



Disruptive and Sustainable Bonding Technology Covering Various Material Combinations for Emerging Applications

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Semicon Europa 2023 – Future Disruptions on Sustainable Semiconductor Technologies

Agenda



Introduction



Fundamentals of anodic bonding and impulse current bonding (ICB)



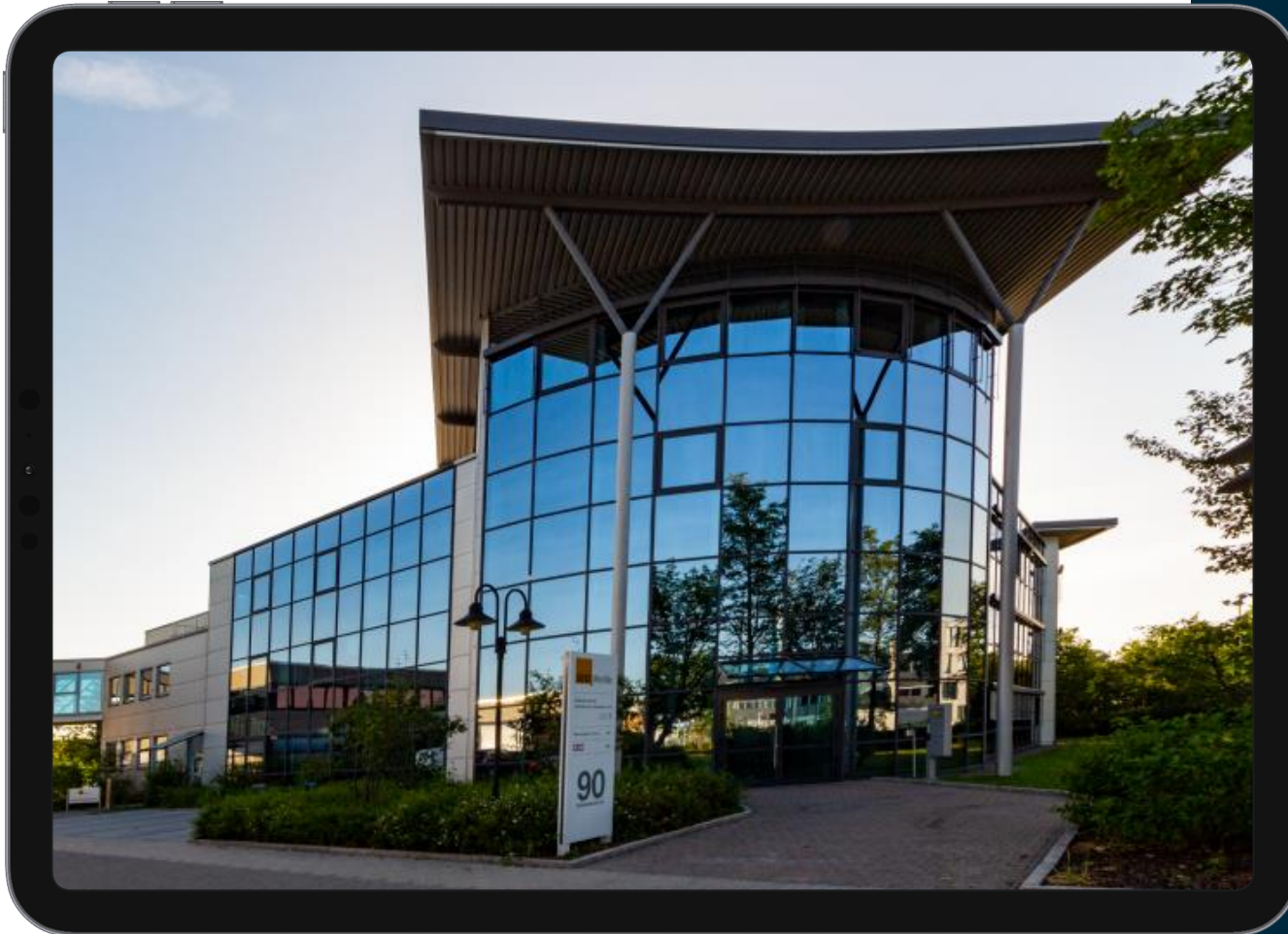
Bonding examples with various material combinations



Summary - Benefits and Limitations



SUSS MicroTec at a glance



Company in numbers

+70
years

Track record of innovation
and growth

1999
year

SUSS MicroTec went public in
Frankfurt (Germany) and is still listed
(ISIN: DE000A1K0235)

~299.1
in € million

FY2022 sales

~446.2
in € million

FY 2022 order entry

~1,250
employees

Our workforce, thereof 69% in EMEA,
26% in APAC and 5% in North
America

Our corporate vision defines our strategies

SUSS MicroTec Vision

**Leader in enabling innovative
advanced backend & photomask
solutions.**

Sustainability is becoming an essential part of our corporate DNA

” ESG has become a must in our industry. In the future, it will have an even greater impact on our customers’ purchasing decisions for or against our products. Our ambition is clear: We will contribute to a sustainable semiconductor value chain.

Dr. Thomas Rohe | Chief Operating Officer

Environmental

Reducing climate emissions to net zero by 2030¹:

- In Germany, we have been using **100% green electricity** since 2022
- **Energy savings** at 14% relative to sales in 2022



Social

People development as a key driver:

- **25% women** in second executive management level in 2022
- Compared to 2021, we have invested **+52%** in **trainings** in Germany

Governance

Implementation and ongoing monitoring of the corporate governance system:

- **100% employee training rate** for compliance and anti-corruption modules in 2022
- **No violations** in 2022



Several internationally renowned ESG rating agencies regularly analyze SUSS MicroTec’s sustainability performance:



1) With regard to SUSS MicroTec’s direct and indirect energy-related and heat-related emissions (Scope 1 and 2)

Our R&D activities are the key to future success

” In our centralized R&D organization, we are working on a platform and modularization strategy for future tool generations. We have a strong focus on disruptive growth technologies such as hybrid bonding, wafer cleaning or impulse current bonding (ICB) which can contribute significantly to SUSS MicroTec’s sales from 2025 onwards.



Hybrid bonding

Our approach: Providing W2W and D2W hybrid bonding solutions which support the industry’s technology roadmap to scale I/O density.



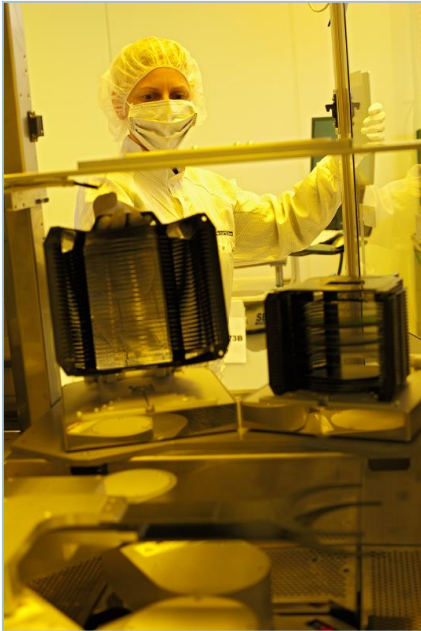
Wafer cleaning

Our approach: Leveraging our photomask cleaning competence to provide environmental friendly, cost-effective wafer cleaning solutions.

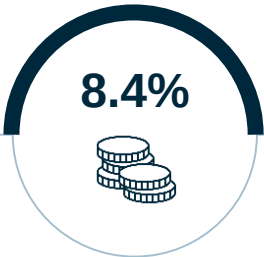


Impulse current bonding

Our approach: Providing a sustainable (r)evolution of anodic bonding for various materials with our partner Sy&Se



R&D laboratory size
We operate R&D and application laboratories with a total size of 2,000 square meters in Germany and at our international sites.



R&D expense ratio
In 2022, we have invested €25 million or 8.4% of our sales in R&D.



R&D employees
With 230 employees, almost one out of five works for R&D (2022).

