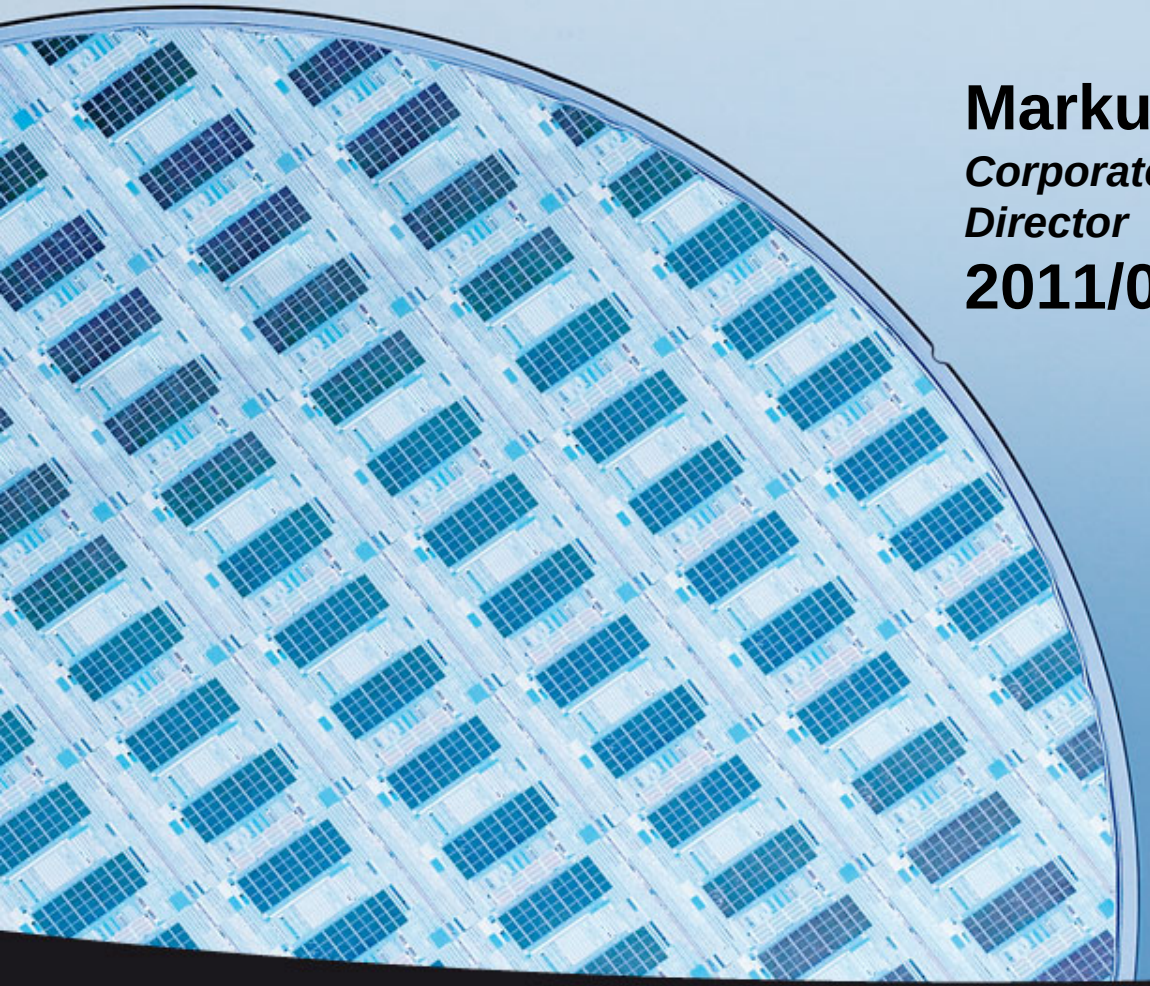
EV Group

Plasma Activated Wafer Bonding



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Corporate Technology Development and IP Director

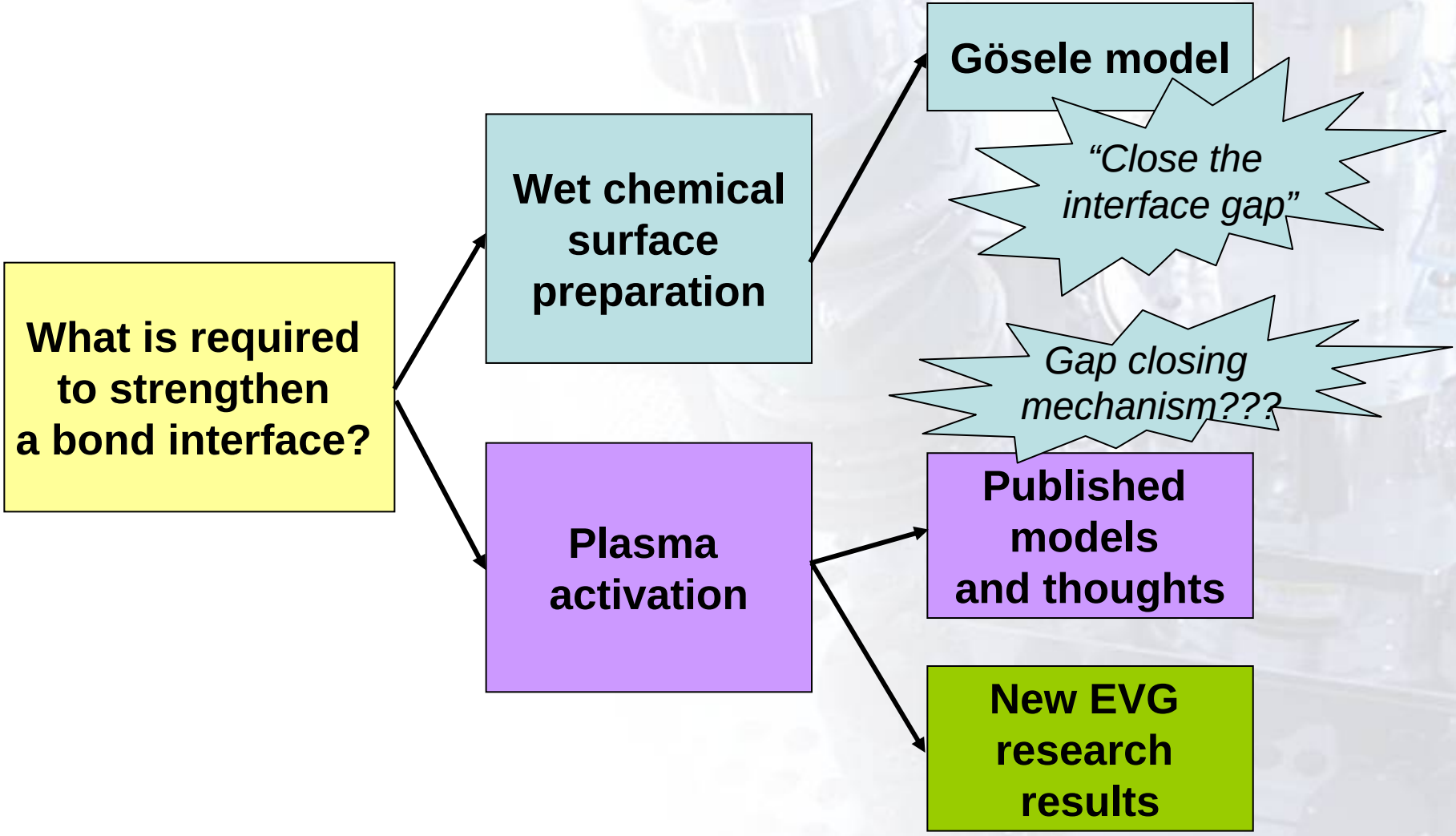
2011/08/23

Acknowledgement

The results presented in this slideshow presentation were created by Dipl.-Ing. Thomas Plach within the framework of a Ph.D. Thesis.

The thesis is carried out in a cooperation between the Christian Doppler Laboratory for Microscopic and Spectroscopy Material Characterization (CDL-MS-MACH) at the Johannes Kepler University Linz and EV Group.

