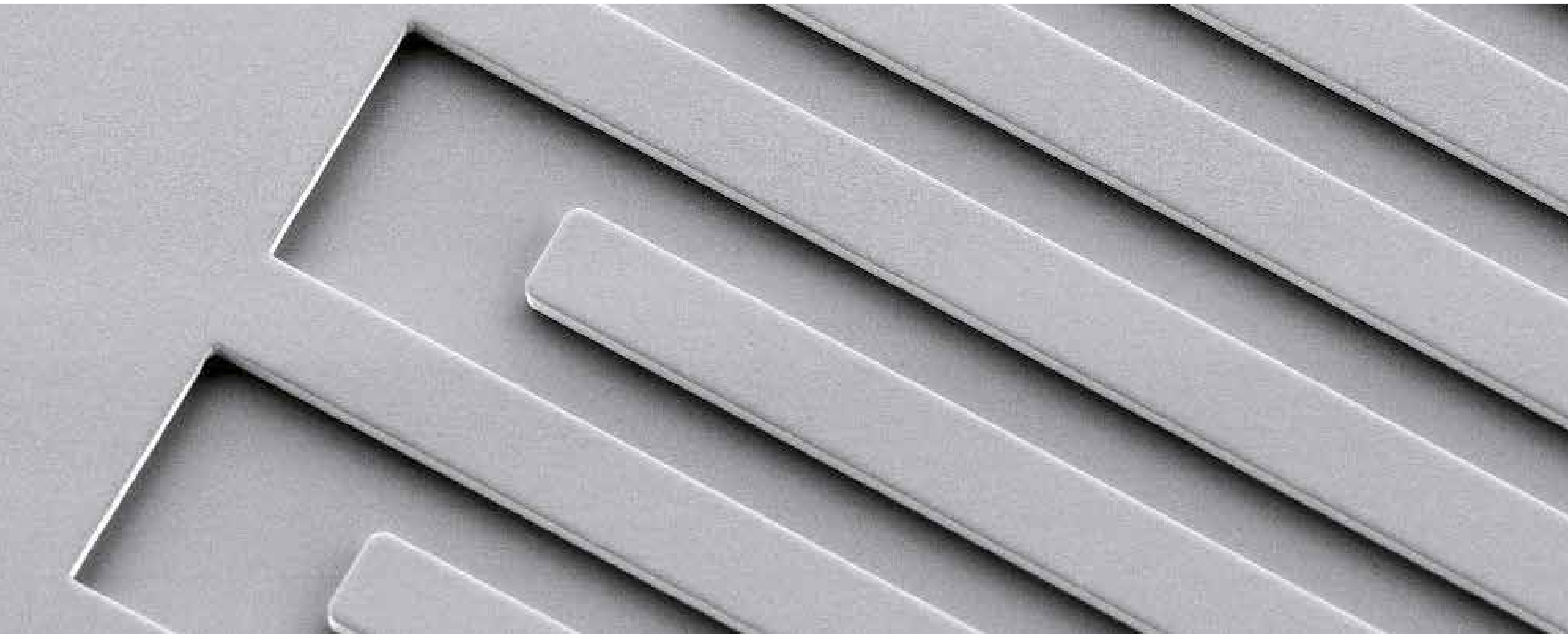

Cu RDL process for fine line plating and microvia filling

< 10 ppm

lowest impurity incorporation as measured by D-SIMS

29%

ductility

Best in class reliability performance for next generation RDL

Next generation packaging technologies such as heterogeneous integration involves the assembly of separately manufactured components and requires the combination of a broad variety of different materials with different characteristics.

Redistribution layers consisting of copper conductor lines and organic dielectric are key components of a variety of technologies to connect the various functional components. In order to improve the reliability of such assembly, the mechanical properties of the individual materials need to be optimized. In particular, fan out wafer level packaging with decreasing lines and spaces requires a pure copper deposition to achieve a high reliability.

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Spherolyte® Cu UF 3
for next generation RDL and microvia plating

Figure 1:
Plating fine lines and Cu pads
Figure 2:
Microvia filling CD ≤ 20µm

High purity and ductility

In a package, thermal expansion is mainly dominated by die and mold, which creates a high strain on thin Cu lines. In order to compensate this high strain, a high material ductility is beneficial to allow a significant plastic deformation before rupture. Investigation shows that a high Cu purity leads to such an improved ductility. Our Spherolyte® Cu UF 3 process use of high purity chemistries significantly reduces the level of additive incorporation and minimizes the risk of microvoid formations that amass after thermal cycle testing and may lead to failures or breakages in the Cu lines.

Via filling capability

Spherolyte® Cu UF 3 is a high purity ECD process that enables stable and optimal mechanical properties within a wide process window. The three additive system is designed for plating sub 5 µm lines and large Cu pads, while simultaneously enabling via filling. The combination of both features exactly addresses the future requirements of FOWLP technology.

Features and benefits

- Single process for both fine line plating and microvia filling
- Low incorporation level of additives, enabling high purity Cu deposit
- Low internal stress: 20 MPa
- High tensile strength: 29,4 kN/cm^2
- Reduction in fine line cracking after thermal treatment

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Promobond® AP 2

Adhesion promoter

Electronics

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Adhesion promoter for next generation packaging

Up to 4.7x

shear force improvement with various components

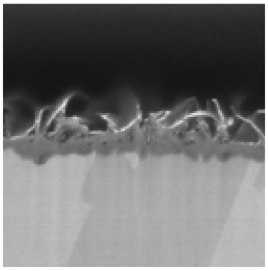

Figure 1:
Microcope FIB cross-section of Promobond® AP 2 treated Cu surface

Cu-mold / PI adhesion strongly determines the device reliability

Next generation heterogeneous integration in packaging processes requires the combination of a variety of different materials with different coefficients of thermal expansion (CTE).
In a package, thermal expansion is mainly dominated by die and mold, which creates a high strain on thin RDL Cu lines. Temperature changes hence lead to increased stress due to different thermal expansion of the materials and thus to potential Cu RDL fractures. This effect is increased with ever smaller Cu lines. To minimize the risk of yield reduction (e.g., via uncontrolled oxidation), the Cu deposits need to be protected against external influences. Additionally, the device reliability can be increased by improving the Cu-mold/PI adhesion respectively the Cu ductility.
For pillars, the adhesion of the mold material to the Cu surface is crucial to avoid gap formation. A good ductility and adhesion of mold/PI to the Cu surface therefore has a significant influence on the overall performance and reliability.