Impulse current bonding – a (r)evolution of anodic bonding

- Disruptive and sustainable enhancement of anodic bonding
- Offers higher throughput, lower energy consumption and expands the applications space to a number of materials that cannot be bonded with traditional anodic bonding
- Supports cutting-edge applications like , RF-devices, MEMS and engineered substrates and power devices which help to improve performance and energy efficiency
- Discovered in 2016 and further developed by Sy&Se in Switzerland



- Available on SUSS MicroTec's permanent wafer bonders for 6-inch since 2022, scaling to 8-inch completed in 2023

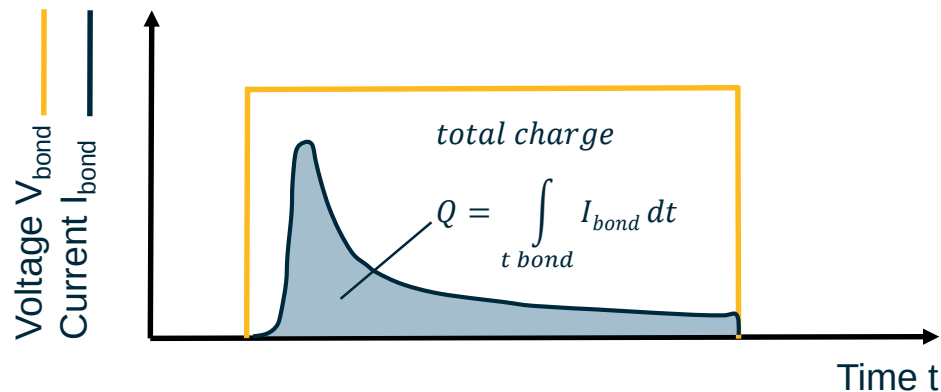


Let's first start with the fundamentals of anodic bonding...

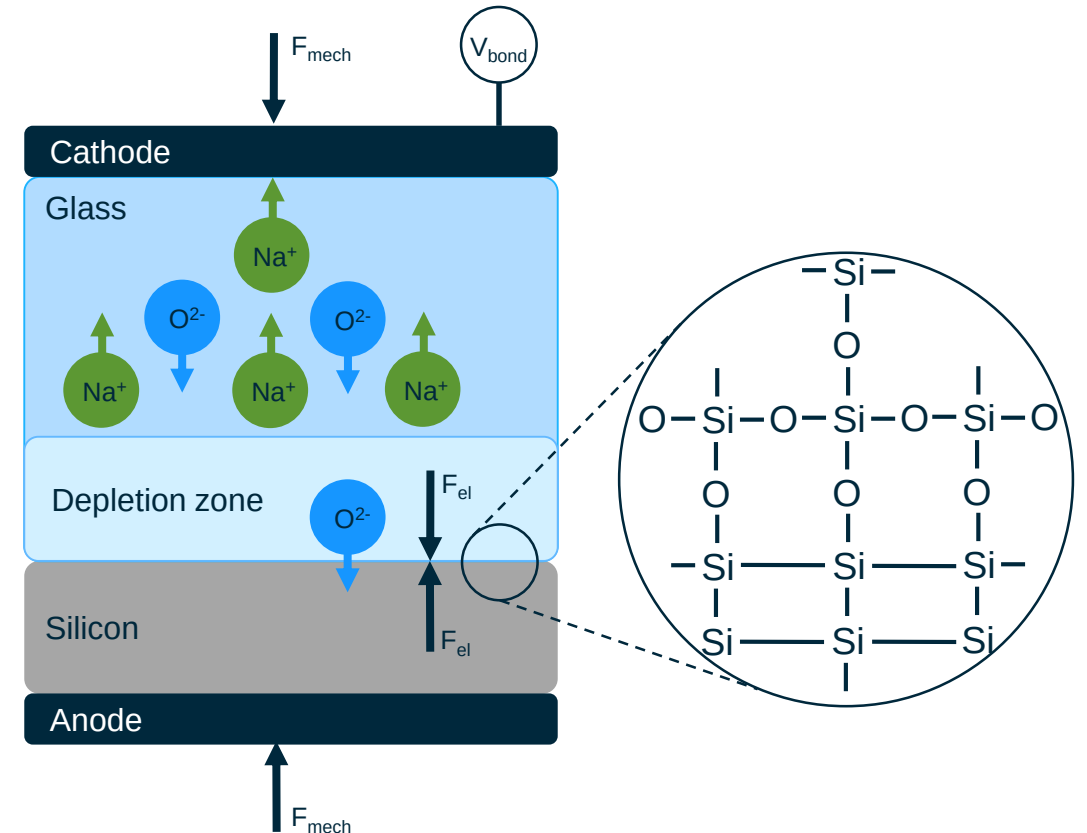
A combination of electrostatic and electrochemical processes leads to anodic oxidation

General bonding process sequence

- Apply mechanical force F_{mech} to ensure intimate physical contact between bonding partners, typ. alkali glass - Si
- Heat up to $T = 350 - 400^\circ\text{C}$ (higher T = higher ion mobility in the glass) and apply an electrostatic field $\rightarrow F_{\text{el}}$



- Depletion zone forms at the interface
 - Field induced ion migration leads to formation of NaOH at the cathode and siloxane (Si-O-Si covalent bonds) at the interface
- $\rightarrow$ Very strong mechanical bond



Sources:

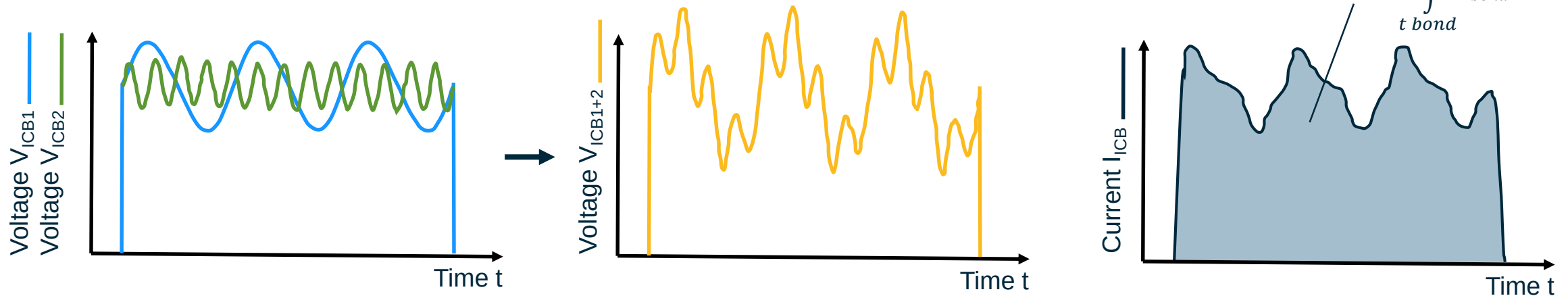
- ECS Transactions, 112 (3) 207-220 (2023), Investigation of Anodic Bond Formation Process and Potential Use of the Results, R. Knechtel, M. Wenig, D. Kley, M. Seyring
- https://en.wikipedia.org/wiki/Anodic_bonding

...to better understand the enhancements of impulse current bonding (ICB)

Impulse current bonding is a dynamic mode (r)evolution of anodic bonding

General bonding process sequence

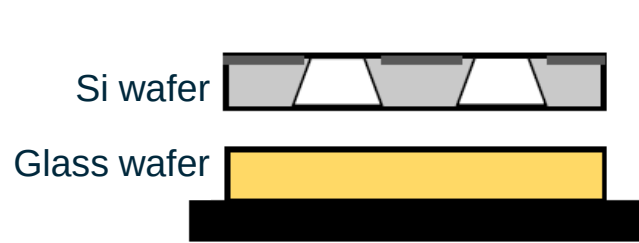
- Apply mechanical force (F_{mech}) to ensure intimate physical contact between bonding partners
- Heat to $T = 150 - 250^\circ\text{C}$ and apply a dynamic electrostatic field (F_{el})
- Static voltage is enhanced with material system specific wave forms, e.g. V_{ICB1} and V_{ICB2}
- Frequency signal induces an impedance change at the bond interface
- Low impedance induces current flow during entire process $\rightarrow$ high total charge



- Mobility of electrons and ions is enhanced $\rightarrow$ helps with rapid formation of covalent bonds
- More complex, material system specific phenomena still under investigation

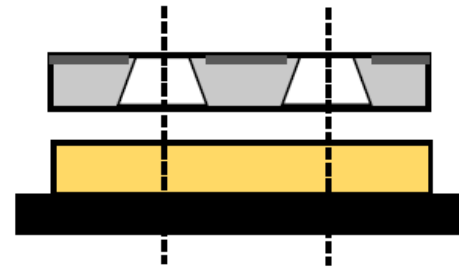
Source: Sy&Se SA, Sébastien Brun and Florian Telmont

ICB process sequence for aligned wafer bonding & exemplary result



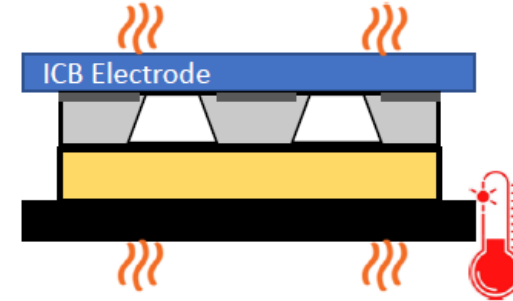
1. Cleaning (optional)