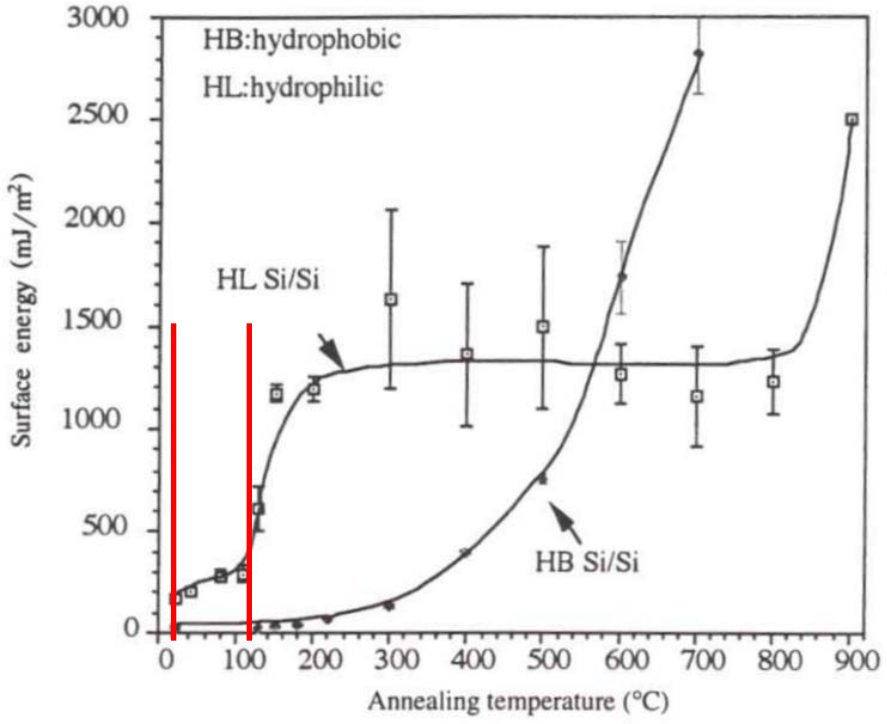
Outline – Process Review

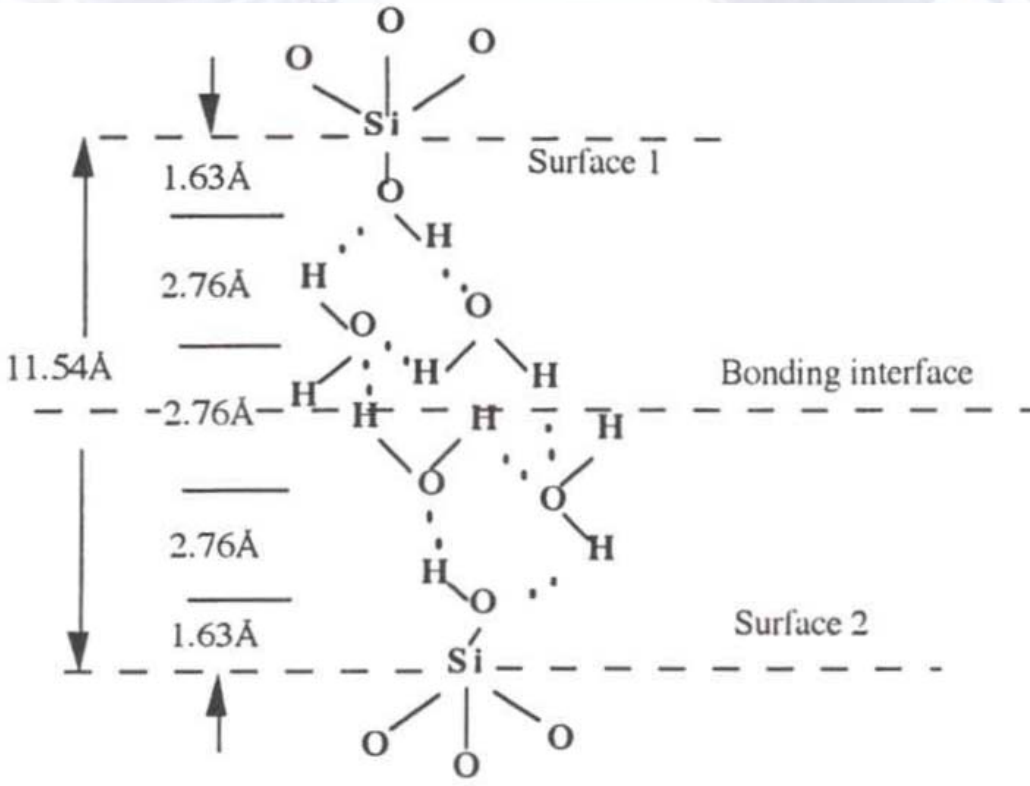


Mechanism behind bond strengthening for fusion bonds

reference process: wet chemical surface preparation

$Si\text{-}SiO_2$ Hydrophilic Bonding RT - 110°C

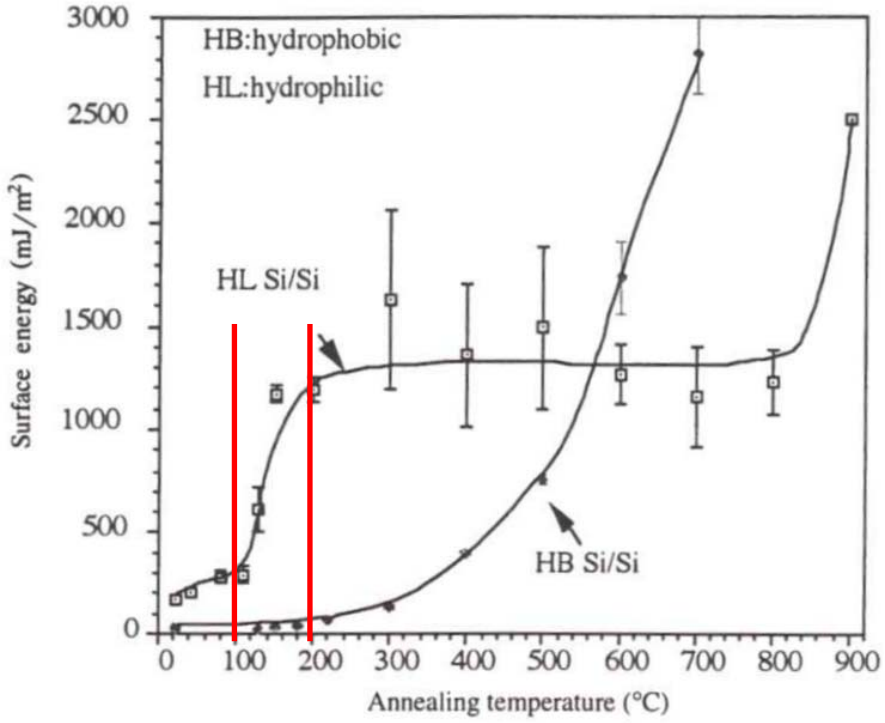


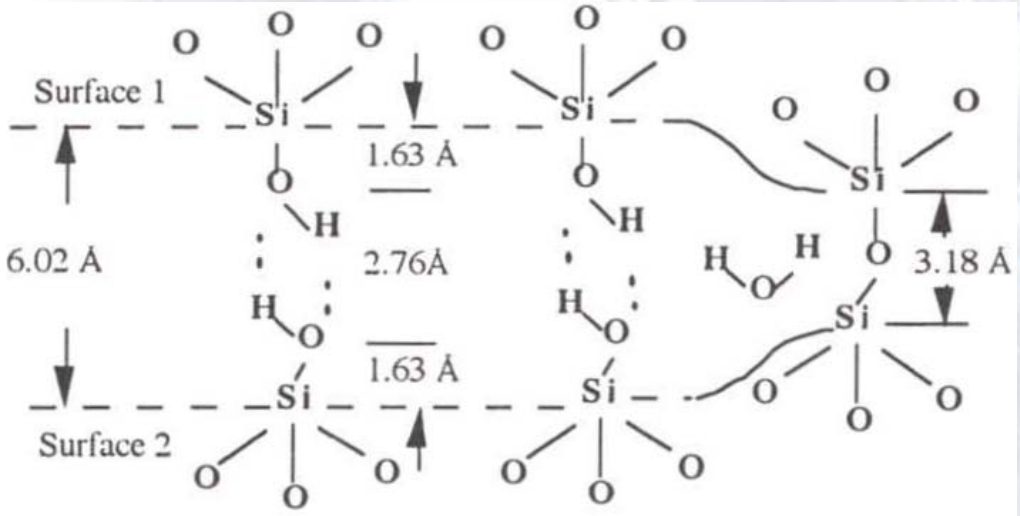


$$Si\text{-}OH + HO\text{-}Si \rightleftharpoons Si\text{-}O\text{-}Si + H_2O$$

$$Si + 2H_2O \rightarrow SiO_2 + 2H_2$$

$Si\text{-}SiO_2$ Hydrophilic Bonding 110 - 150°C





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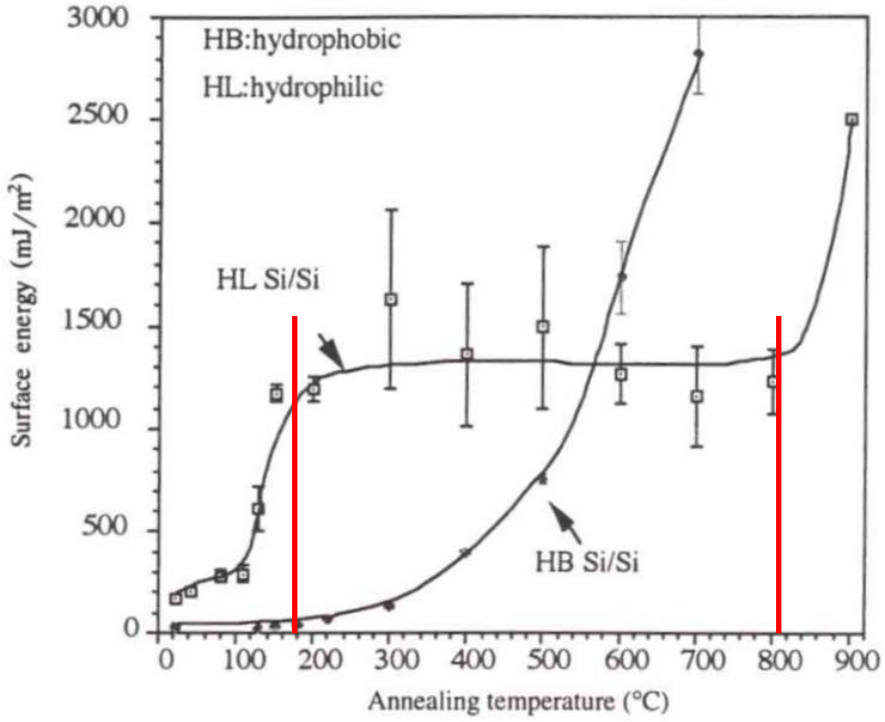
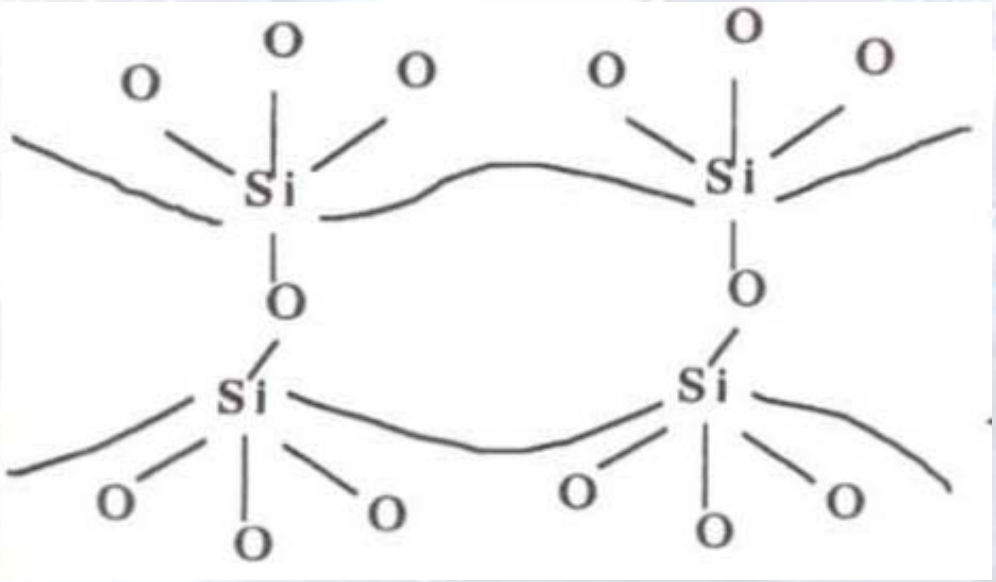
$Si\text{-}SiO_2$ Hydrophilic Bonding 150 - 800°C





$$Si\text{-}OH + HO\text{-}Si \rightleftharpoons Si\text{-}O\text{-}Si + H_2O$$

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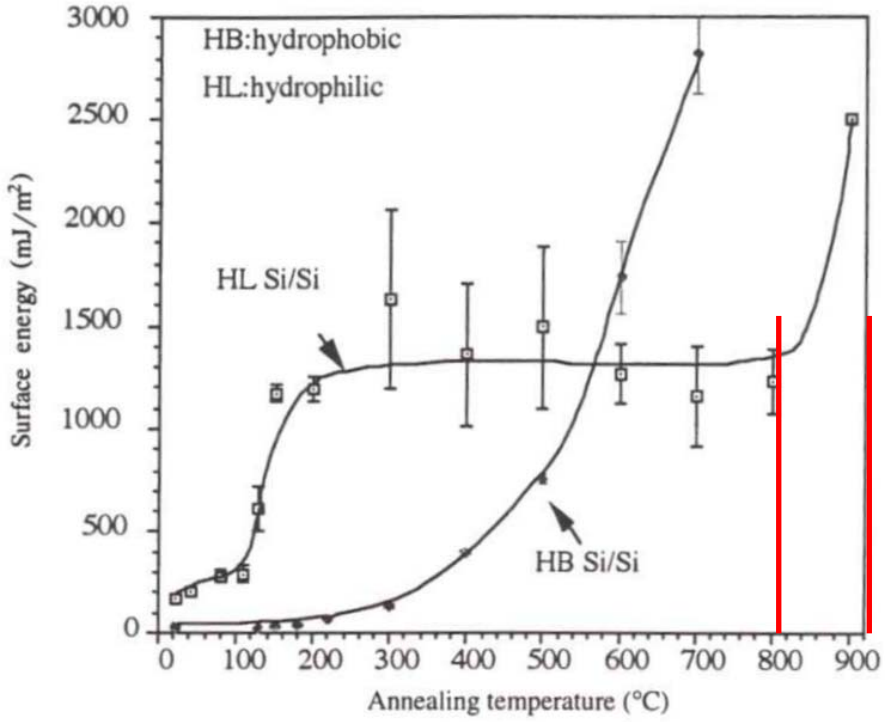
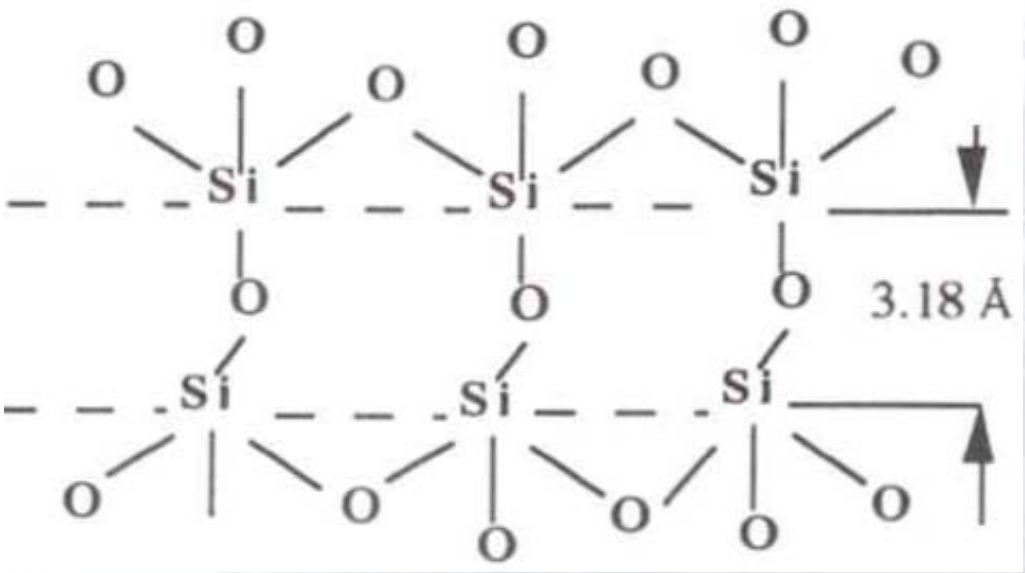
Si-SiO_2 Hydrophilic Bonding above 800°C