Promobond® AP 2 significantly increases the adhesion between Cu and mold/ PI

Promobond® AP 2 is Atotech's next generation adhesion promoter for mold/PI material on copper. It significantly increases the reliability of Cu RDL/pillar structures due to the controlled and self-limiting formation of dense oxides. This ensures good ductility of the PI/Cu or mold/Cu due to composite formation and leads to better mechanical properties of the resulting structures. The possibility of batch processing additionally allows cost efficient processing.

Quickfacts about Promobond® AP 2

- Adhesion promoter for mold/PI material on Cu
- Increased reliabilities
- Possibility of batch processing ensures cost efficient processing

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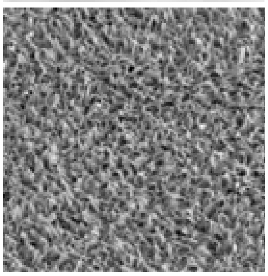
Promobond® AP 2 –
Increased adhesion between Cu and mold/PI



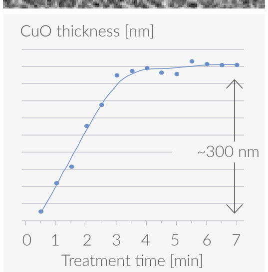


Figure 2: TEM image

Figure 3: SEM – top view of Promobond® AP 2 treated Cu surfaces

Figure 4: CuO thickness is tailorable via process conditions

Needle structures increase adhesion by Cu /polymer composite formation

With the application of Promobond® AP 2 needle-like Cu oxide structures are formed on the Cu surface. These needles allow the formation of Cu-polymer composites and hence significantly increase the adhesion of the polymer (e.g., mold, PI) and the underlying Cu layer resulting in higher ductility.

Controlled, self-limiting oxide formation prevents uncontrolled oxidation

Uncontrolled oxide growth can be caused by diffusion of oxygen through PI material. This can significantly decrease the device reliability and is often visible when performing reliability tests. Promobond® AP 2 leads to the controlled and self-limiting formation of oxides on the Cu surface before the mold/PI application and hence successfully prevents further uncontrolled oxidation. The Promobond® AP 2 application hence leads to significantly increased device reliabilities.

Additional features and benefits

- Ensures good ductility of the mold/Cu combination
- Minimal required exposure time
- Excellent mechanical properties of Cu RDL and increased reliability
- Possibility of batch processing ensures cost efficient processing