Standard wafer cleaning with e.g. DIW, RCA or Piranha



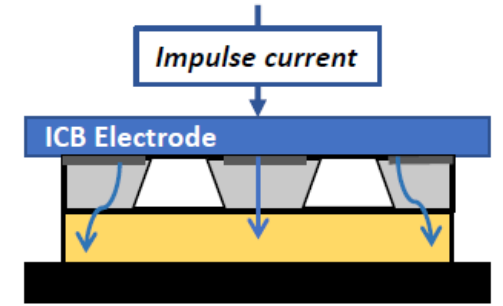
2. Alignment

Wafer to wafer alignment in bond aligner



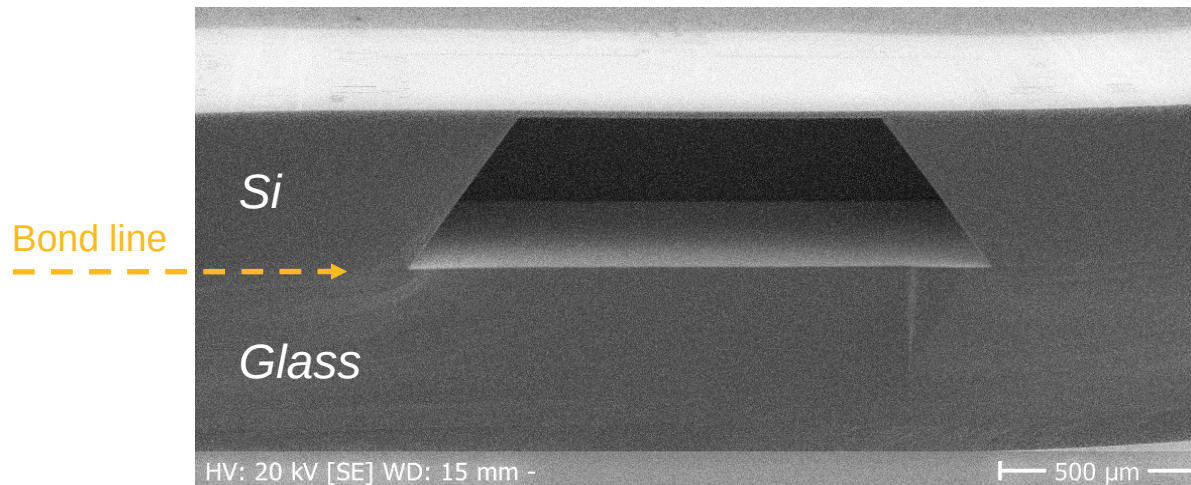
3. Apply heat & force

Heating up to 180°C for a typical glass – Si bond and applying a low joining force



4. Impulse Current Bonding

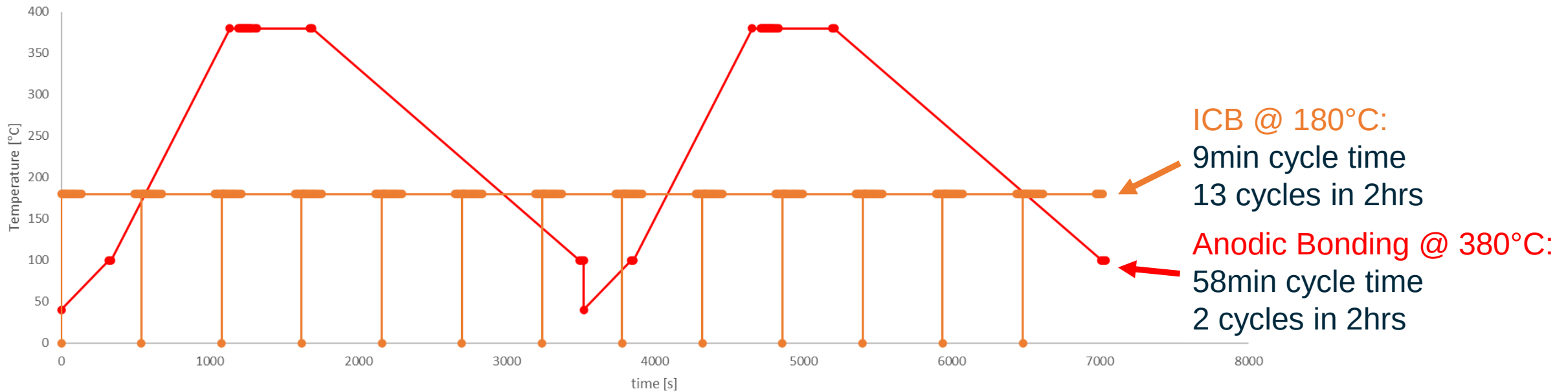
Ion migration induced formation of covalent bonds for high mechanical strength



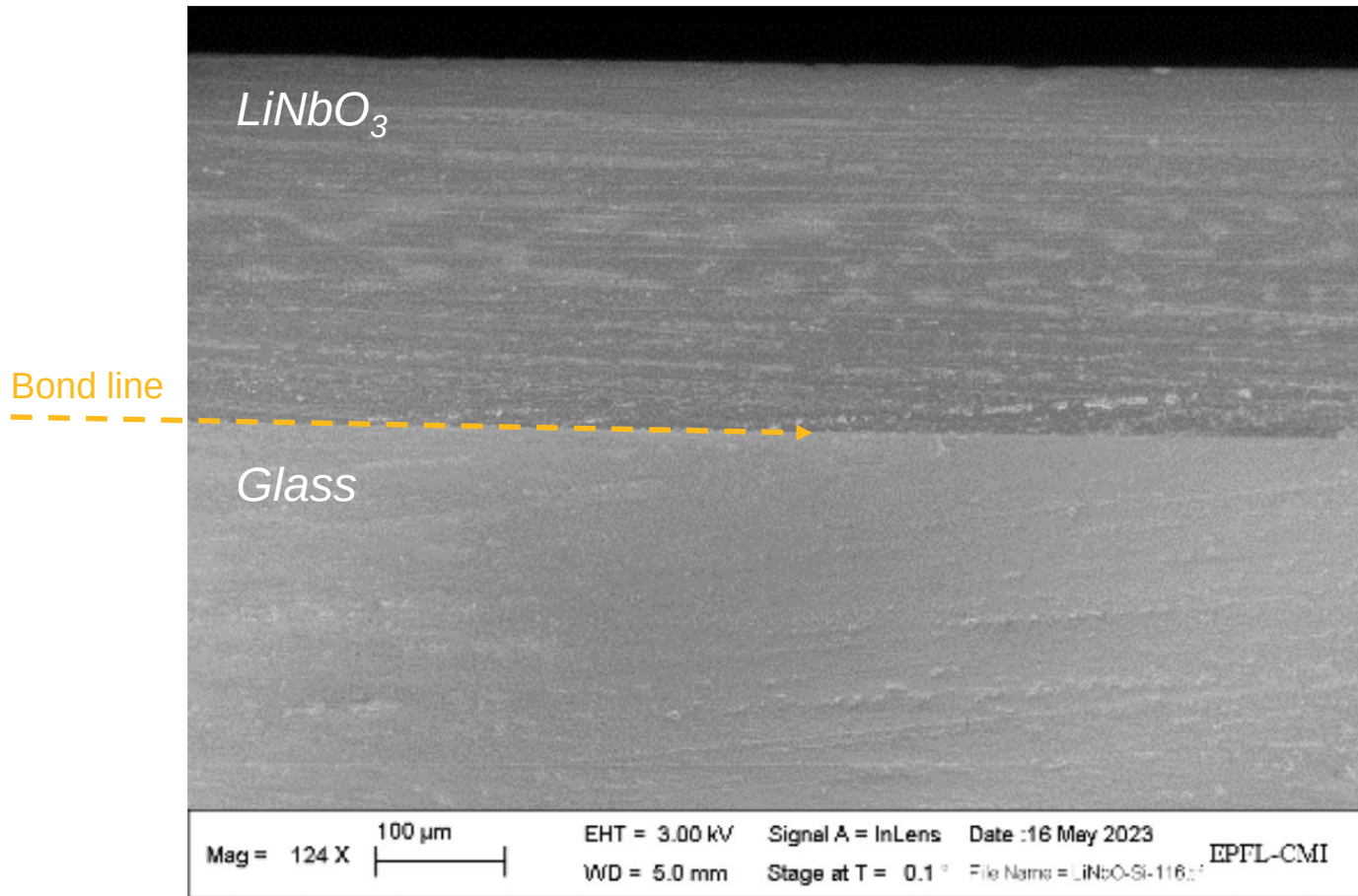
N-doped Si (100) wafer bonded to a borosilicate glass wafer at 180°C with a process time of 4 min