$$Si\text{-}OH + HO\text{-}Si \rightleftharpoons Si\text{-}O\text{-}Si + H_2O$$

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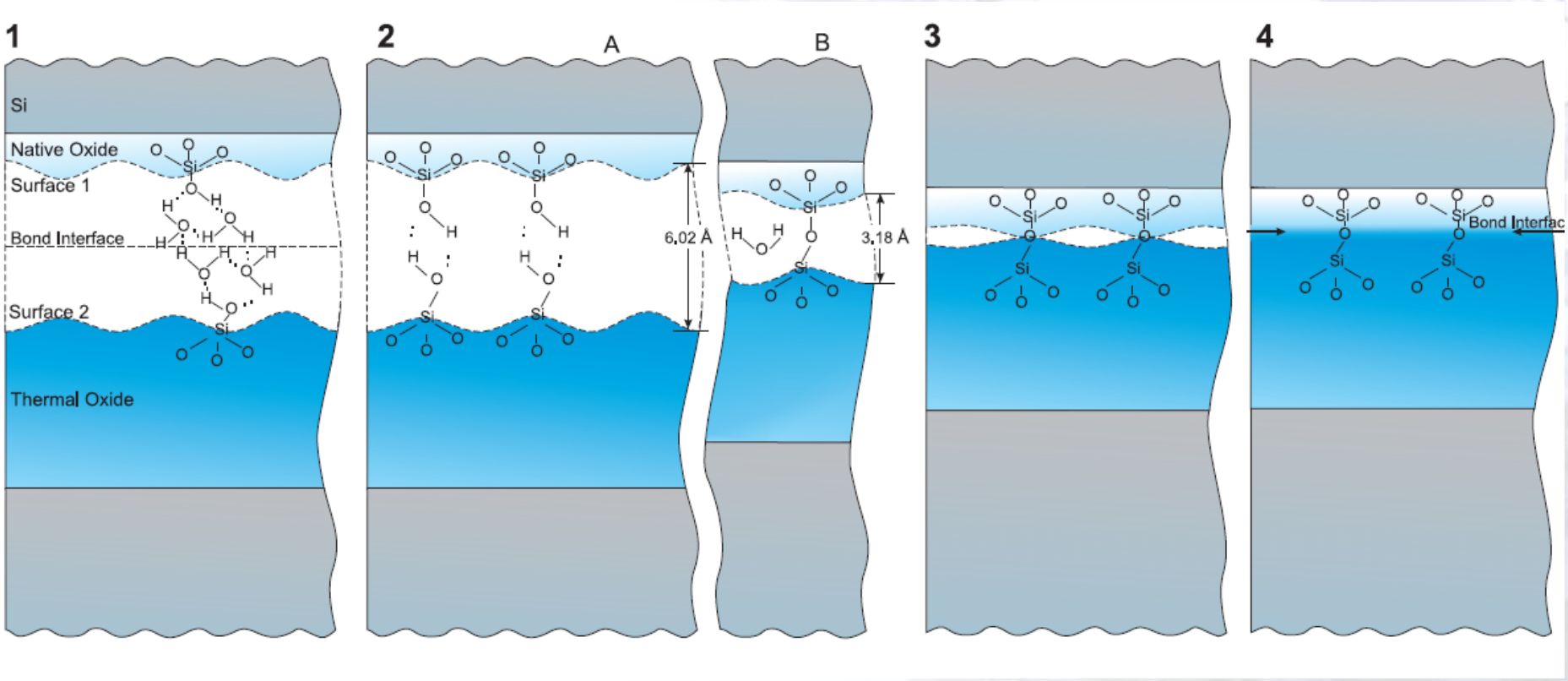
Gösele Model - Summary



Gap closing due to viscous flow of oxide during high temperature annealing

Published Models & thoughts for Plasma Activated Wafer Bonding

EVG:

- Only gentle surface change / gentle plasma
- Break surface bonds and make surface more reactive → dangling bonds
- Remove contamination

Other groups:

- Surface activation increases density of OH groups on surface
- Disordered surface structure
- Porous system traps water
- Plasma cleans surfaces

These models don‘t fully explain…

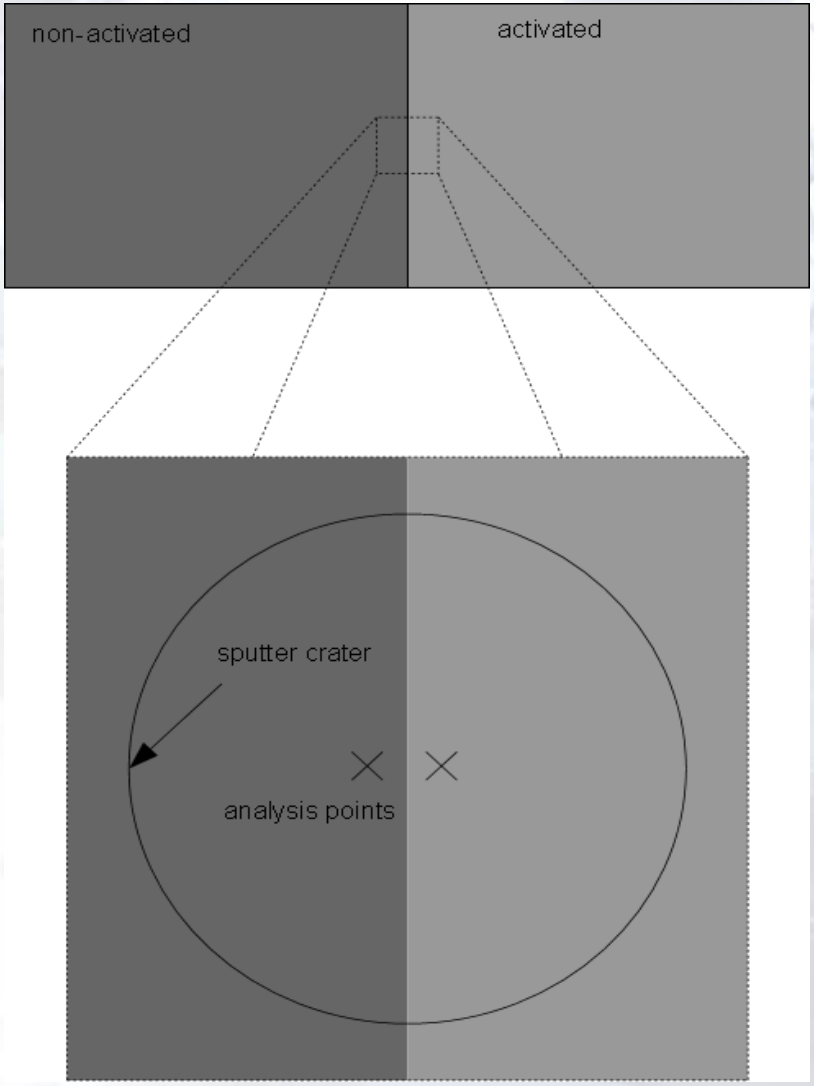
- How gaps are closed
- Why plasma activation effect lasts for several weeks and even months if wafers are stored.
- Why in-situ plasma activated bonding does not reliably yield good results

Research Approach

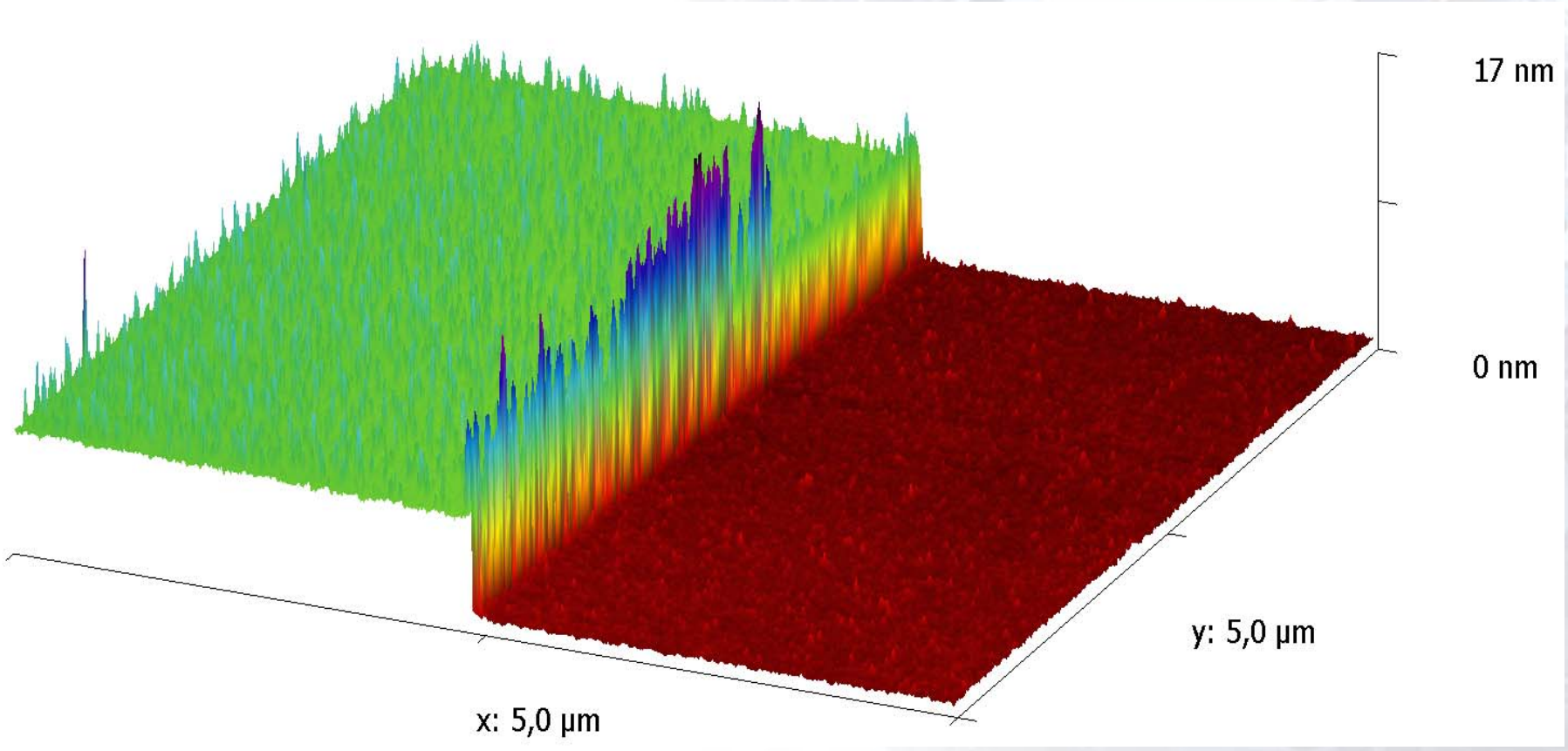
- Analytical Methods to characterize surface changes due to plasma activation
  - AFM
  - Ellipsometry
  - Auger
  - XPS
  - etc.
- Investigation of bonded interfaces
- Based on analytical data and bond behavior:
  - Find an appropriate model that describes the mechanism of plasma activated bonding.

AFM samples

- samples were half covered by other wafer pieces during activation
- therefore on one sample both an activated and an non-activated side was available
- Initially, AFM was used to confirm the effect of plasma activation on surface roughness.
- A step profile created on the surface was discovered / measured during this investigation as well.