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Xenolyte® Au TG

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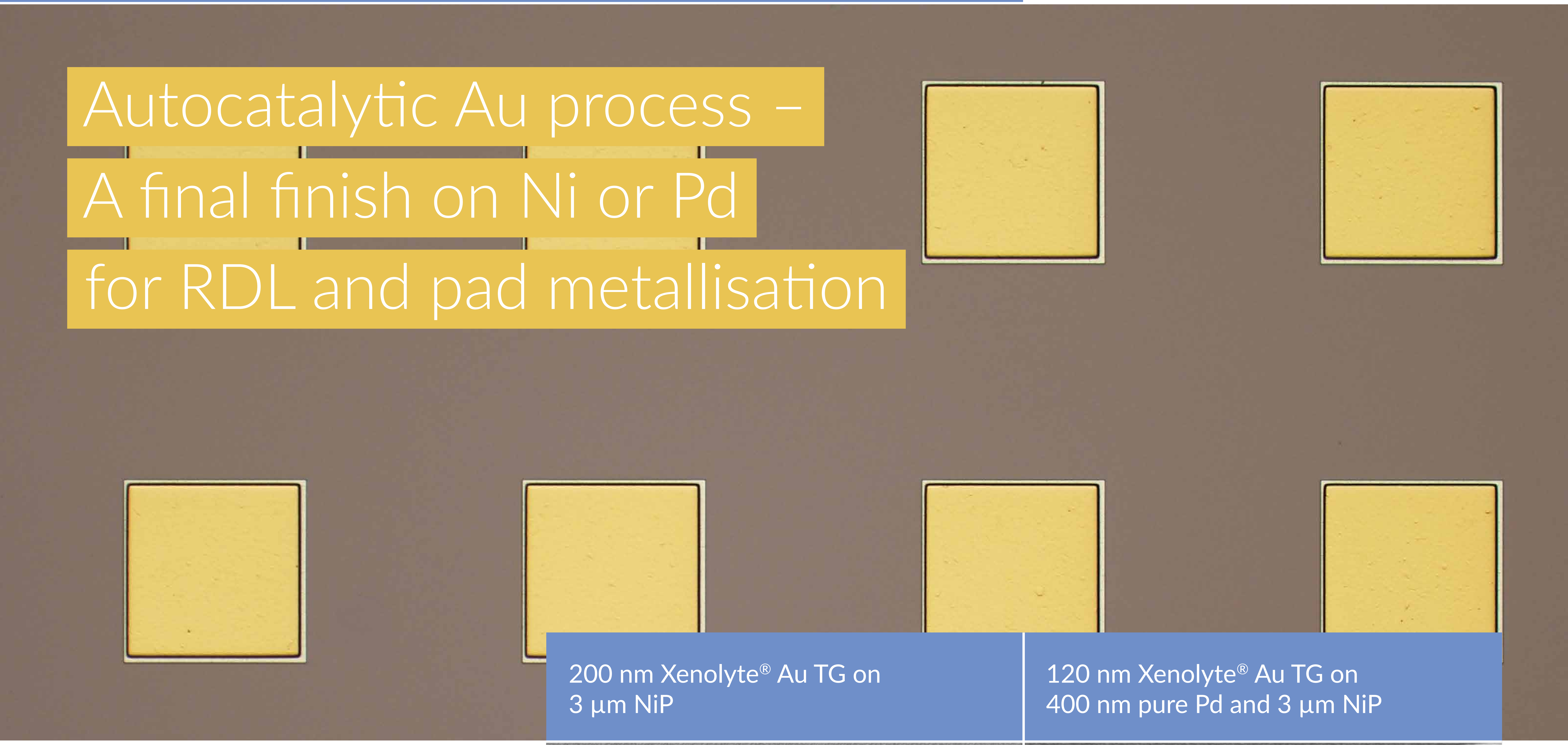
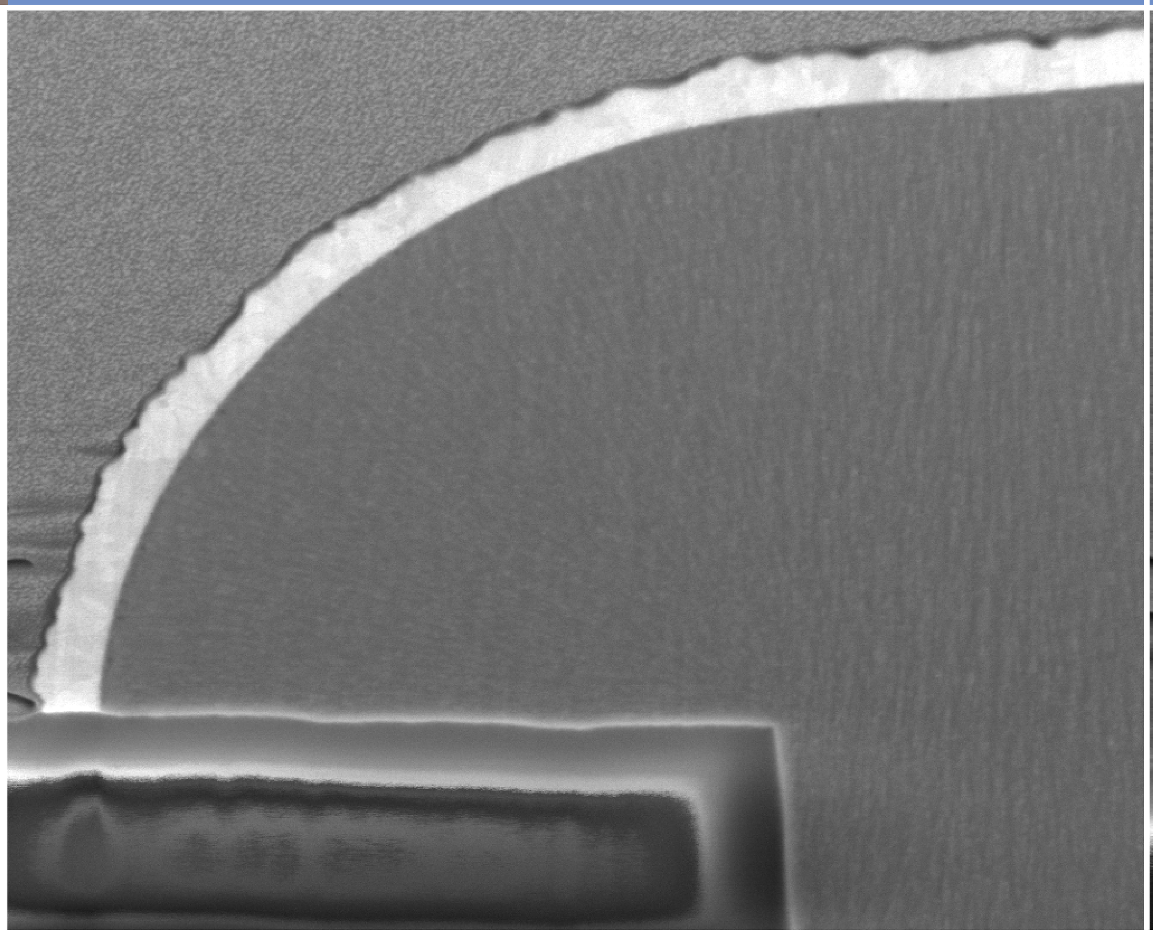
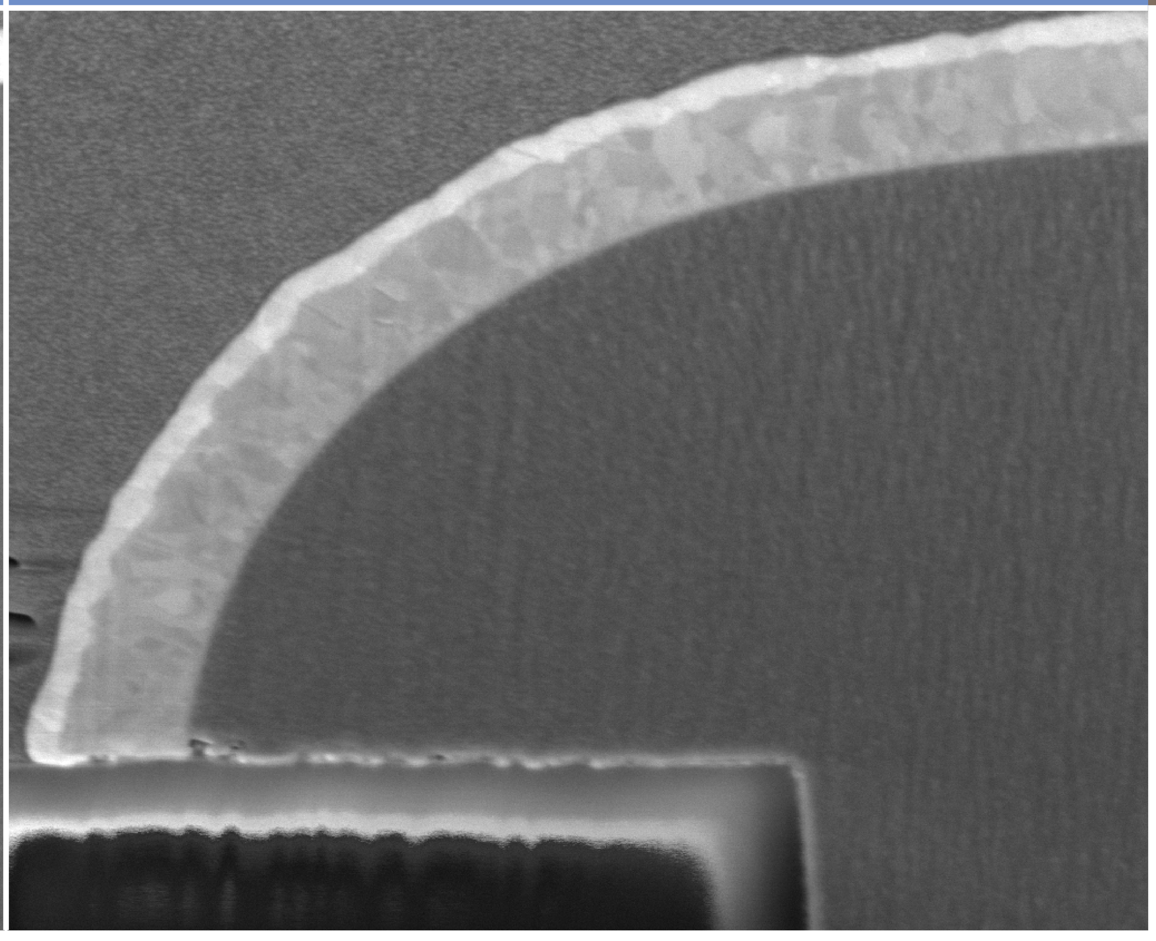