Cycle time comparison ICB vs. anodic bonding for 6-inch wafers

ICB – Disruptive and sustainable (r)evolution with **~6x** higher throughput
~50% lower temperature



Bonding example: ICB of LiNbO_3 to glass for RF-MEMS

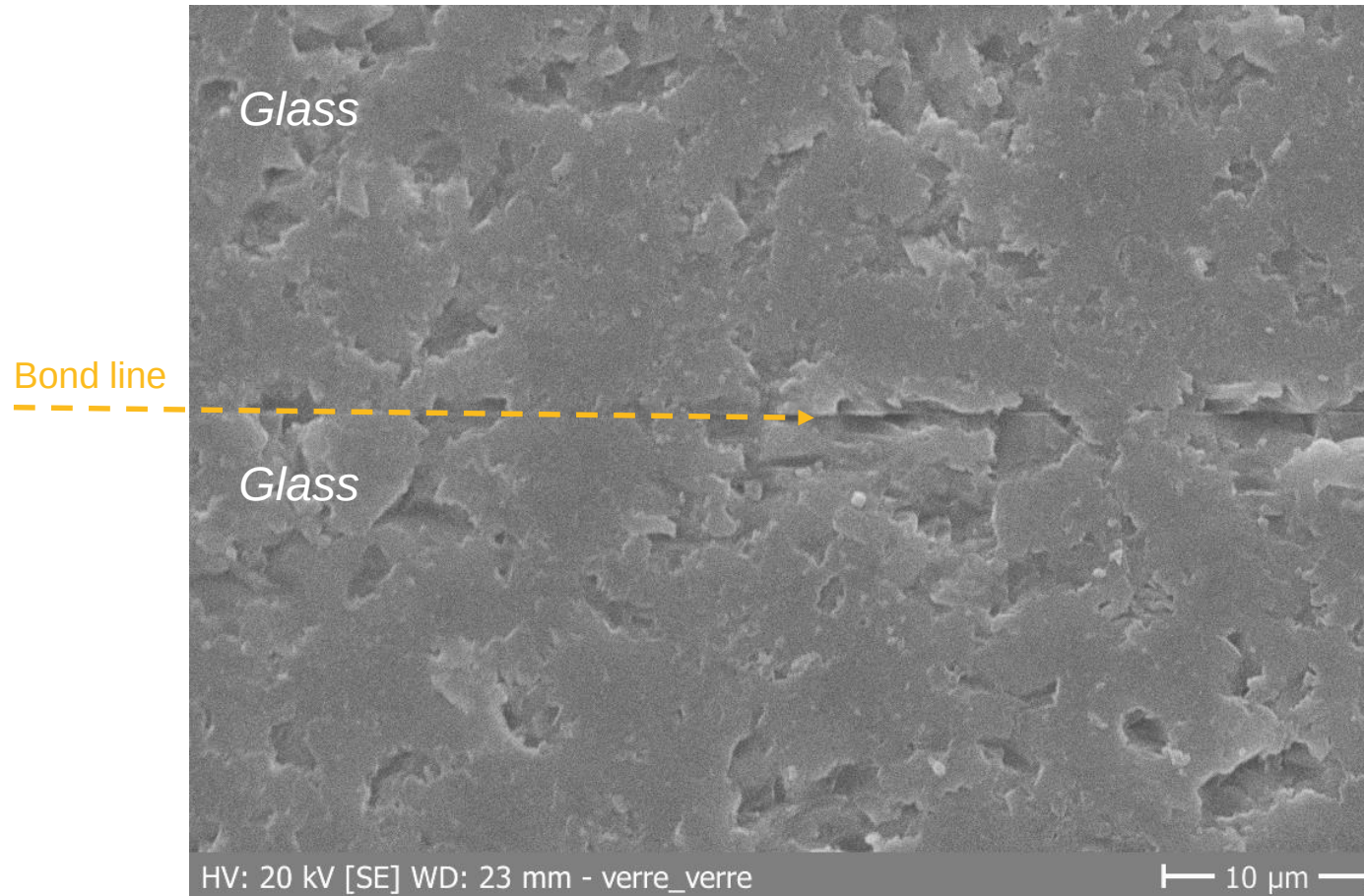


Main recipe parameters

Temperature: 350°C - work in progress, may require PVD layer to lower temperature