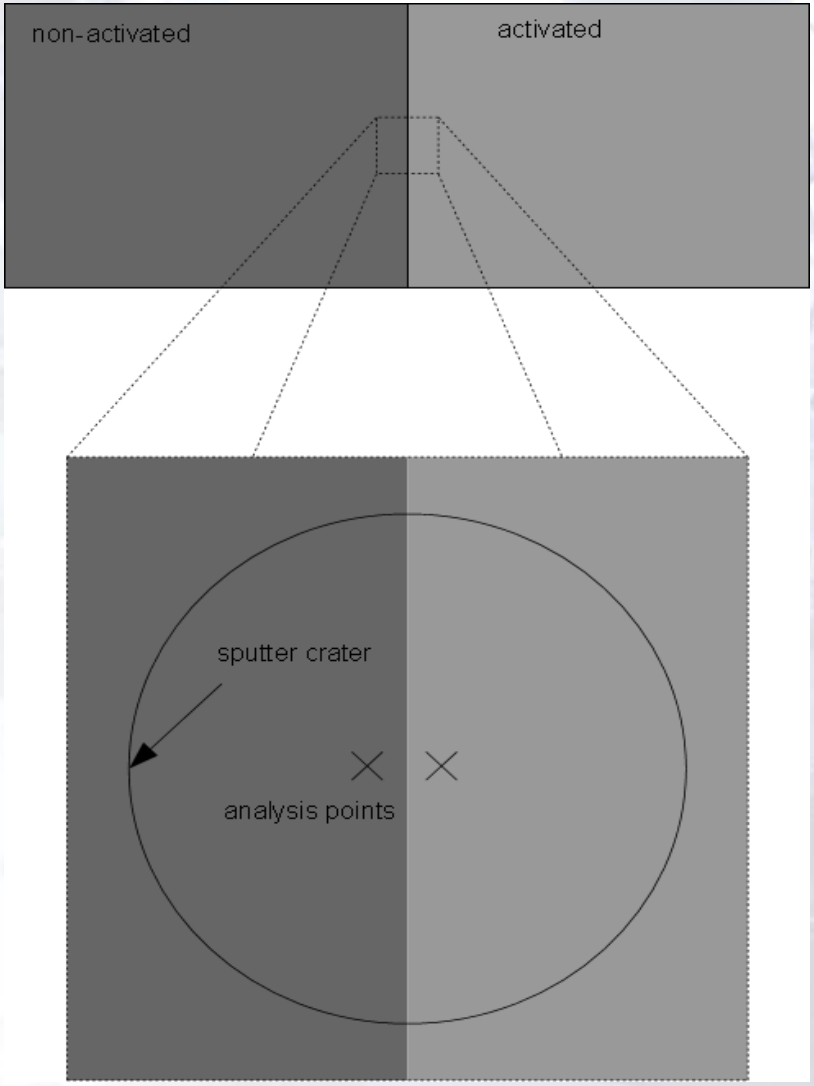


AFM: Step-Analysis

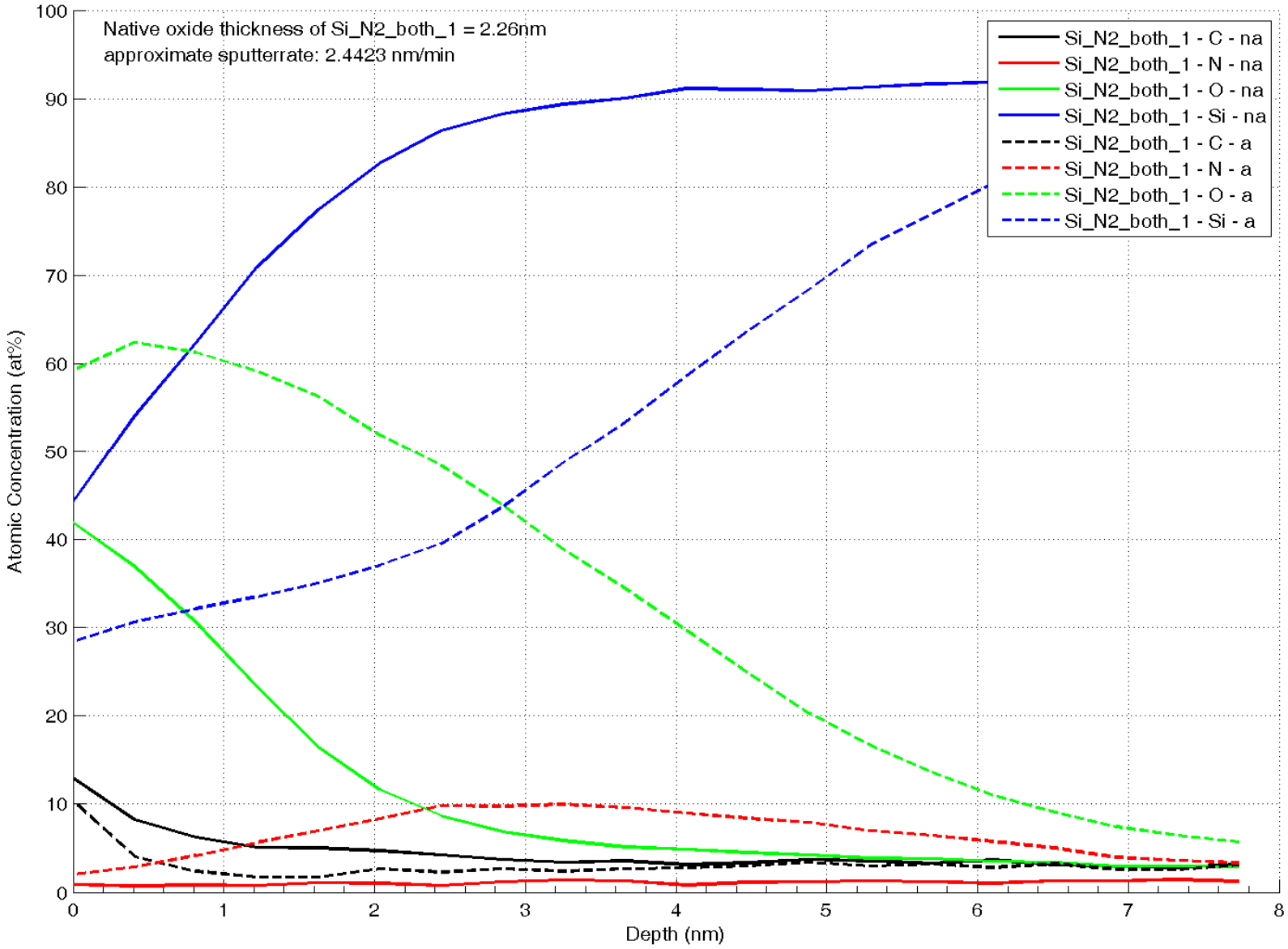


AES samples

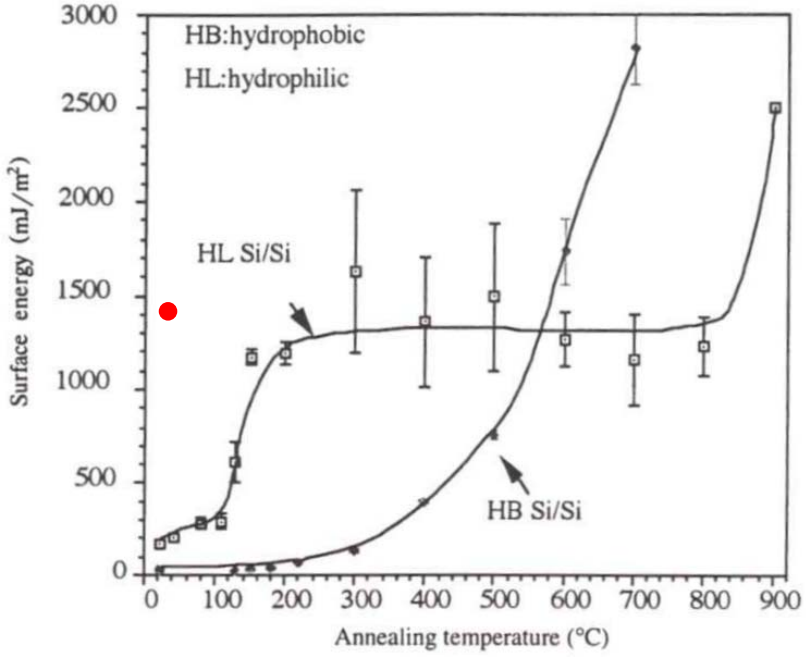
- samples were half covered by other wafer pieces during activation
- therefore on one sample both an activated and an non-activated side was available
- both sides were analyzed in one common depth profile → sputter conditions were equal
- native oxide thickness was measured with Spectroscopic Ellipsometry → depth reference for the depth profile data