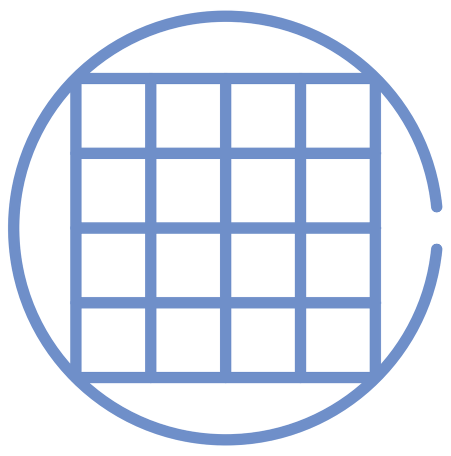
Autocatalytic Au process – A final finish on Ni or Pd for RDL and pad metallisation

200 nm Xenolyte® Au TG on 3 µm NiP

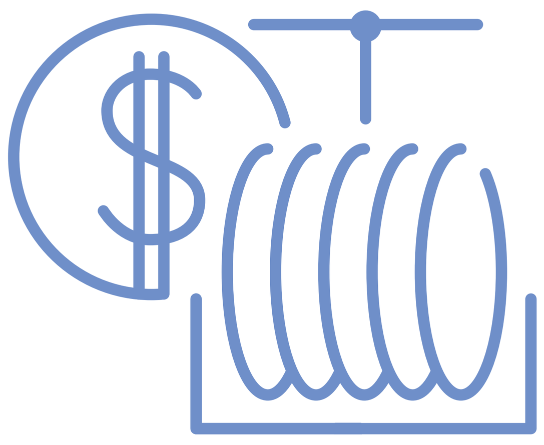


120 nm Xenolyte® Au TG on 400 nm pure Pd and 3 µm NiP





One step autocatalytic Au process for thick Au deposits



Compatible with batch processing in wet bench

Autocatalytic Au for automotive and power IC customers

Our pure autocatalytic Au process Xenolyte® Au TG is the perfect addition to our electroless RDL and pad metallization portfolio. It provides thick and pure gold deposits on electroless nickel and palladium layers. The deposition of thick Au layers from Xenolyte® Au TG does not require an immersion Au strike step and thus reduces corrosion of underlying metal layers to a minimum.

Features and benefits

- Pure gold deposits
- No immersion Au prestrike step required
- Deposition rates between 5-15 nm/min
- Extended bath lifetime
- Applicable to electroless Ni and Pd layers
- Suitable for soldering and wire bonding applications

Xenolyte® Ni TR

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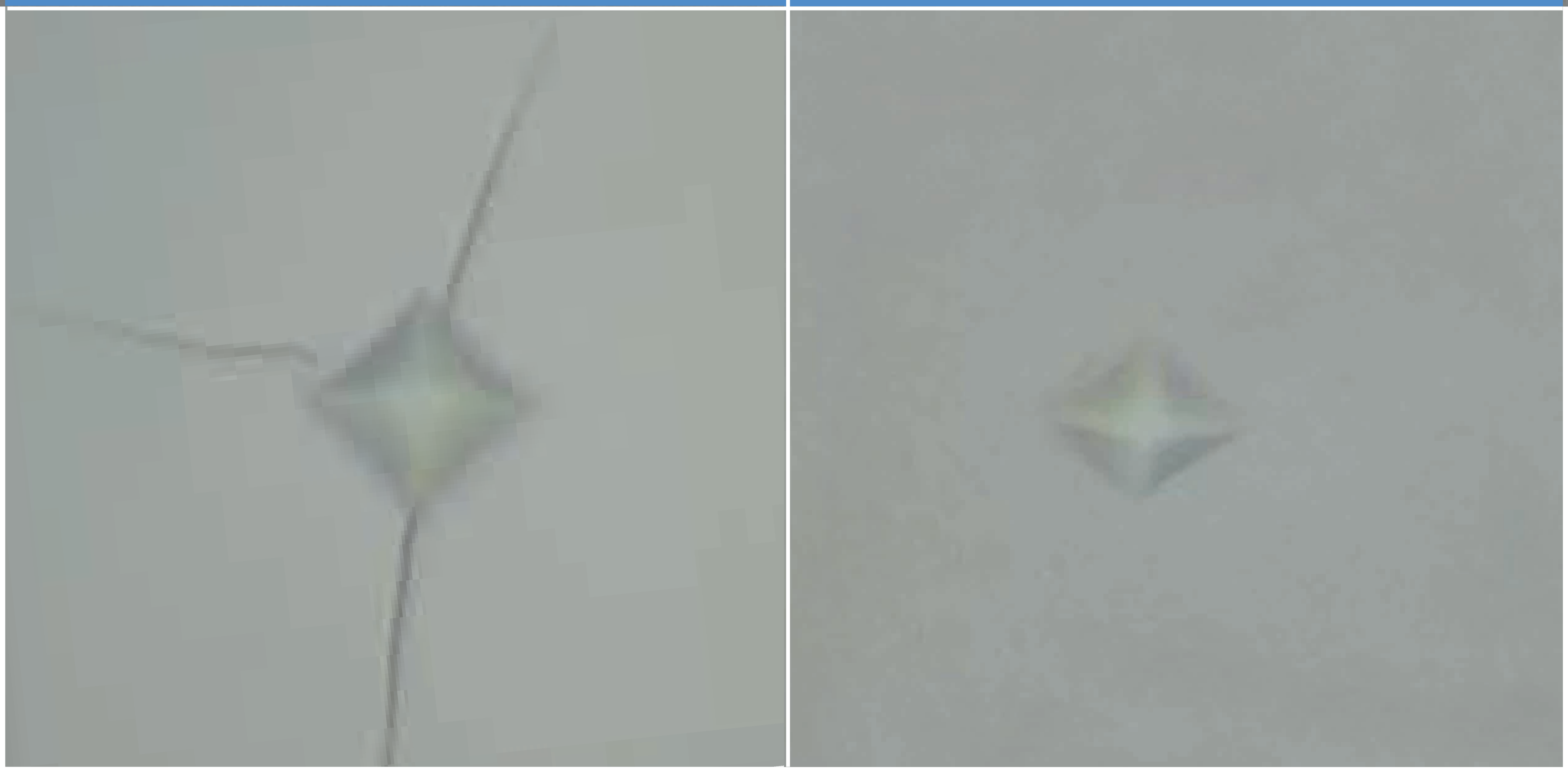
High temperature resistant Ni for RDL and pad metallization