Time: 4 min

Bonding example: ICB of glass to glass for MEMS

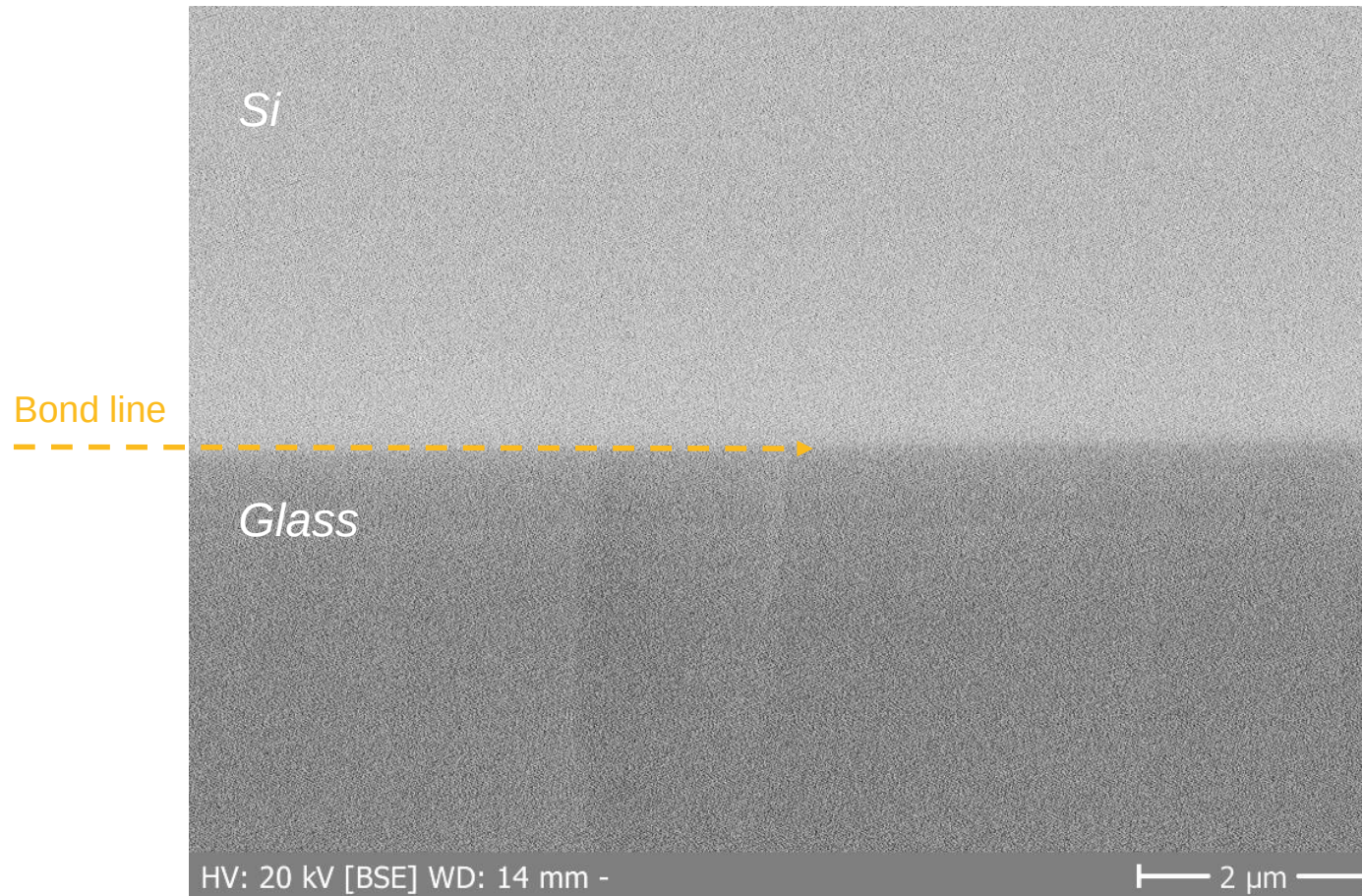


Main recipe parameters

Temperature: 200°C

Time: 4 min

Bonding example: ICB of Si to glass for MEMS

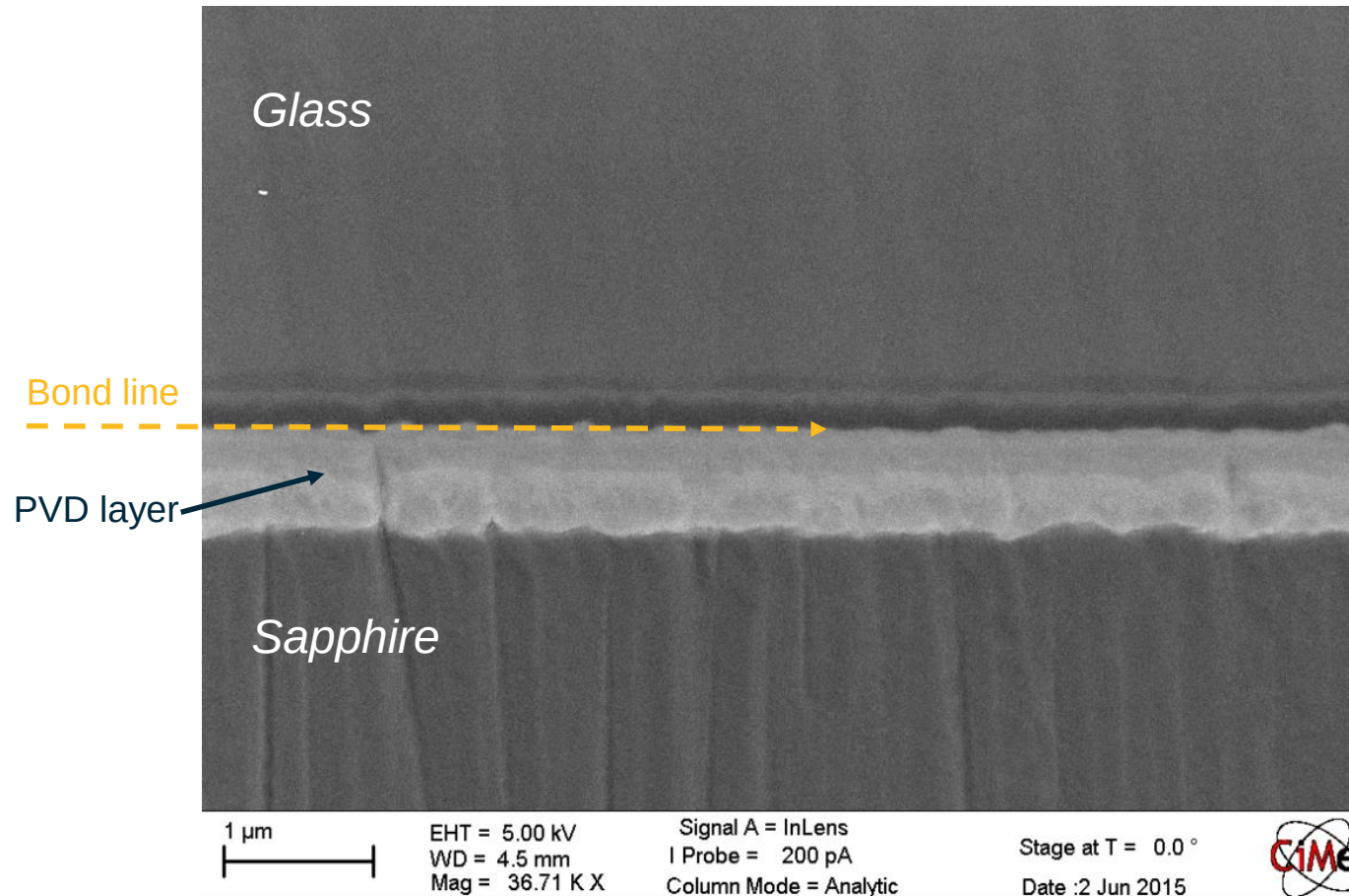


Main recipe parameters

Temperature: 180°C

Time: 4 min

Bonding example: ICB of glass to sapphire for MEMS

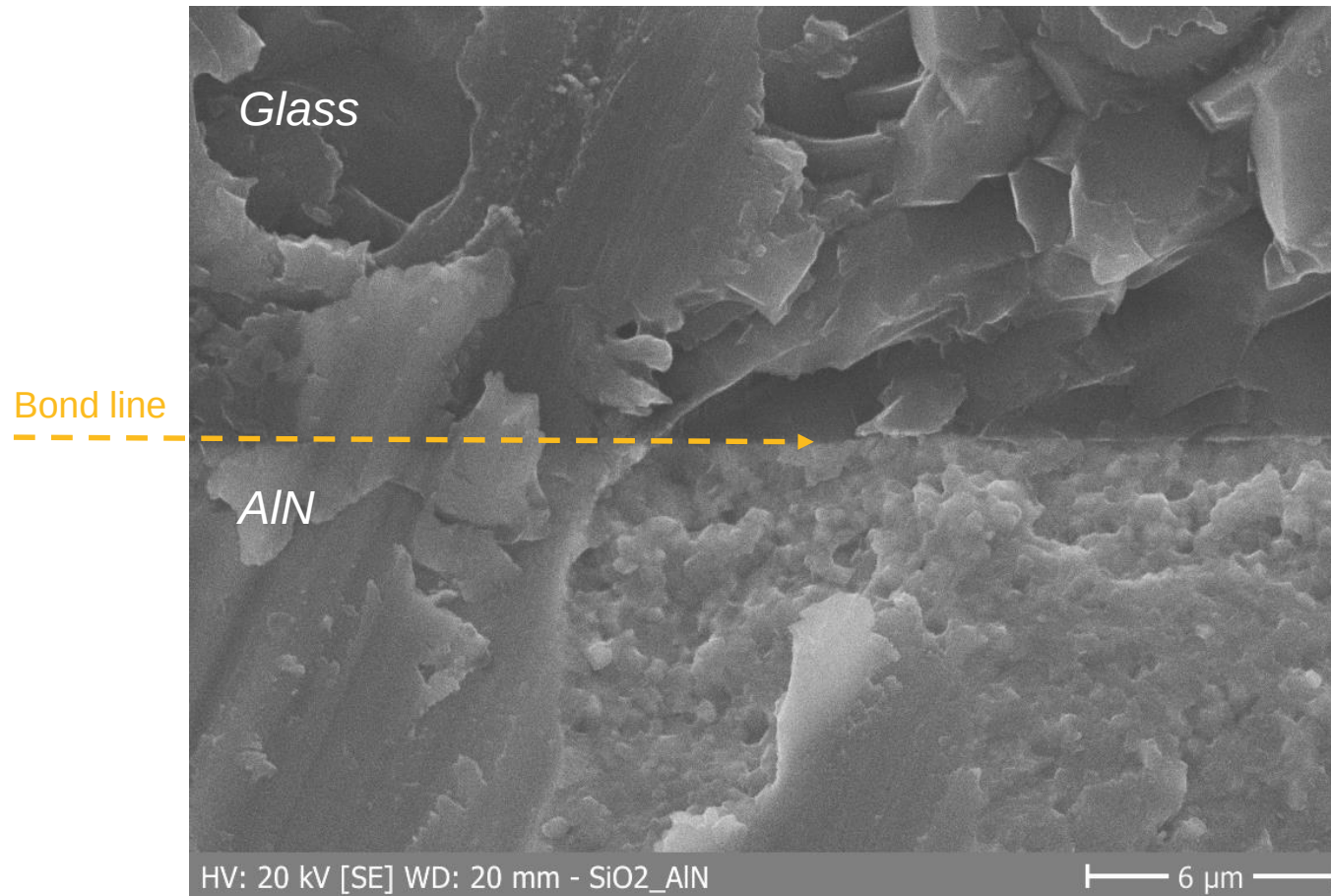