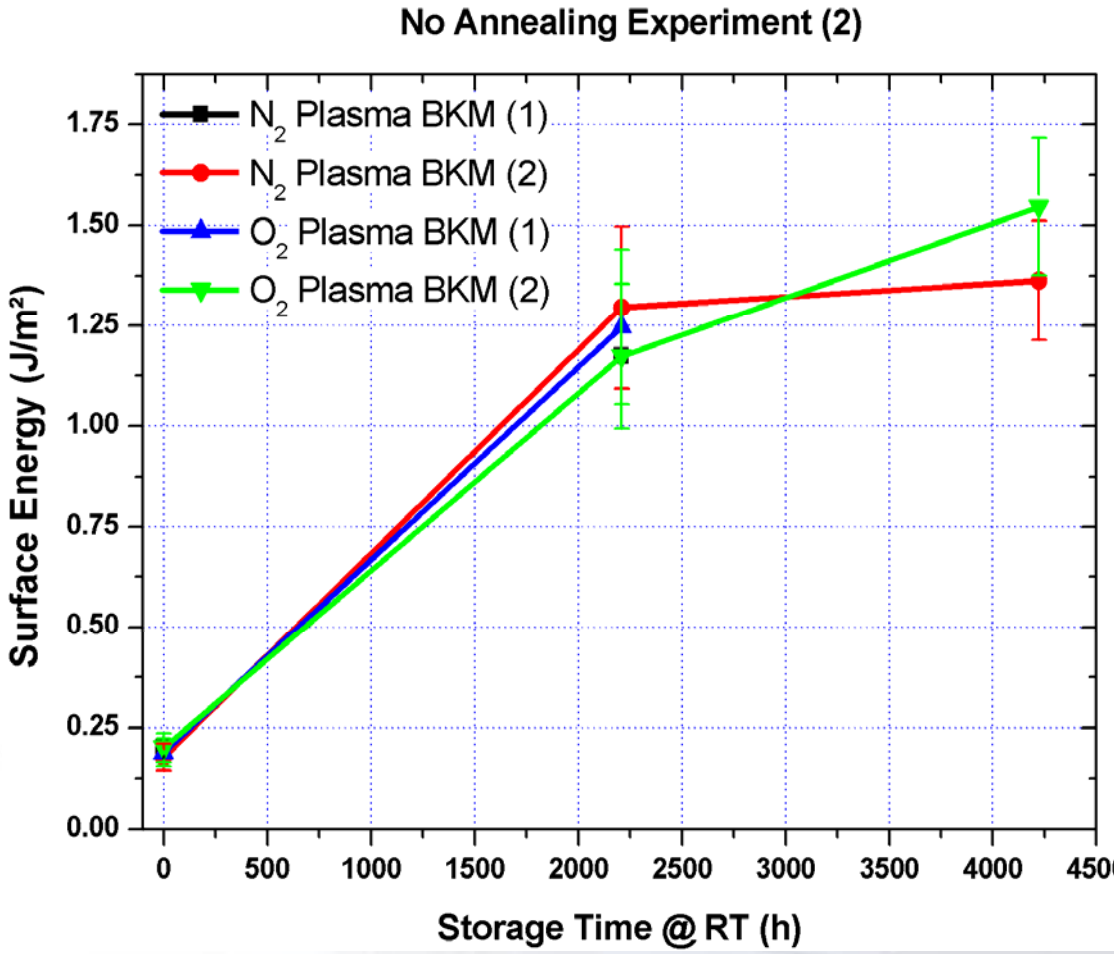


Auger Analysis – Comparison a and na



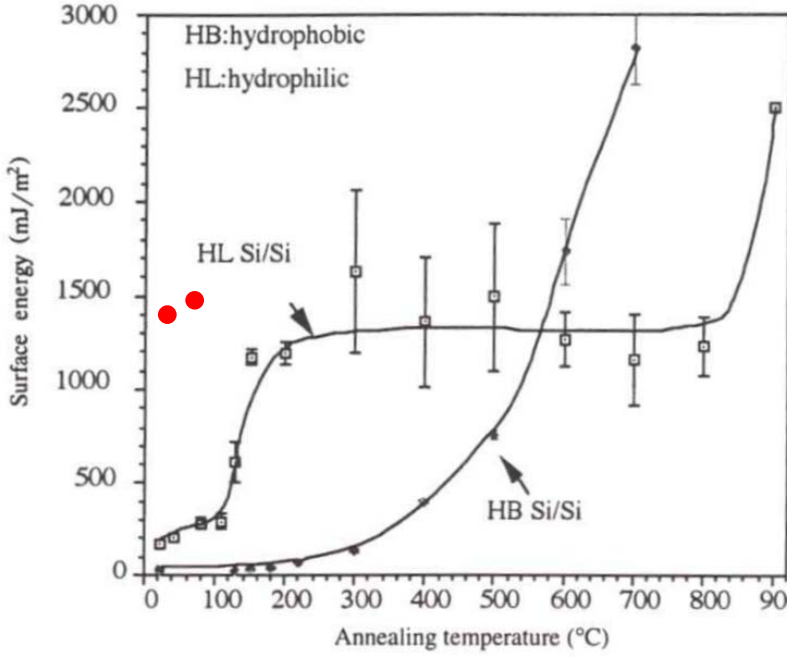
Bond Strength PAWB - no annealing

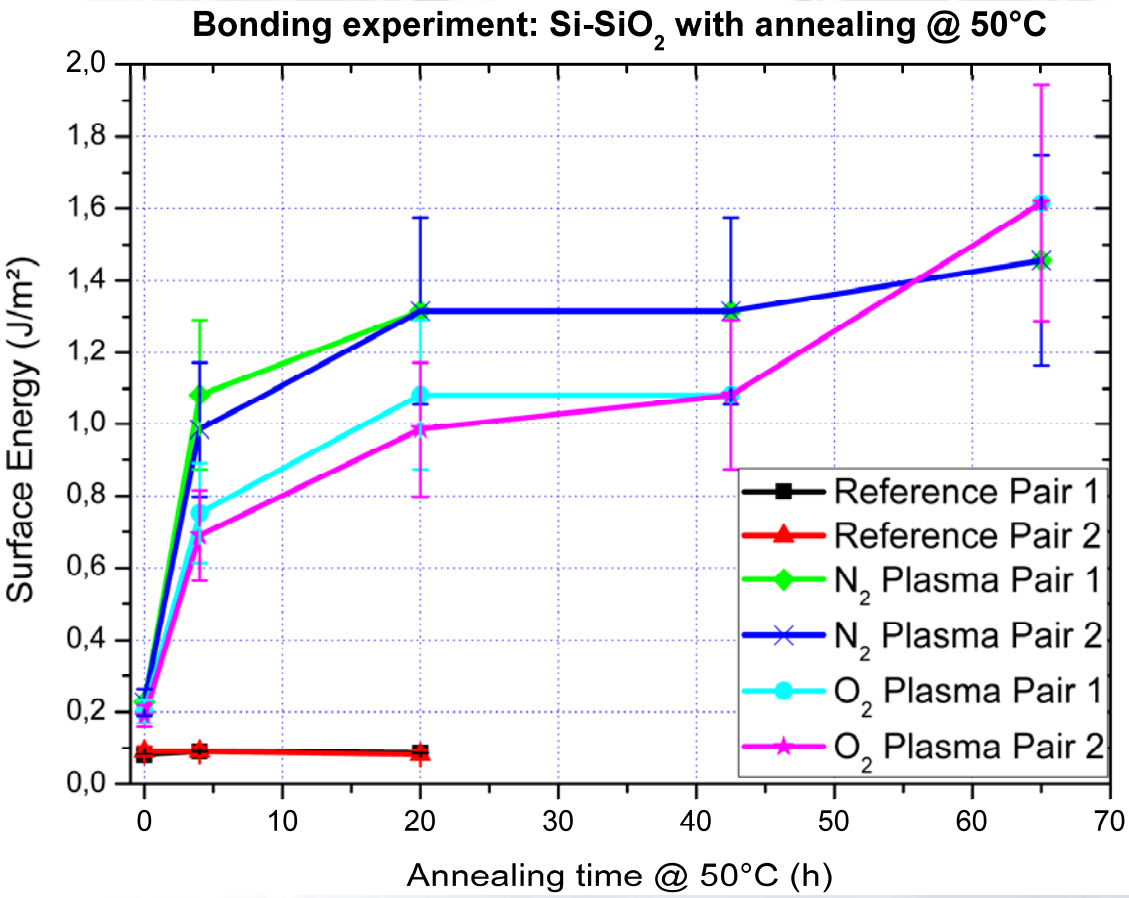




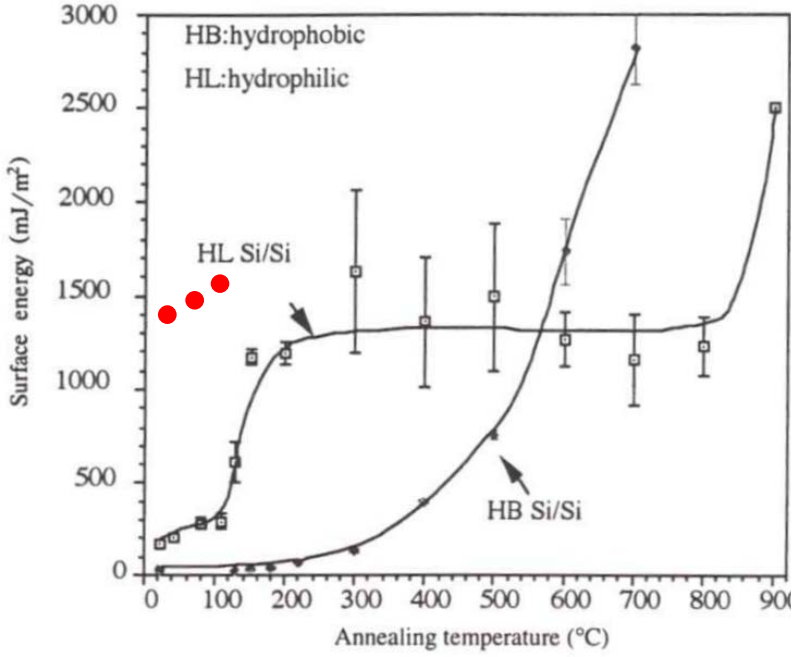
EVG

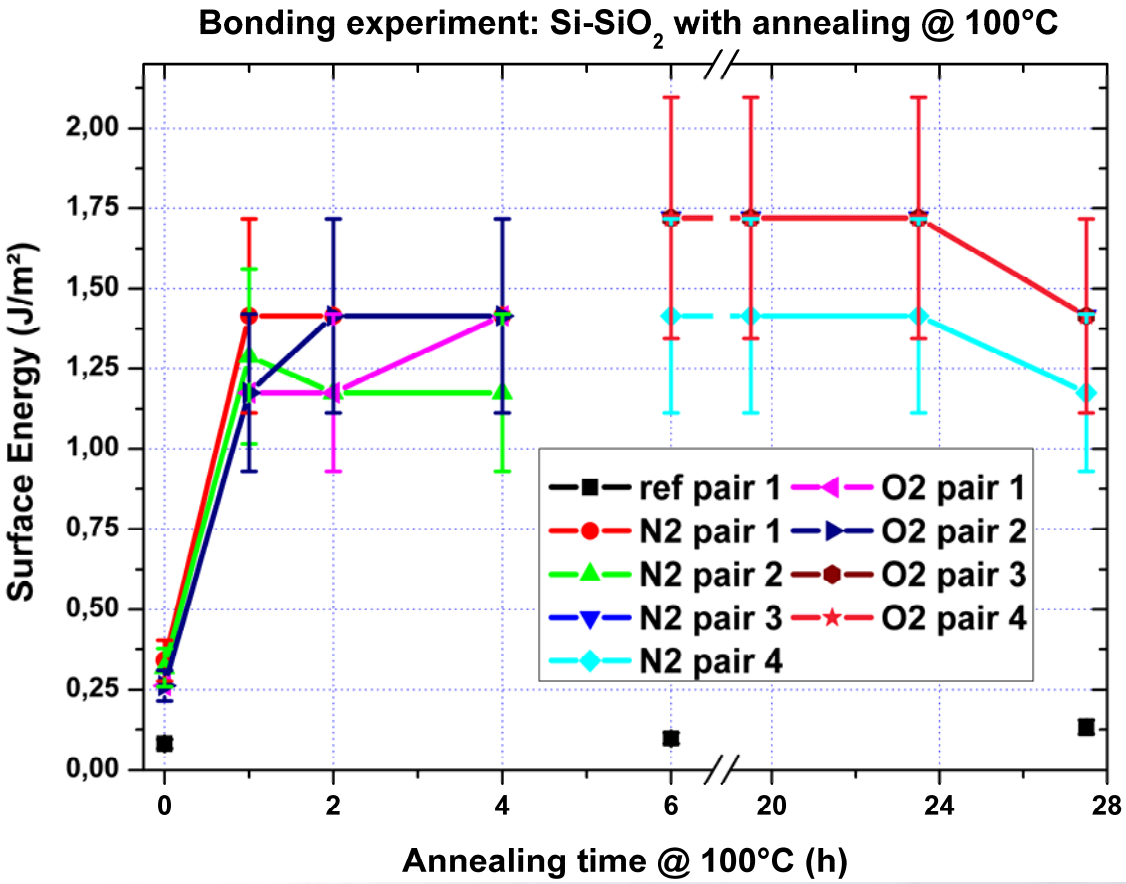
Bond Strength PAWB - annealing @ 50°C



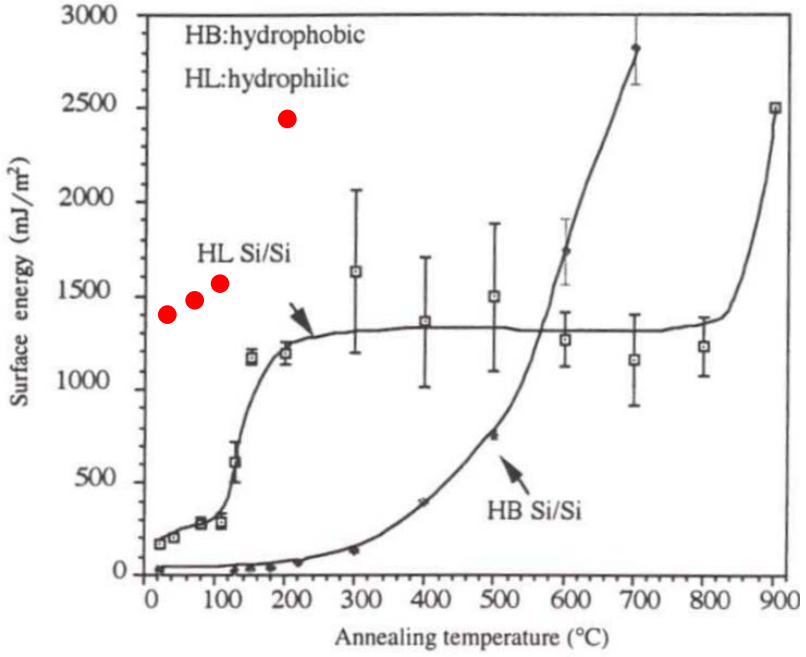


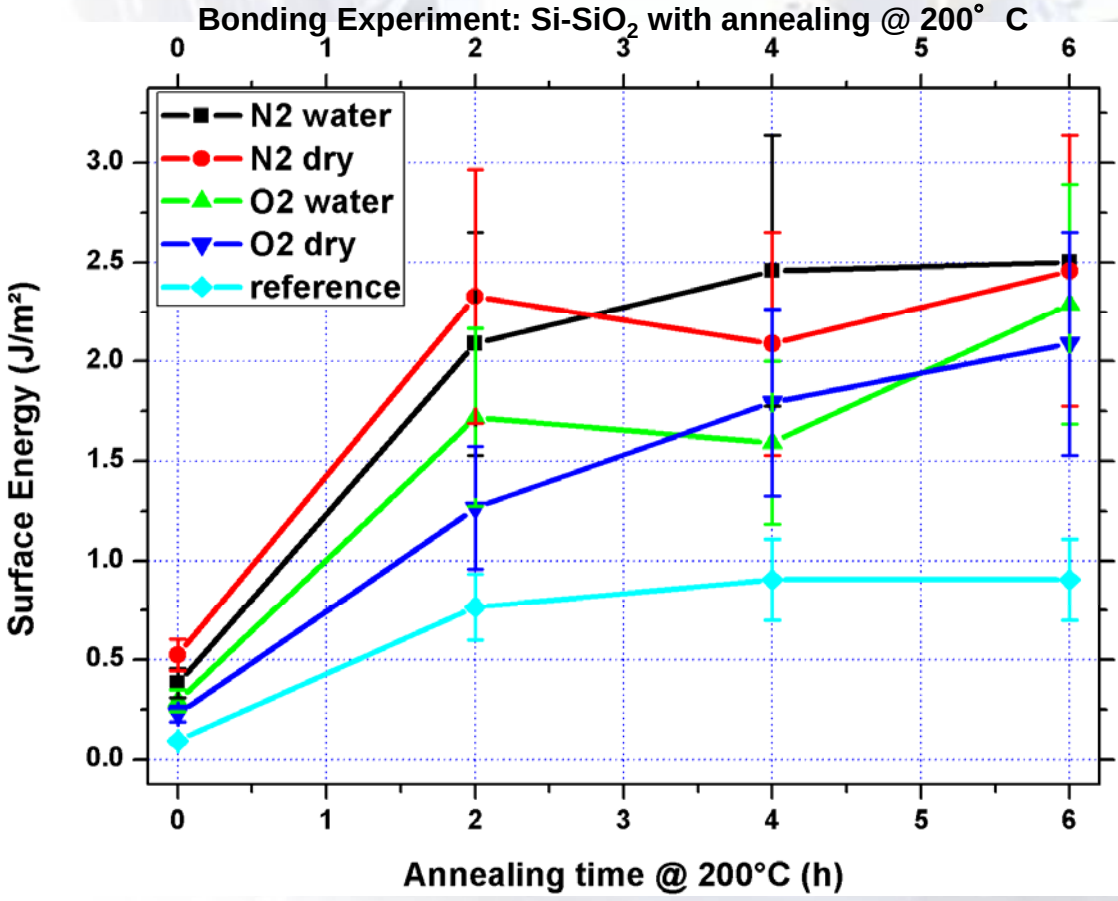
Bond Strength PAWB - annealing @ 100°C





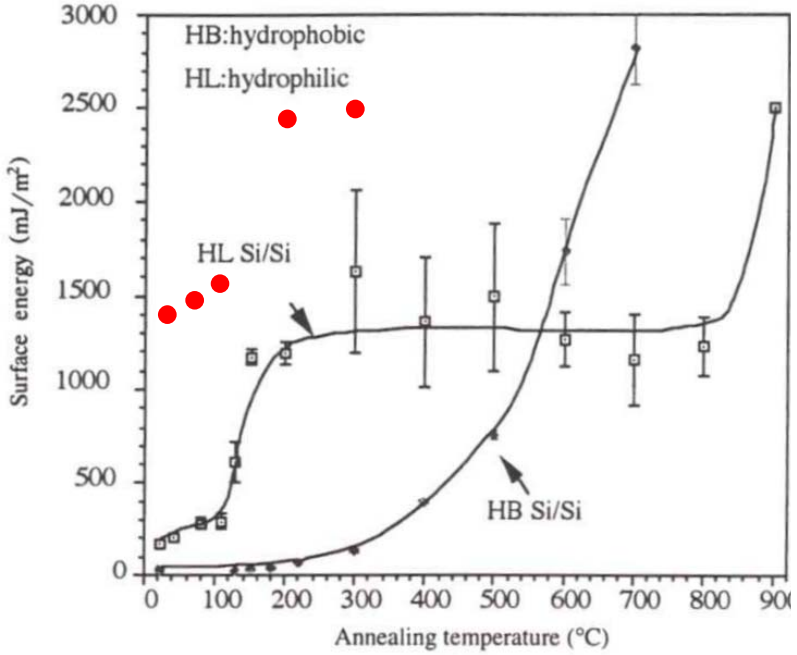
Bond Strength PAWB - annealing @ 200°C

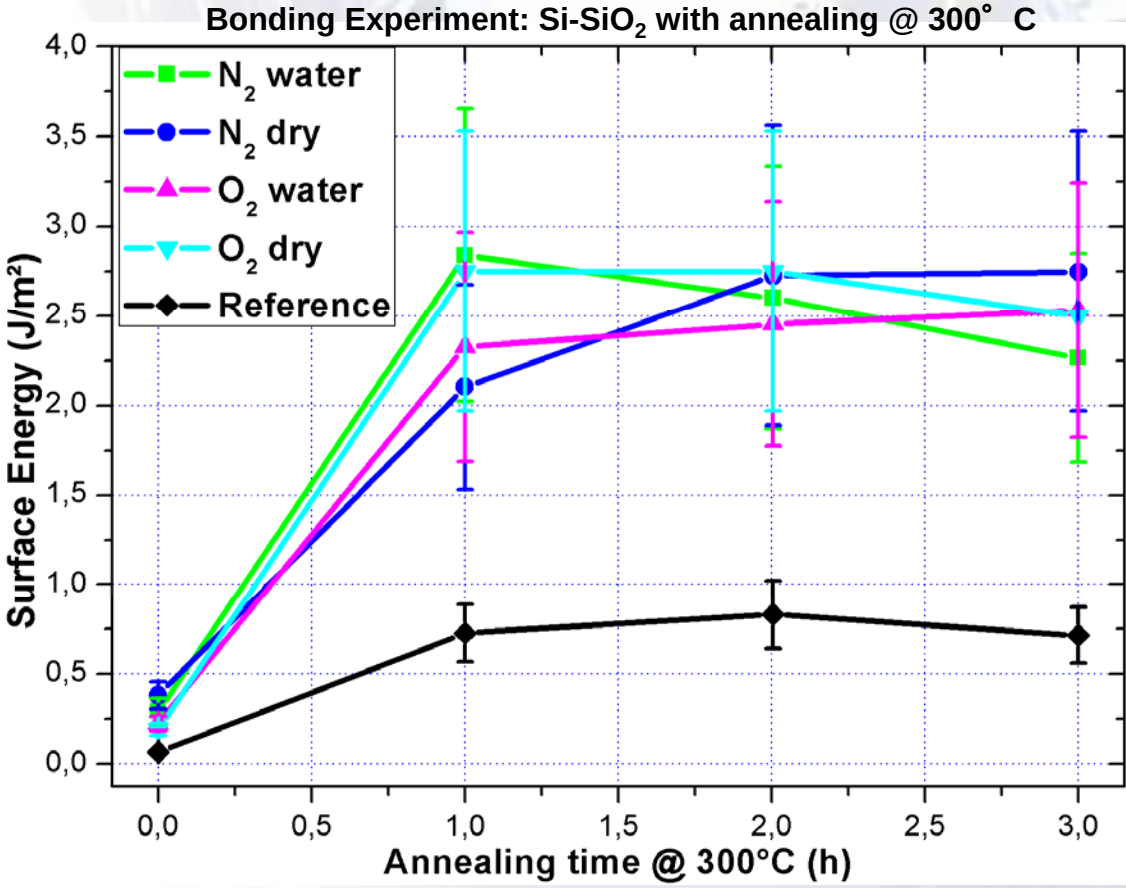




EVG

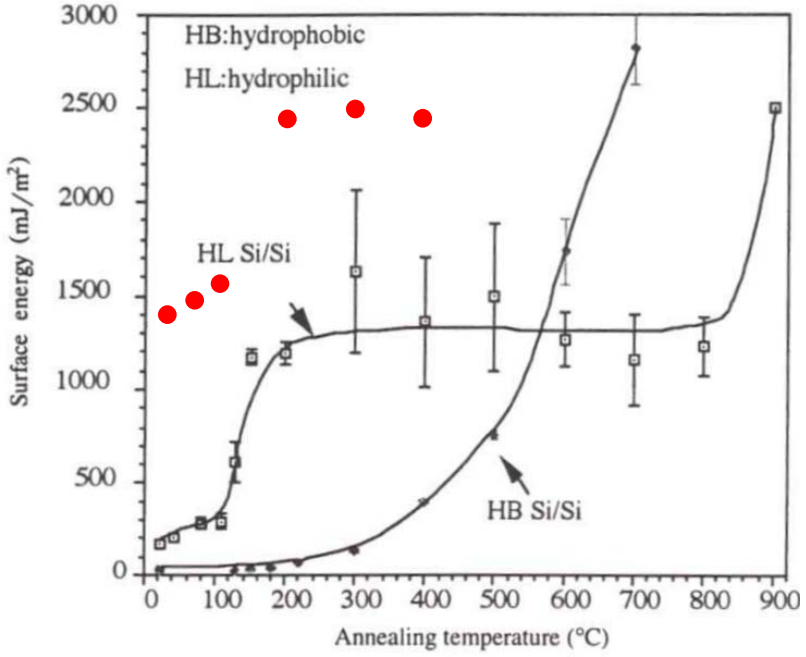
Bond Strength PAWB - annealing @ 300°C



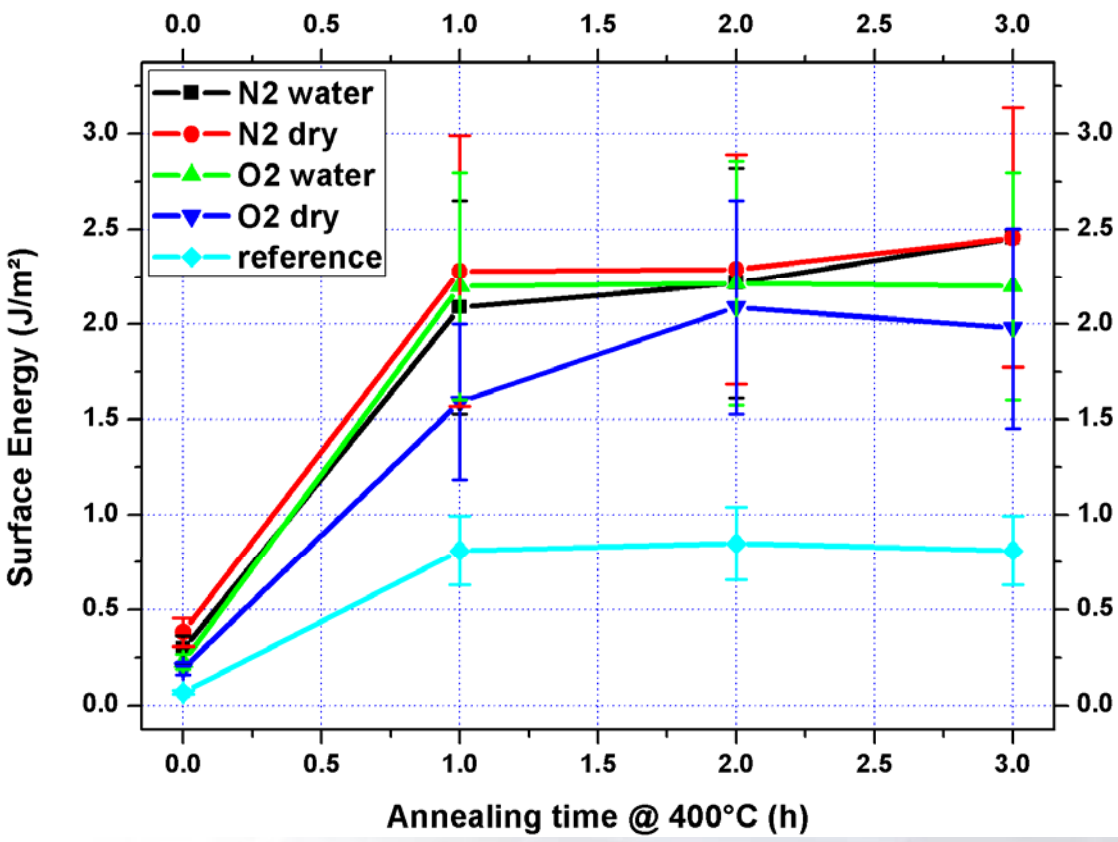


EVG

Bond Strength PAWB - annealing @ 400°C