Fracture toughness (indenter test after 10 min at 400 °C)

Deposits from standard binary Ni systems show a tendency for cracking after treatment	Deposits from Xenolyte® Ni TR show no crack formation after thermal treatment



up to

450 °C

treatment possible without any cracks

Reduced stress for Taiko wafer processing

Capable for batch processing in wet bench

Stable process for automotive and power IC customers

Our electroless Xenolyte® Ni TR process is part of the ENEPIG/ENIG RDL and pad metallization portfolio and perfectly addresses the requirements of growing automotive and power industry. The Nickel deposits from Xenolte® Ni TR withstand even high temperature budgets of up to 450 °C during chip processing.

Features and benefits

- Electroless deposition of ternary Ni
- Reduced stress for Taiko wafer processing
- Crystalline deposition
- No cracks over wide temperature range (up to 450 °C)
- Lower resistivity compared to binary systems
- High fracture toughness

Xenolyte® Pd HS

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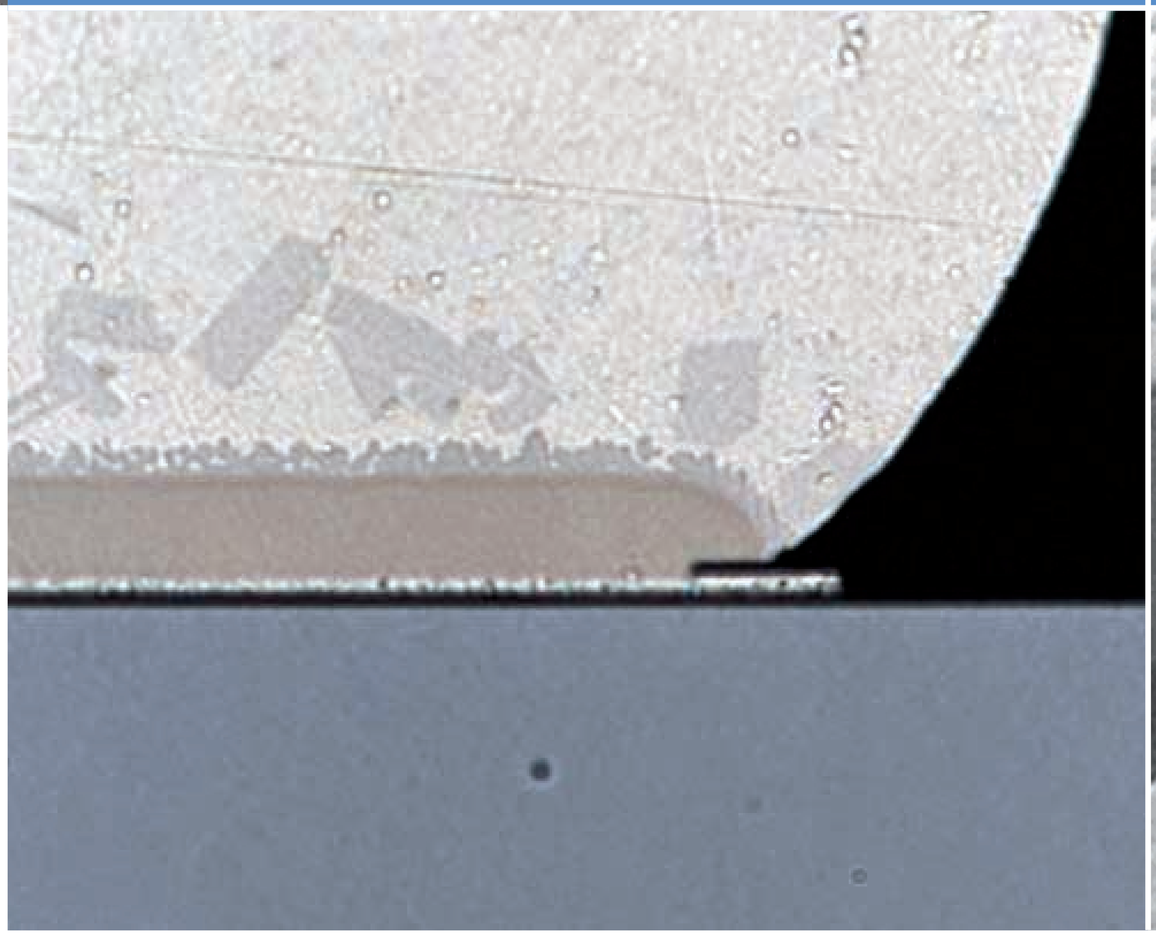
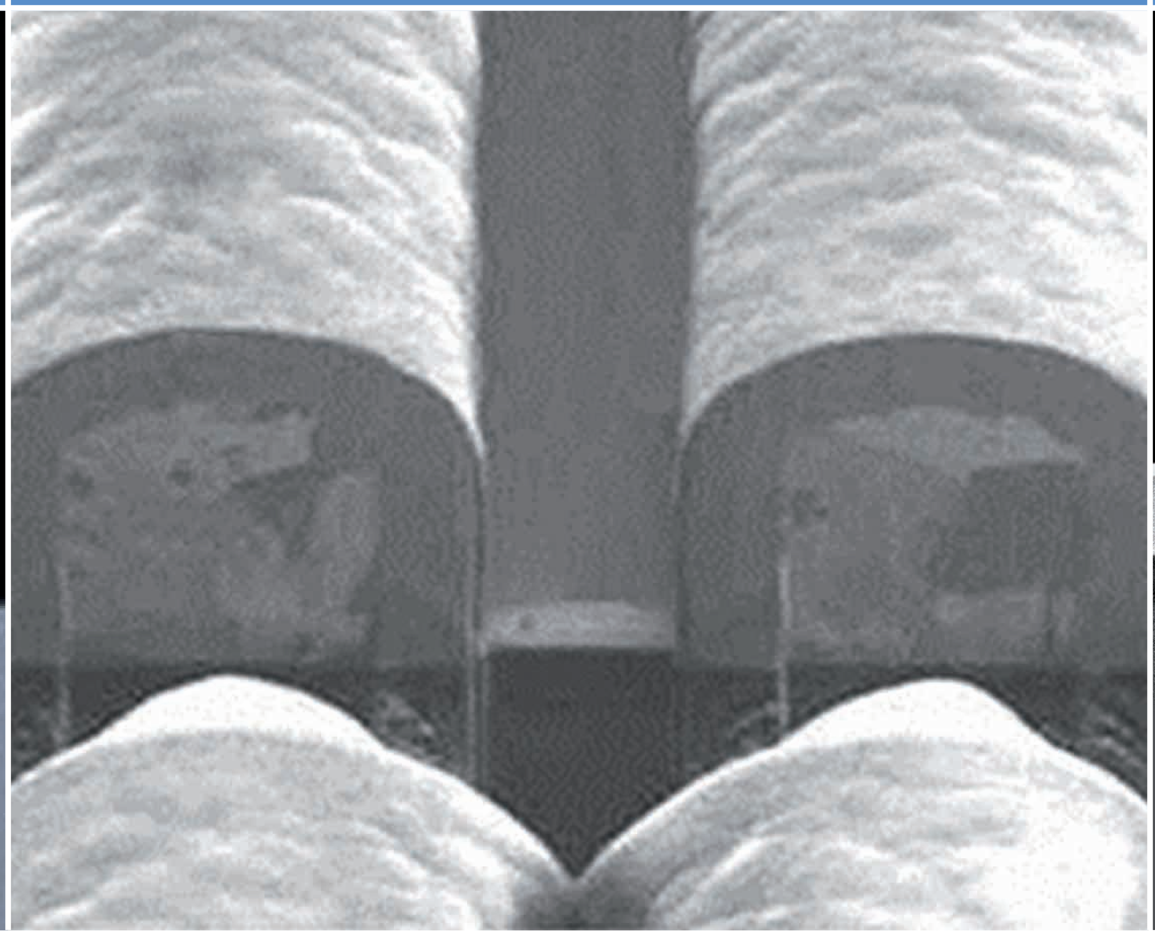
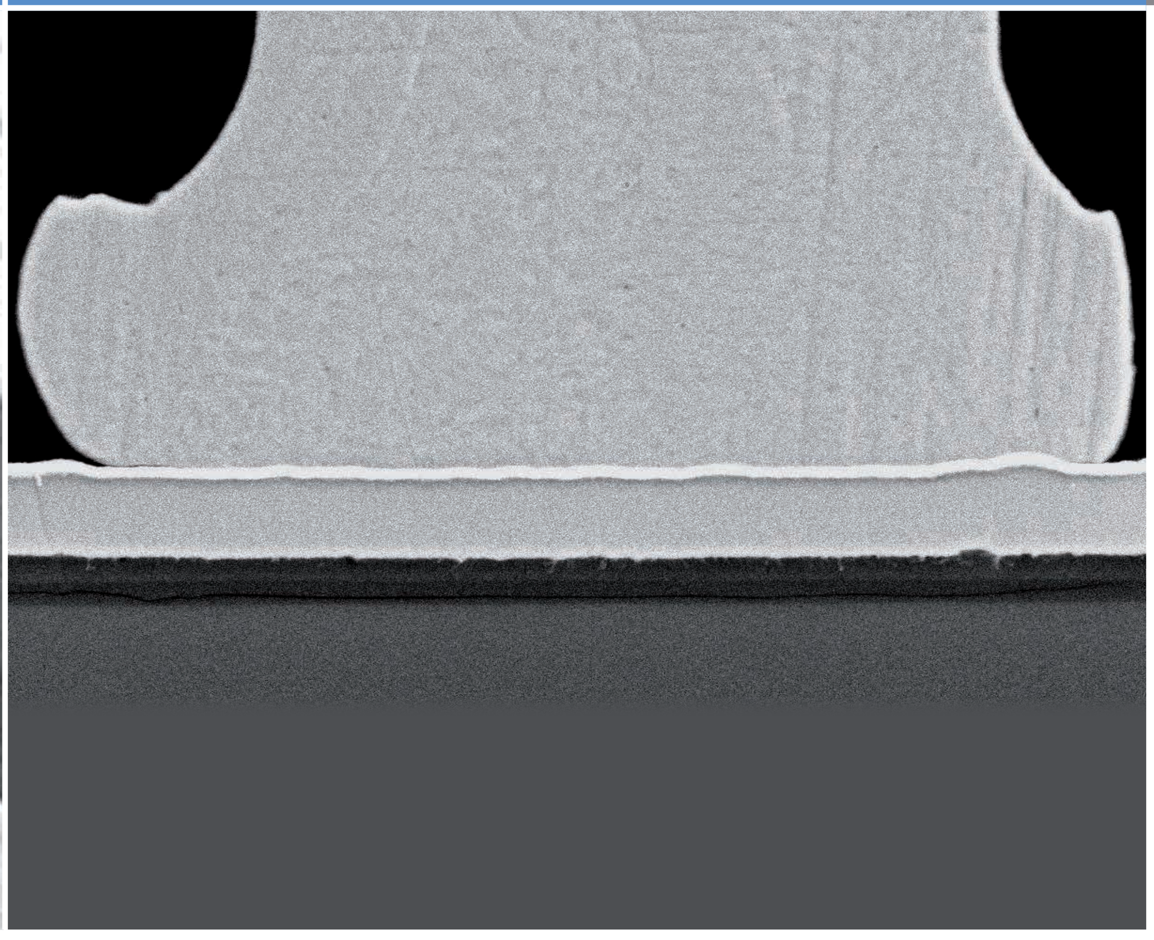
Pure Pd deposits for high reliability pad metallization and RDL housing

Soldering	RDL housing	Wire bonding







Significant cost savings due to high lifetime

Pure

Pd

for high reliability in power application

High process reliability and stability

Our electroless Xenolyte® Pd portfolio, as part of the ENEPIG/ENIG pad metallization process, perfectly addresses the requirements of growing automotive and power industry. Our process uses pure Pd to ensure high reliability and stress-reduced deposits with an excellent process stability.