Main recipe parameters

Temperature: 200°C

Time: 4 min

Bonding example: ICB of AlN to glass for piezoelectric MEMS

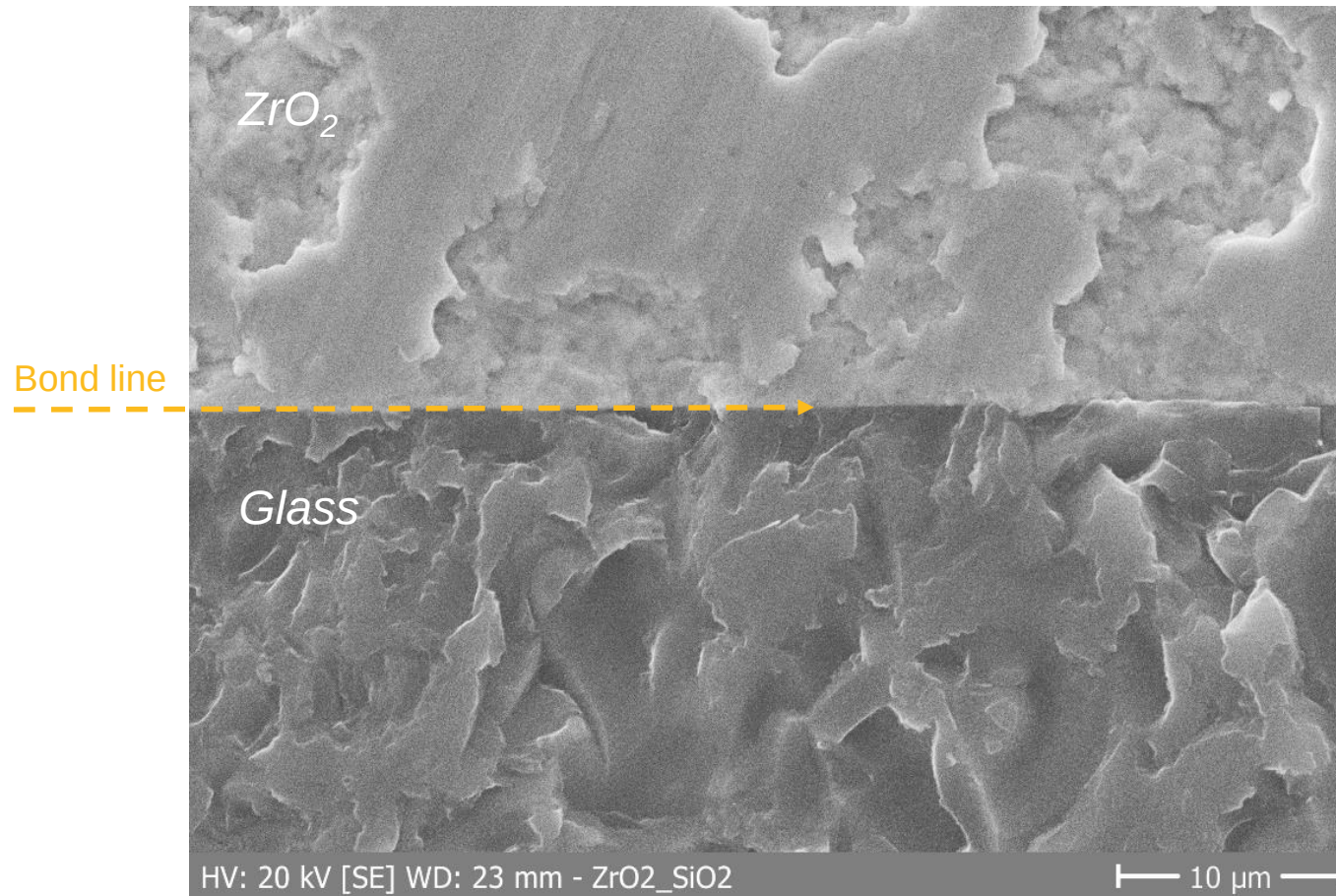


Main recipe parameters

Temperature: 180°C

Time: 4 min

Bonding example: ICB of ZrO_2 to glass for MEMS

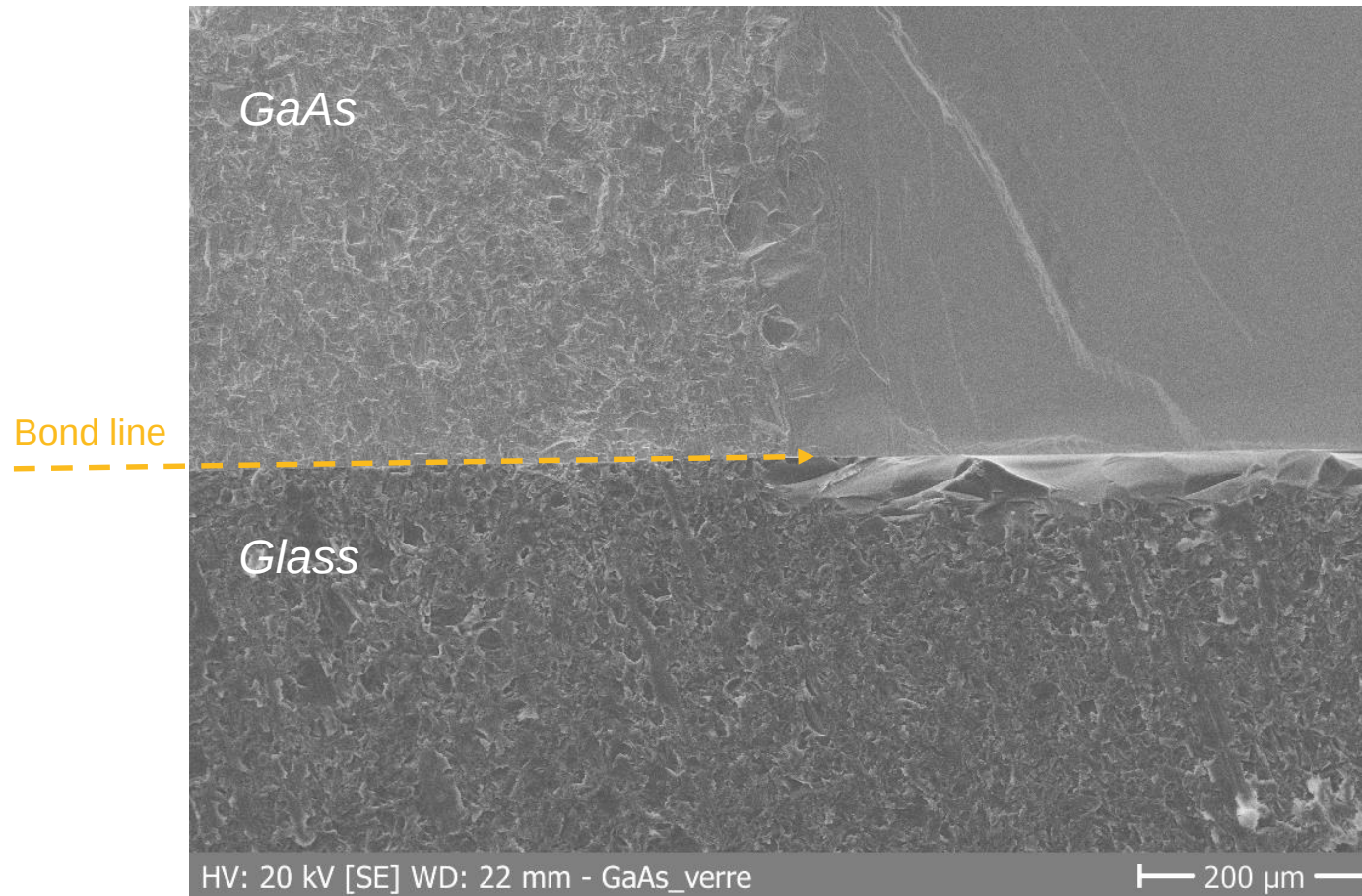


Main recipe parameters

Temperature: 180°C

Time: 4 min