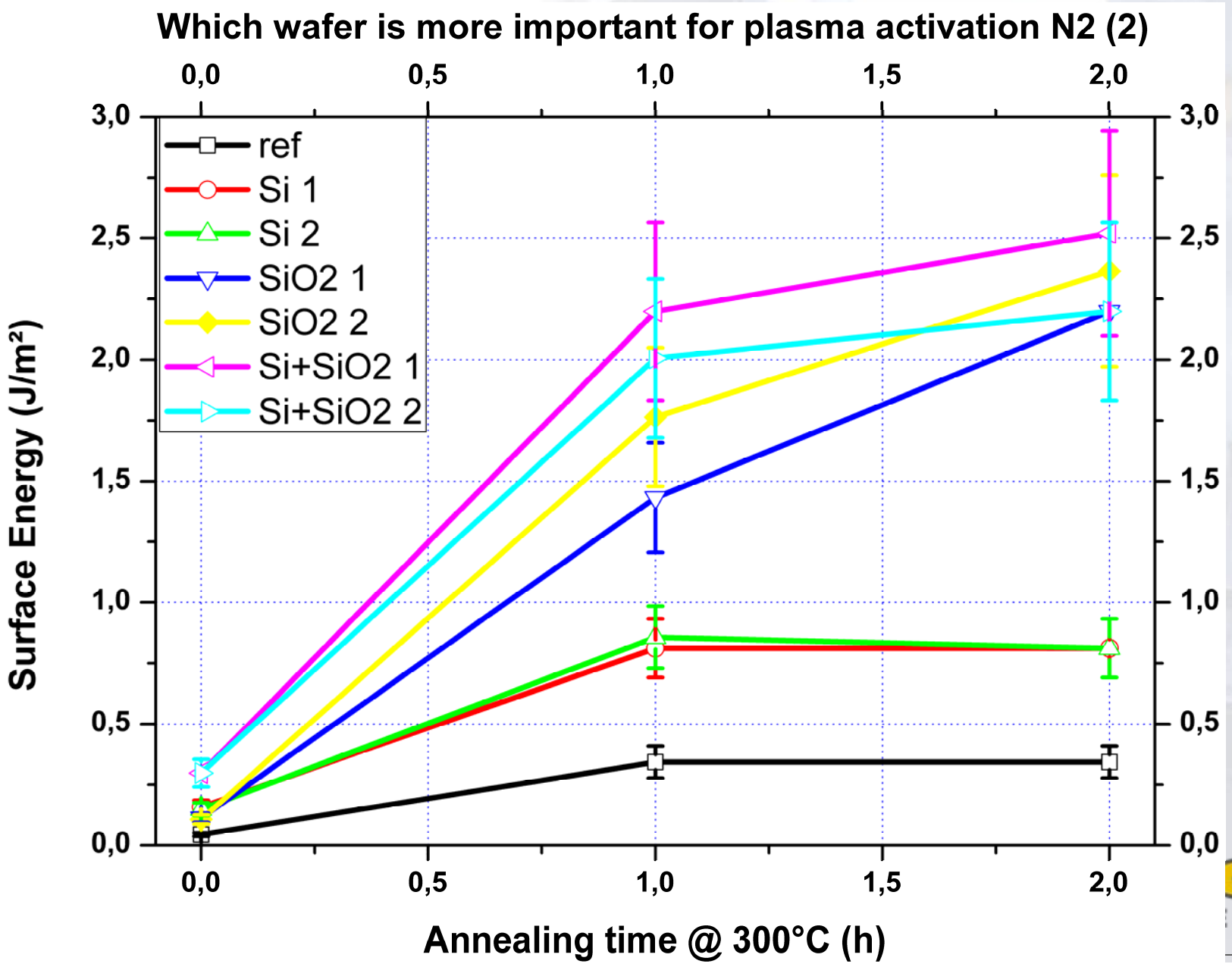


Bonding Experiment: Si-SiO_2 with annealing @ 400° C



EVG

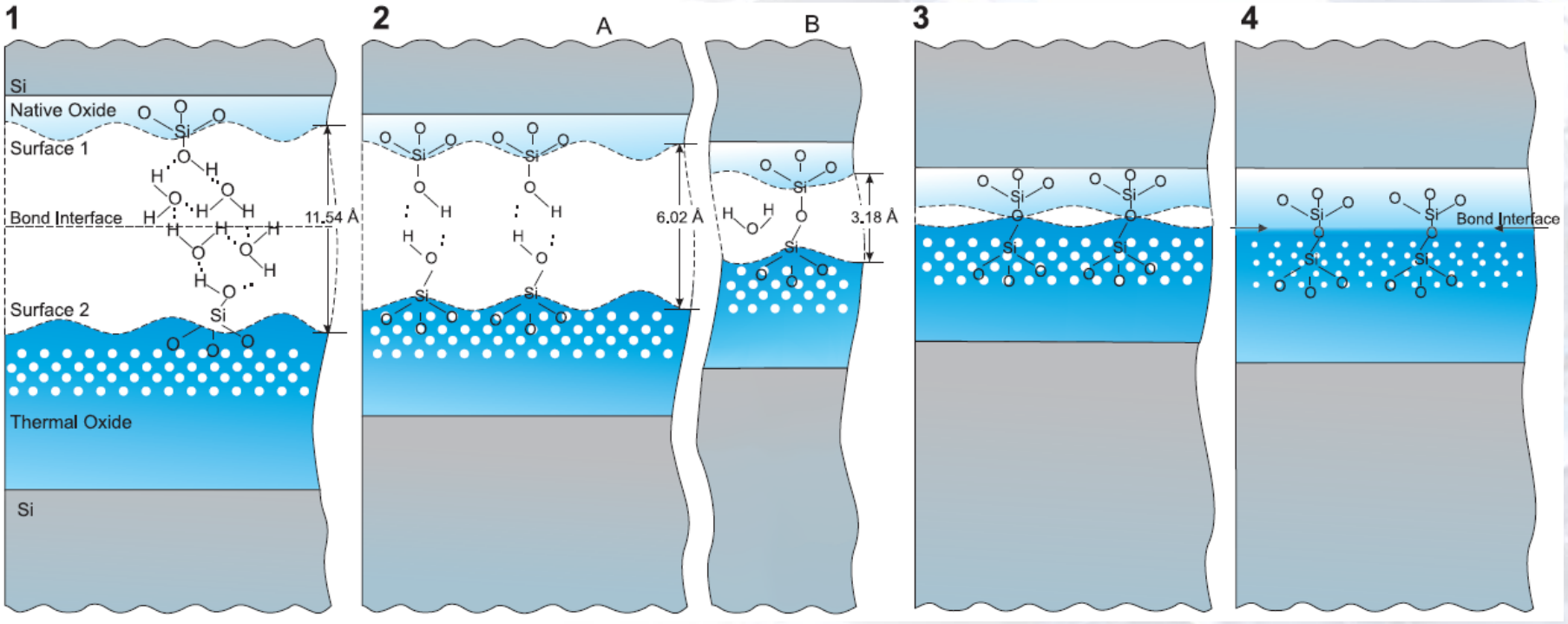
Which Wafer is more important (2)



New Model for Plasma Activated Wafer Bonding

Several patents pending for the model presented in the next slides.

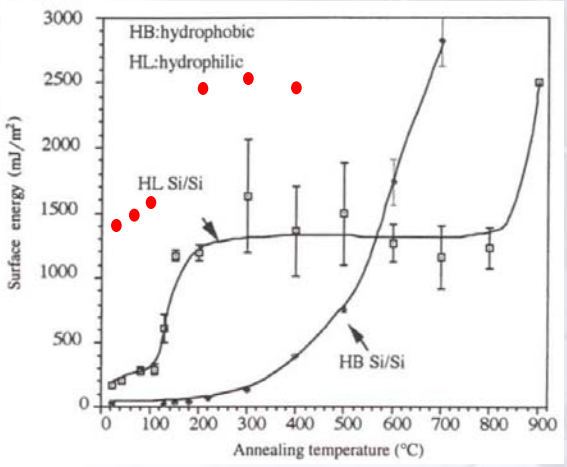
New Model for Plasma Activated Wafer Bonding



Stages 1-3: occur at RT

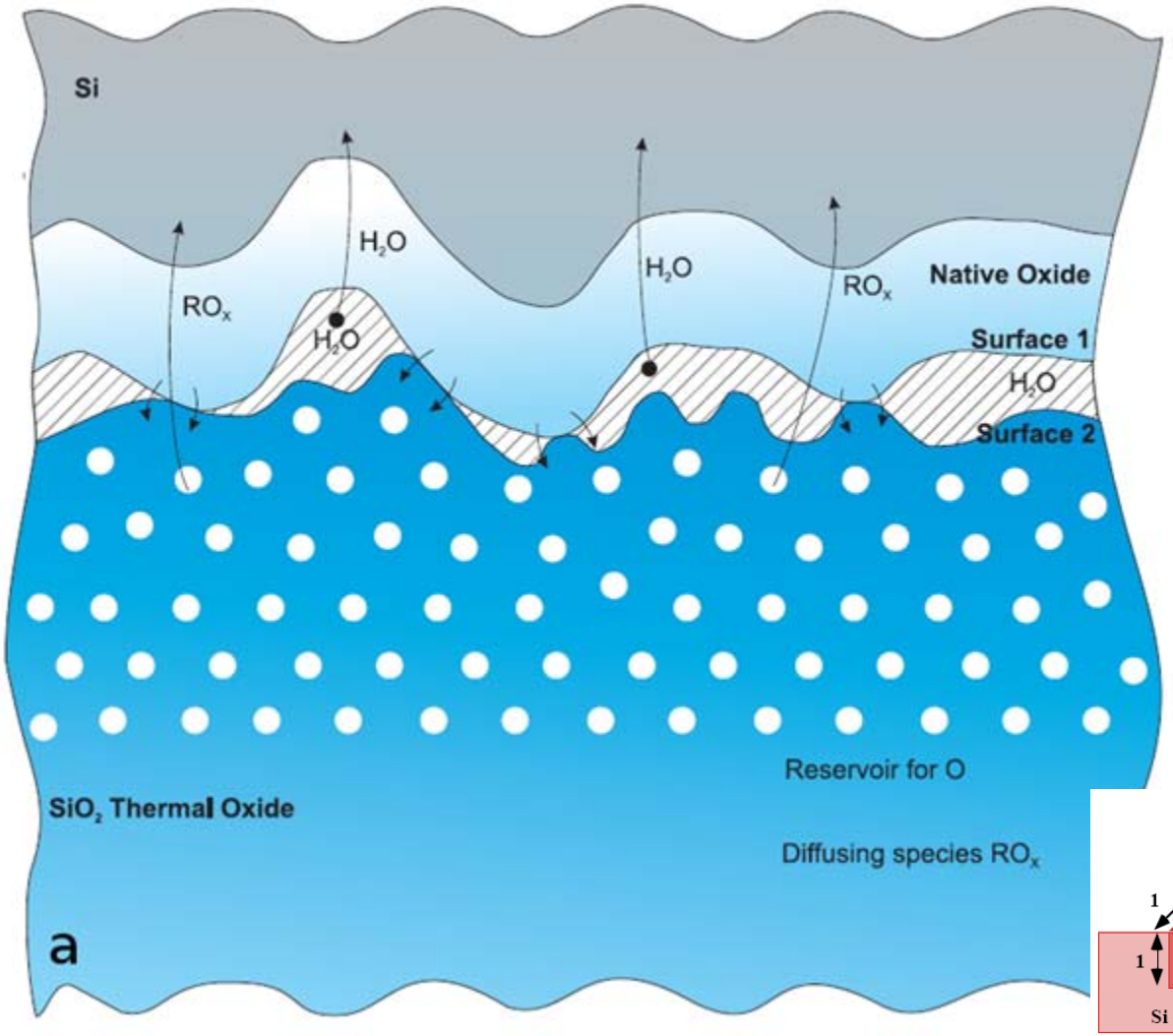
Stage 4: at elevated temperatures

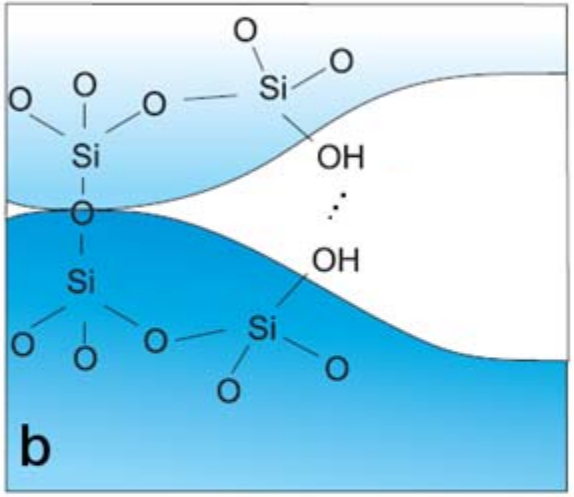
100°C < T < 200°C

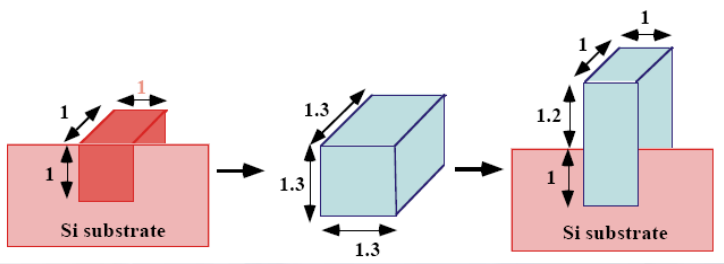


EVG

Processes at the Bonding Interface



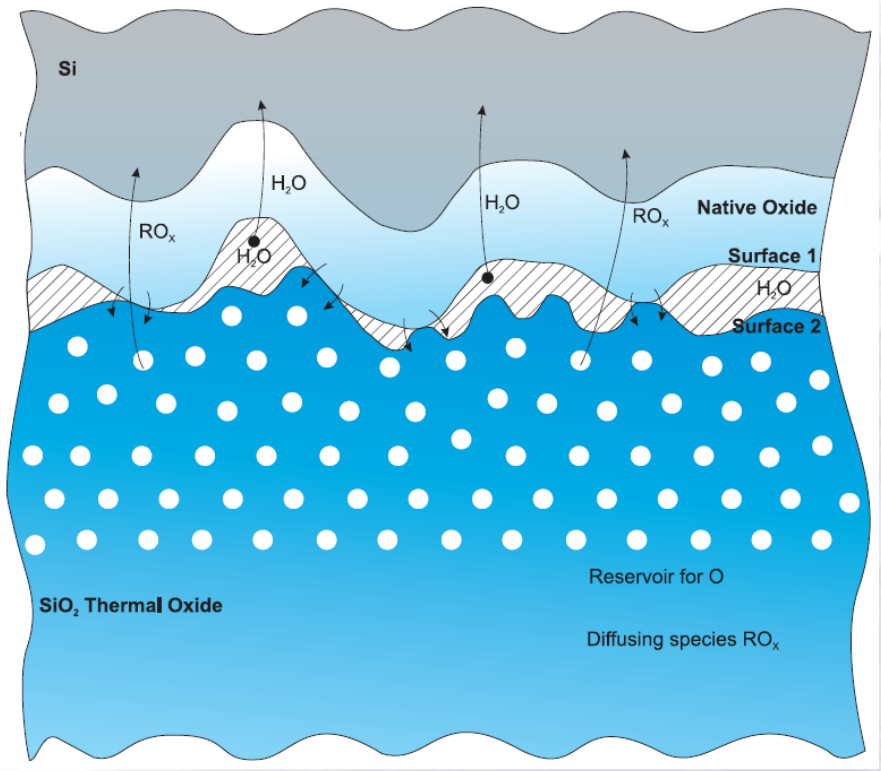




EVG

Summary of the New Model

- create a reservoir for a reactant (e.g. H_2O) which can oxidize the substrate
- fill the reservoir with the reactant
- Slightly elevate temperature in order to allow reaction between reactant and reaction layer



Some Data Points / Trends

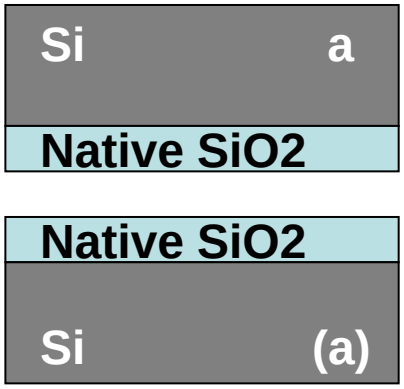
- For Th. Ox – Si bonding, it is more important to activate the Th. Ox wafer.
  → Reservoir is needed in the Th.Ox wafer.
  → Activation of the native Ox assists, as it makes the native Ox more permeable to diffusion.
- For Deposited (TEOS, etc.) Ox – Si bonding, it is more important to activate the native Ox wafer
  → Deposited Ox is already more porous and therefore, in some cases (depending on oxide quality) able to store humidity.
  → Activation of the native Ox makes the native Ox more permeable to diffusion.