Features and benefits

- Qualified according to automotive spec AEC-Q100-010 RE
- 0.04 – 0.06 µm/min
- Low temperature process at 55 -60°C
- No P Co-deposition
- Improved solder wetting
- Larger process window for wire bonding

Approaches towards copper-copper direct bonding: Bond formation by Cu grain growth over the interface or nano twinned Cu

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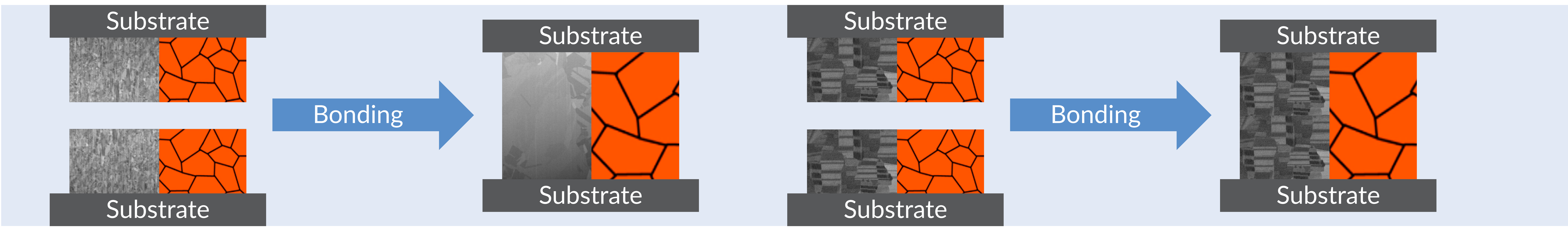
Compatibility of electrolytic copper deposition to hybrid bonding process flow

Hybrid bonding with direct copper-to-copper interconnects constitutes a promising technology for stacking of components in high interconnect density packages. While extensive research focused on the optimization of the CMP and oxide-to-oxide bonding process steps, little attention was given to the adjustment of the copper electrodeposition process.

This work emphasizes the potential of copper electrodeposition processes for the optimization and proper adjustment to the hybrid bonding process sequence and discusses our work towards enabling future Cu-Cu direct bonding processes.

a) Bond formation by Cu grain growth over the interface | **b) Bond formation by nano twinned Cu**

Illustration



Properties

a)
+ Bond formation at low temperatures (≤ 200 °C)
  → High purity Cu
+ Good mechanical properties (ductility)
+ Good electromigration performance
+ Compatible to via filling requirements
+ Smooth surfaces
- Time critical due to self annealing

b)
+ Bond formation at low temperatures (≤ 200 °C)
  → High Cu adatom surface diffusion speed
+ Good mechanical properties (tensile strength)
+ Good electromigration performance
+ Little limitations regarding Q time between plating and bonding
- Rough surfaces
- Filling is difficult to achieve

Scheme 1. Schematic representation of interface formation **a)** in case of grain growth during copper-to-copper bonding and **b)** growth over the interface in case of grain growth during bonding and corresponding advantages.

Atotech is working on the next solutions for Cu-Cu bonding

The behavior of the Cu deposits can be tuned, e.g., as a function of the co-deposited impurities and the initial microstructure. Both, purity and microstructure usually depend on the electrochemical characteristics of the plating additives and the process parameters. By purposefully changing the post-processing behavior of the initially formed layer after deposition and throughout subsequent processes (e.g., CMP), the formation of the final microstructure and properties of the deposits may be directed to a post-processing step at elevated temperatures.

Optimization of the annealing temperature

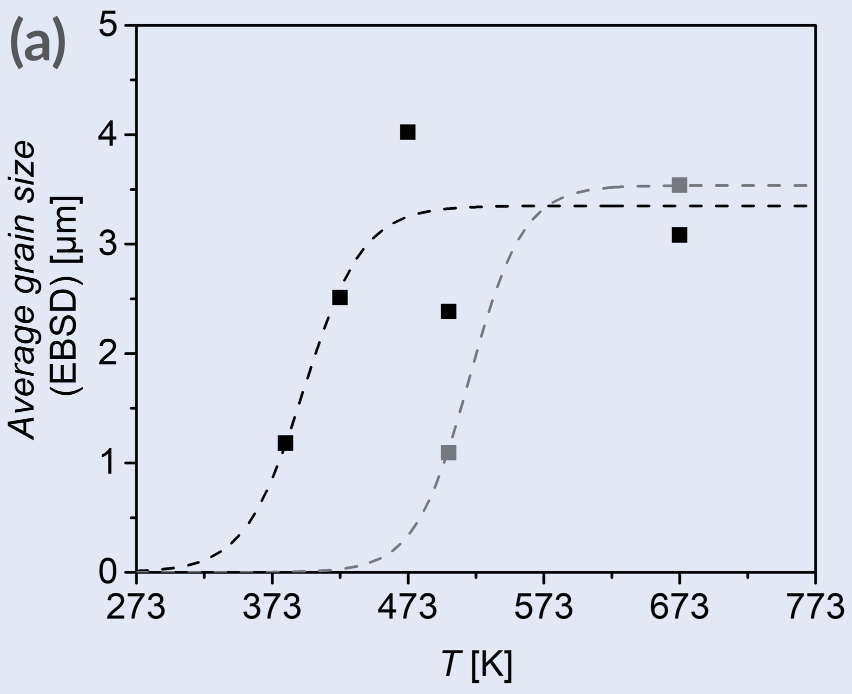
The annealing temperature of Cu deposits may be modified by co-deposition of impurities. The impurities in the Cu layer depend on the composition of the electrolyte. Cu with higher impurities requires higher crystallization temperatures.