Bonding example: ICB of GaAs to glass for Optoelectronics

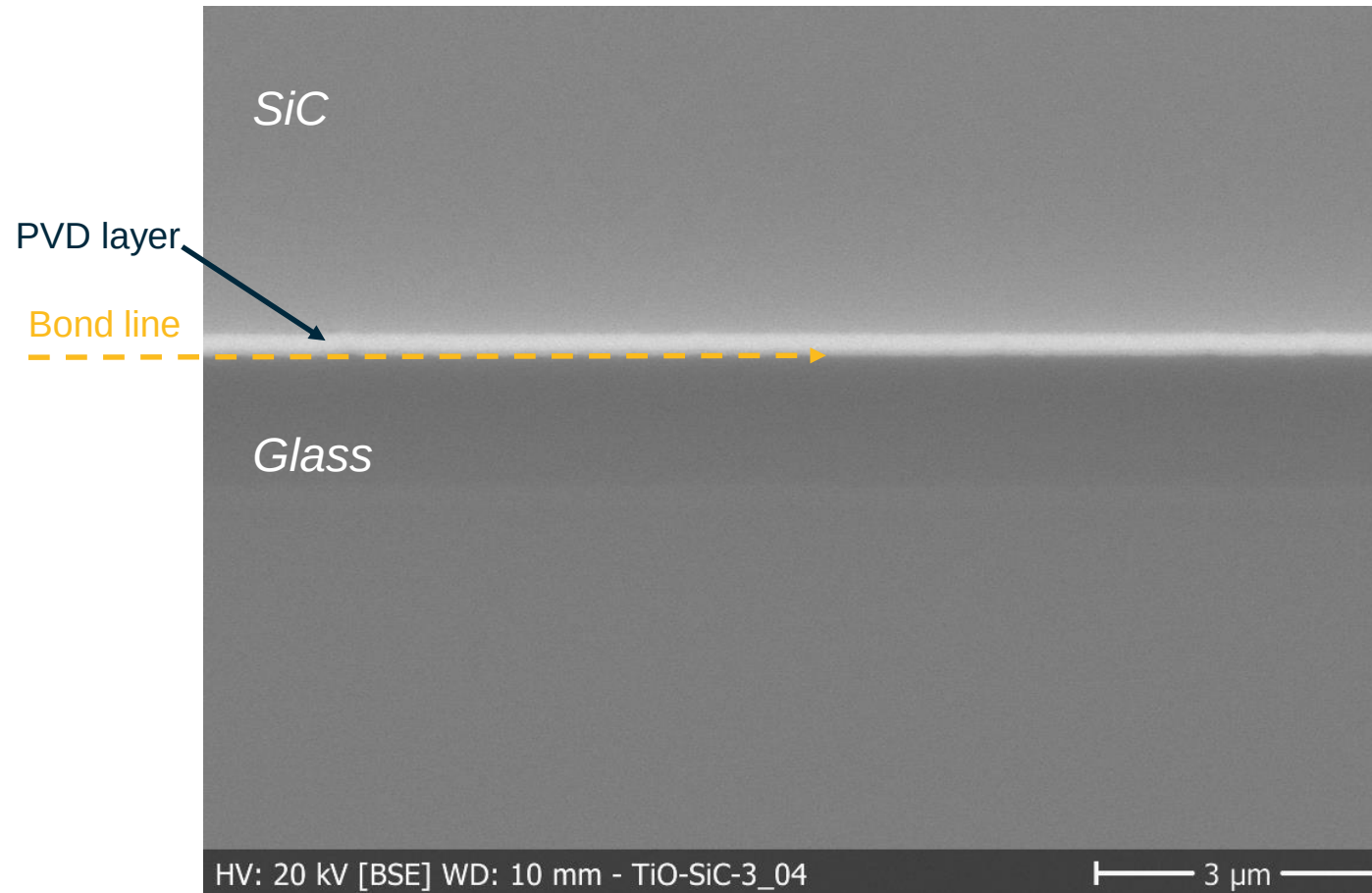


Main recipe parameters

Temperature: 200°C

Time: 4 min

Bonding example: ICB of SiC to glass for Photonics

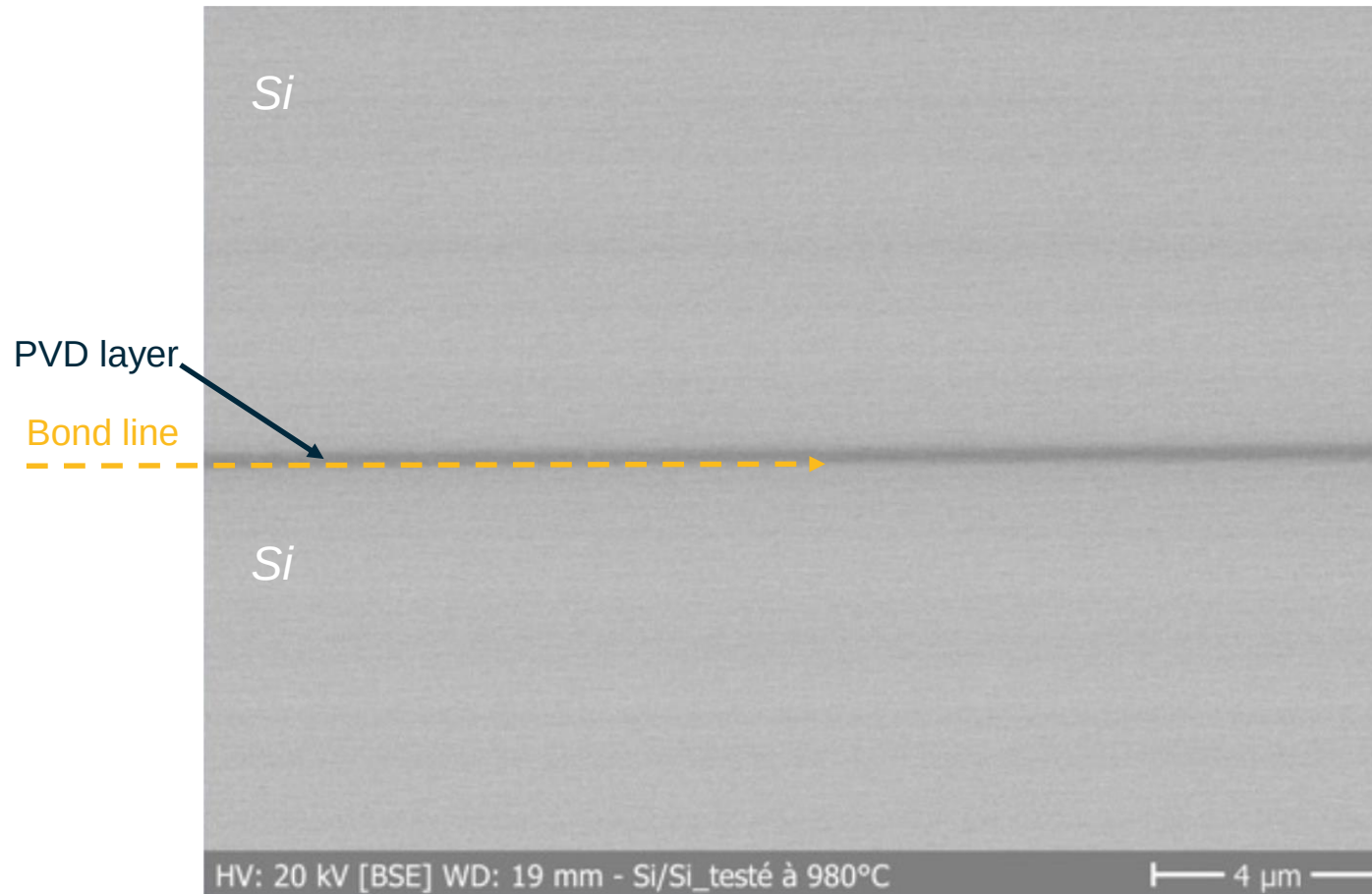


Main recipe parameters

Temperature: 200°C

Time: 4 min

Bonding example: ICB of Si to Si for MEMS with intermediate PVD layer - after temperature test