Some Data Points / Trends

- For therm. Ox to Si, N2 activation shows a tendency of slightly better results. This is believed to be related to the fact that N2 is present as N2 ions while O2 is present as O ions.
- For bonding of native oxide to native oxide, short activation times with O2 are recommended, as implanted O2 can be converted to SiO2 during annealing.
  → Excessive amounts of O2 will still lead to bubbles formation (see results)

Examples for Bonding based on Oxidation

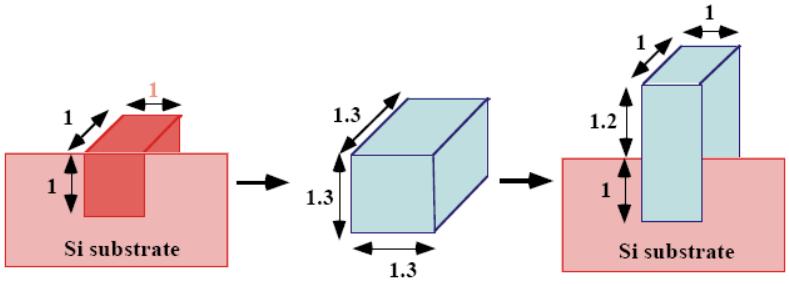
2



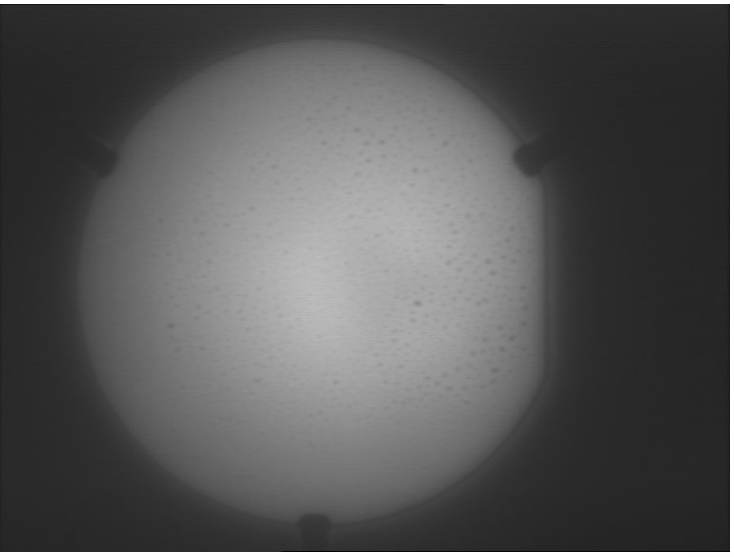
- Low enough implant dose to avoid bubbles
- creation of a reservoir by plasma activation avoids bubbles due to gaseous byproducts typically seen w/o plasma activation

a … activated surface

(a) … optionally activated surface



Voids - Si with Si – after 2h @ 300°C



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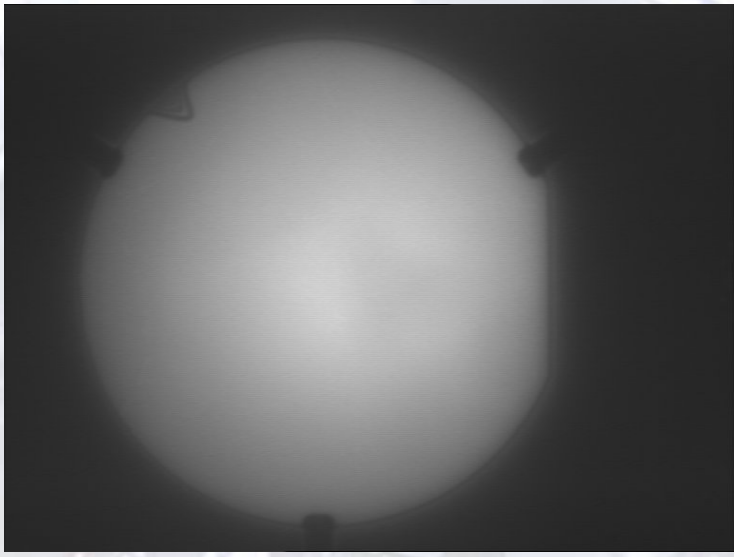
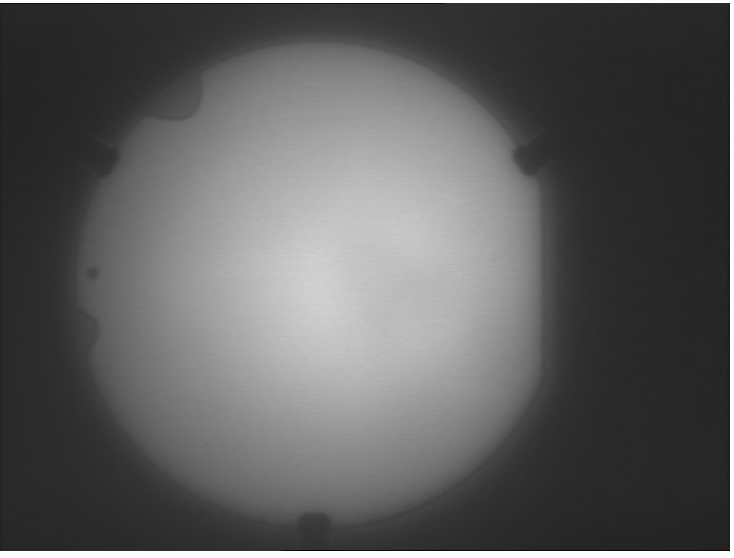
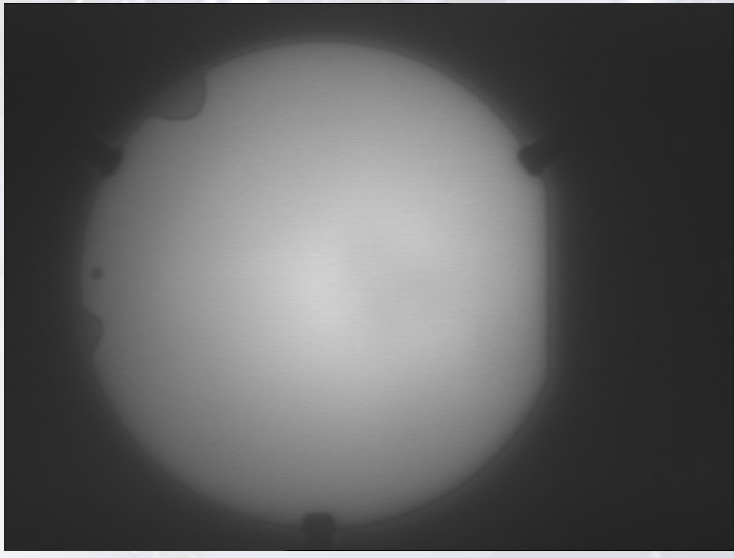


5s activated

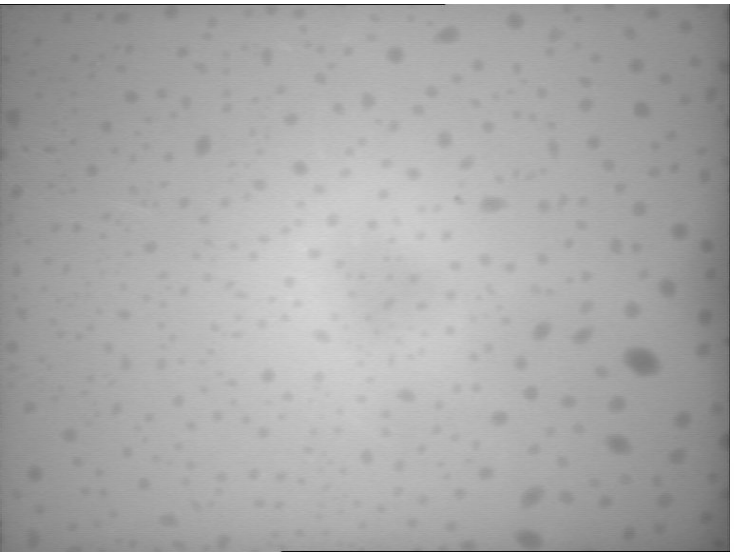


10s activated



30s activated

Voids - Si with Si – after 2h @ 300°C



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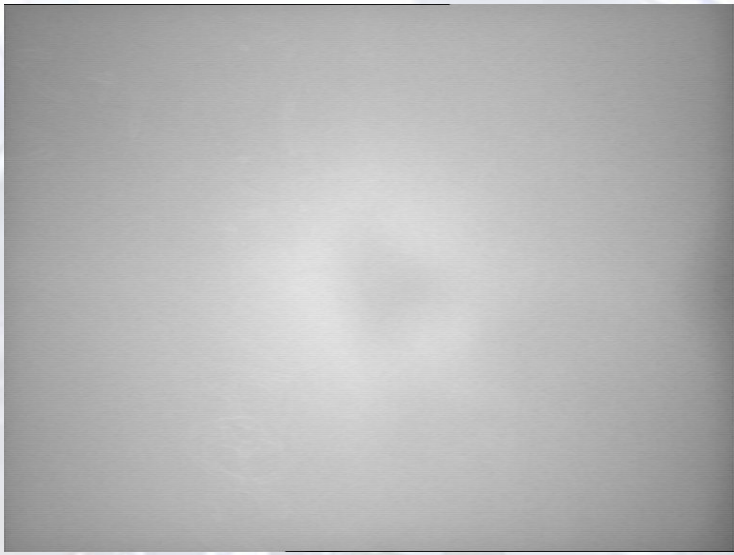
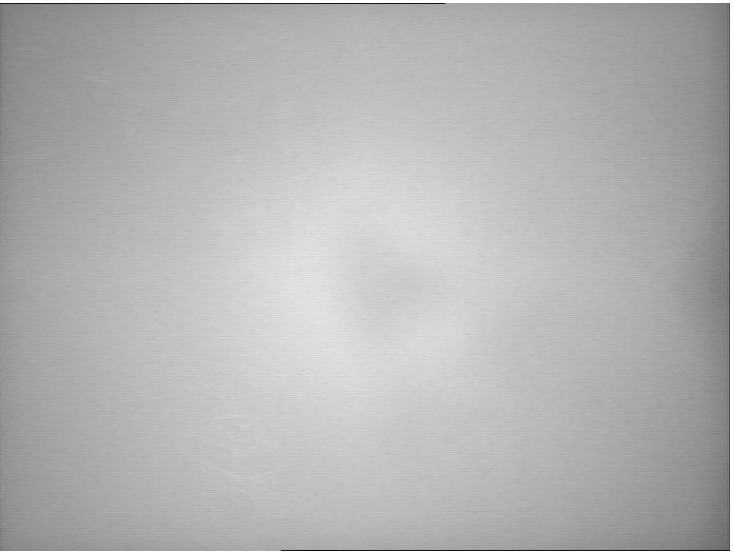
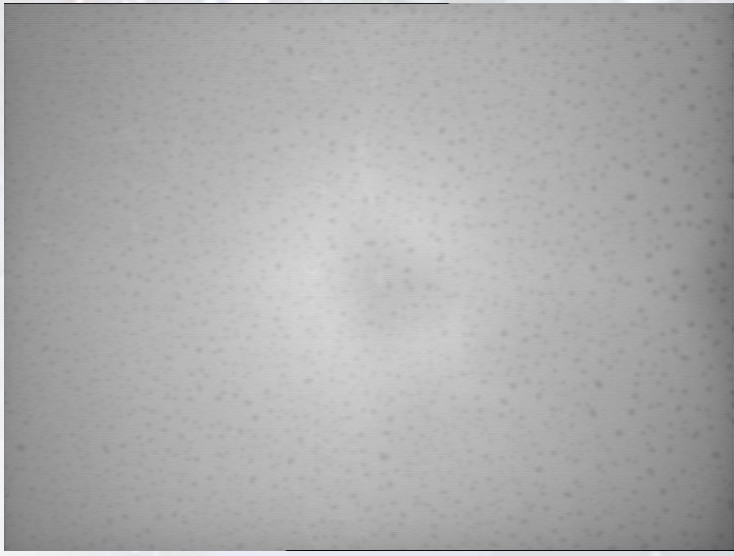


5s activated



10s activated



30s activated