System	Total impurities[a]	T_c[b]
Electrolyte 1	2694 ppm	153 °C
Electrolyte 2	55 ppm	115 °C

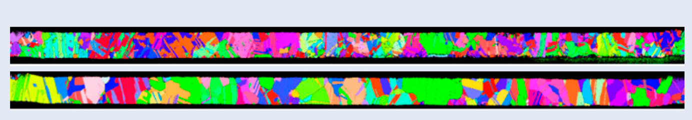
[a] Determined by DSIMS, [b] Determined by DSC

Table 1. Total impurities and crystallization temperatures T_c of deposits prepared from different electrolytes

(a)



(b)



(c)

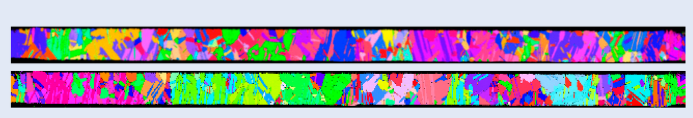
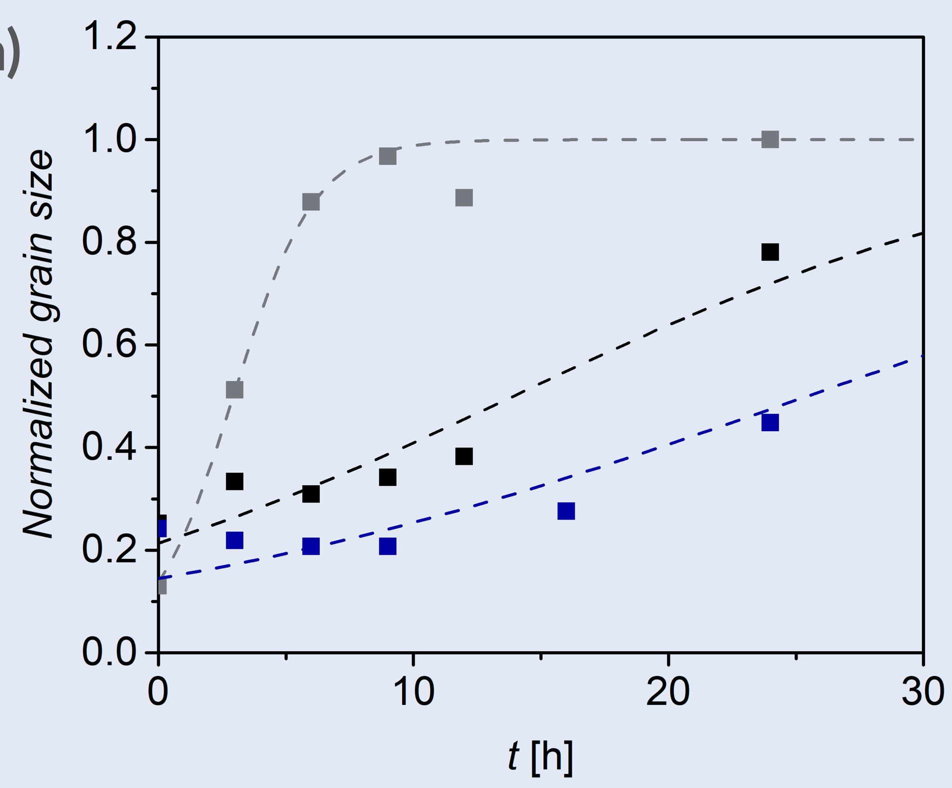


Fig. 2. (a) Average grain size including twins of 4.5 µm thick copper deposits obtained from electrolytes 1 (grey) and 2 (black) determined by EBSD after annealing for 1 h at different temperatures. **(b)** Examples of the corresponding EBSD images for electrolyte 2 after annealing for 1 h at 110 °C and 400 °C, respectively; **(c)** EBSD images of 4.5 µm thick copper deposits obtained from electrolytes 1 (top) and 2 (bottom) after annealing for 1 h at 230 °C.

Optimization of the microstructure for copper-to-copper bonding

In order to investigate the timescale of the changes of the microstructures, the grain sizes of deposits prepared from electrolyte 2 were determined after different times at room temperature. Maximum grain size results could be modified by the process parameters of the electrolytic deposition.

(a)



(b)

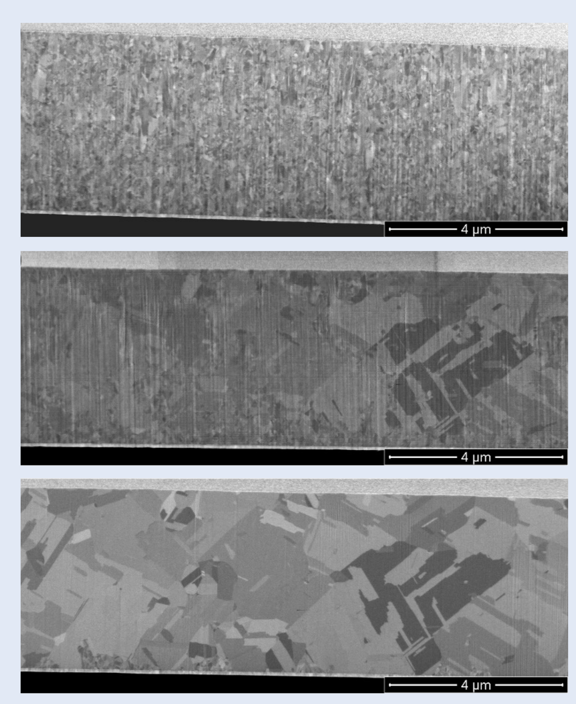


Fig. 3. (a) Normalized grain size of deposits prepared from electrolyte 2 with parameter sets 1 (grey), 2 (black) and 3 (blue) at rt; **(b)** examples of microstructures of deposits prepared from electrolyte 2 with parameter set 2 directly after deposition (top), after 12 h (middle), and 24 h (bottom).

We can tune the grain size of the Cu deposits via the process parameters, which allows the deposition of smooth surfaces and depicts the next step towards advantageous Cu-Cu direct bonding.