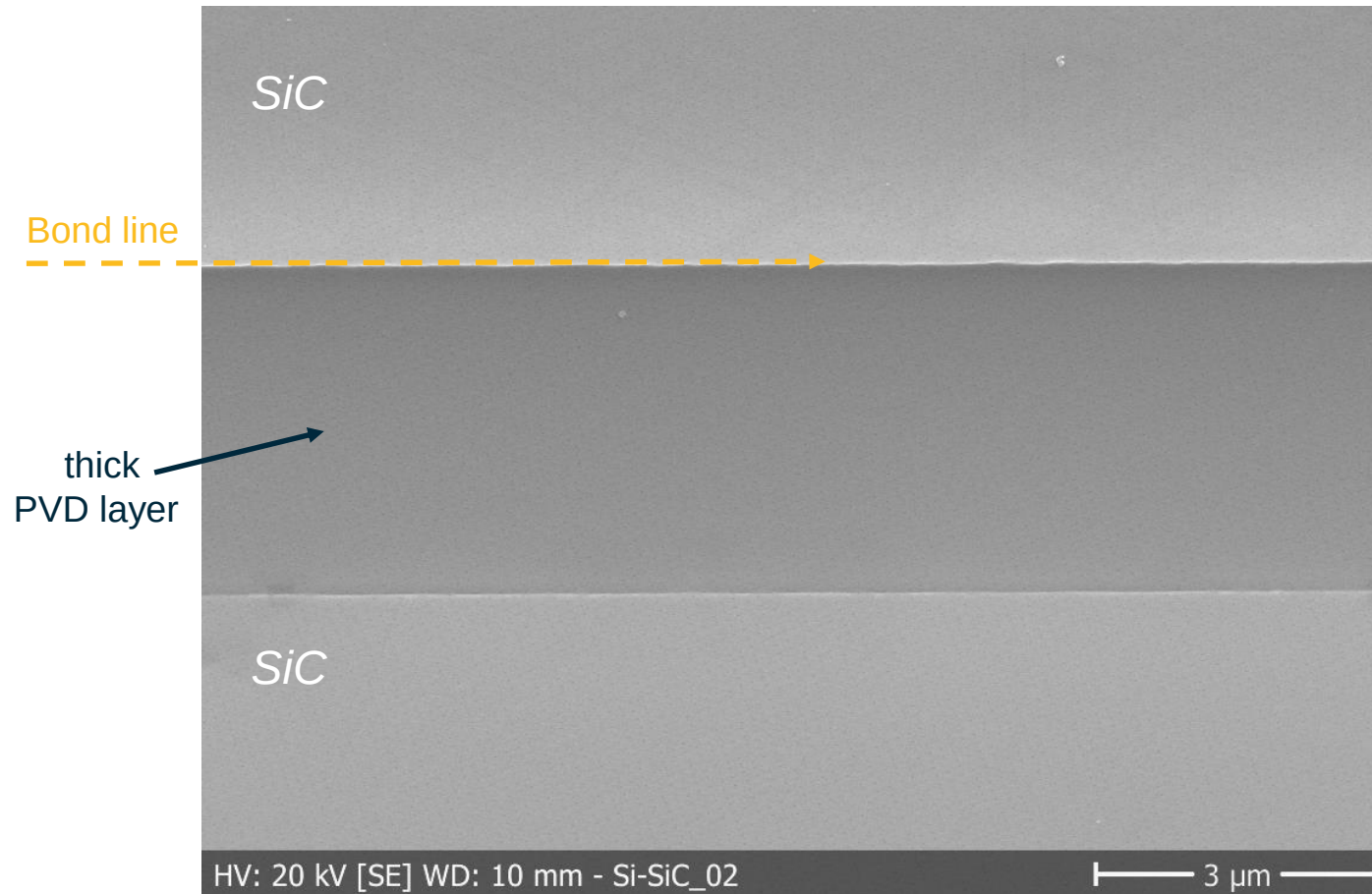
Main recipe parameters

Temperature: 220°C

Time: 5 min

No impact on bond line from high temperature stress test @ 980°C

Bonding example: ICB of SiC to Si for Power Devices

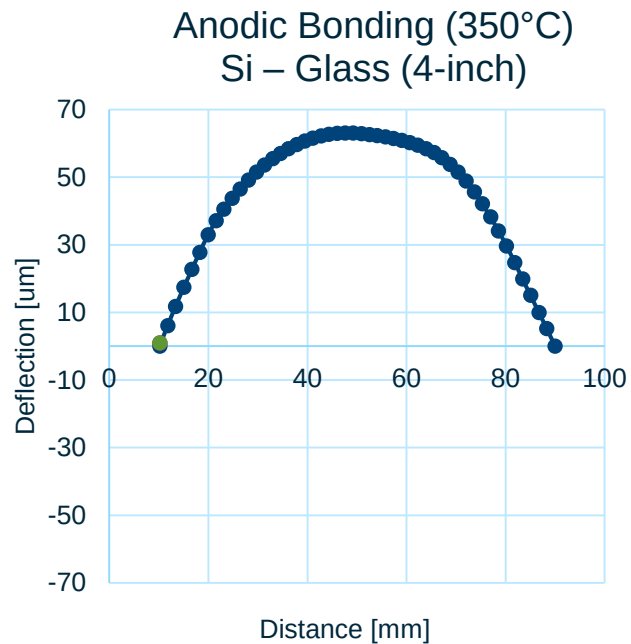


Main recipe parameters

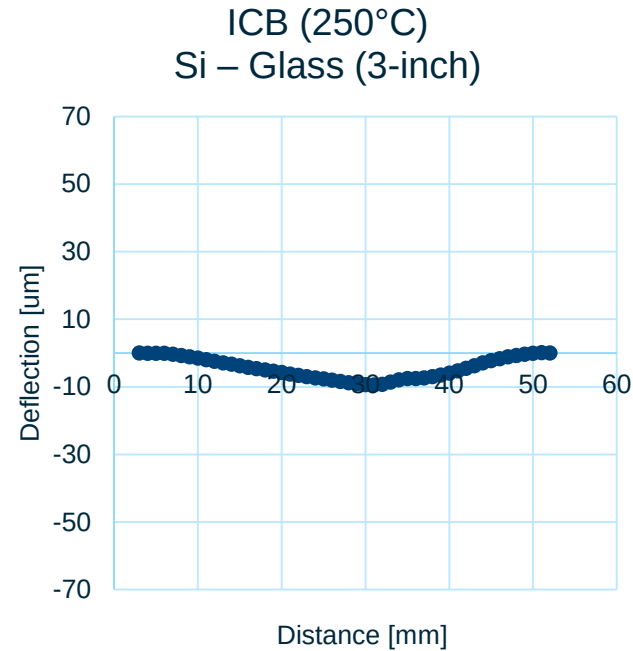
Temperature: 220°C

Time: 5 min

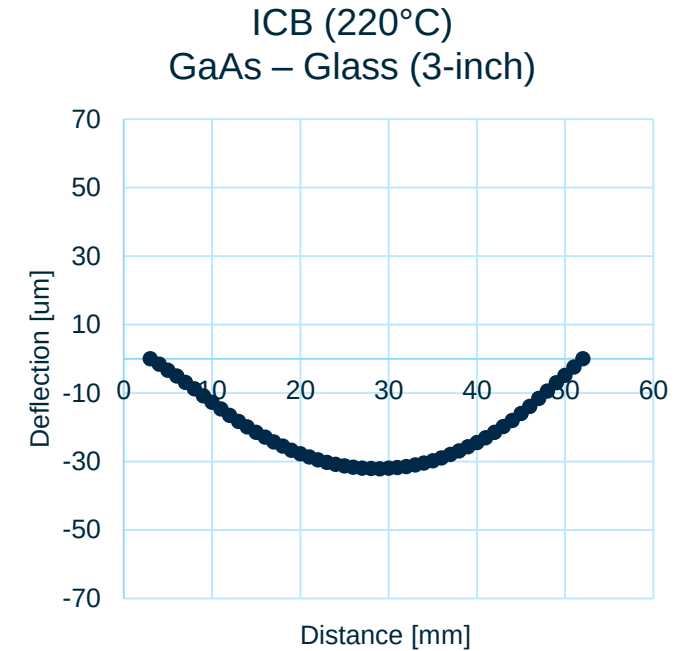
ICB offers low post bond bow, even for materials with high CTE mismatch



Bow 65μm → Radius of Curvature 12m



Bow 13μm → Radius of Curvature 92m



Bow 36μm → Radius of Curvature 15m

Linear thermal expansion coefficients of used materials

- Si: $2.6 \times 10^{-6} \text{ K}^{-1}$
- Glass (BF33): $3.25 \times 10^{-6} \text{ K}^{-1}$
- GaAs: $5.73 \times 10^{-6} \text{ K}^{-1}$

Data courtesy of Fraunhofer ENAS

Summary - Benefits and Limitations

Benefits Anodic Bonding

- Combination of electrostatic and electrochemical processes that leads to anodic oxidation → strong covalent bonds
- Allows for alkali-glass based bonding
- Tolerates surface roughness in the tens of nm range
- Widely used in the industry since decades

Limitations Anodic Bonding

- Conductive bond partners needed, does not work with SOI or other non-conductive bonding partners
- Significant part of energy to enable ion mobility is provided by the high process temperatures of 350 – 400°C
- High process temperatures result in interface stress, especially for materials with large CTE mismatch

Benefits Impulse Current Bonding

- Dynamic mode **(r)evolution** of anodic bonding with higher throughput and reduced power consumption
- Compatible with non-conductive materials → allows for bonding various materials beyond the capabilities of anodic bonding
- Tolerates surface roughness in the tens of nm range
- Lower temperature budget → less interface stress / lower wafer bow, especially for materials with large CTE mismatch
- Electrode can be designed for selective bonding, e.g. at wafer edge

Limitations of Impulse Current Bonding

- May require glass-like interface layers to allow ion migration to take place, especially when using identical or similar bonding partners
- Extensive recipe development and testing required for new material combinations

Impulse Current Bonding (ICB) -
a (r)evolution of anodic bonding and
game changer in permanent bonding

For More Information please visit the
SUSS MicroTec booth at B1530

Semicon Europa 2023 – Future Disruptions on Sustainable Semiconductor Technologies