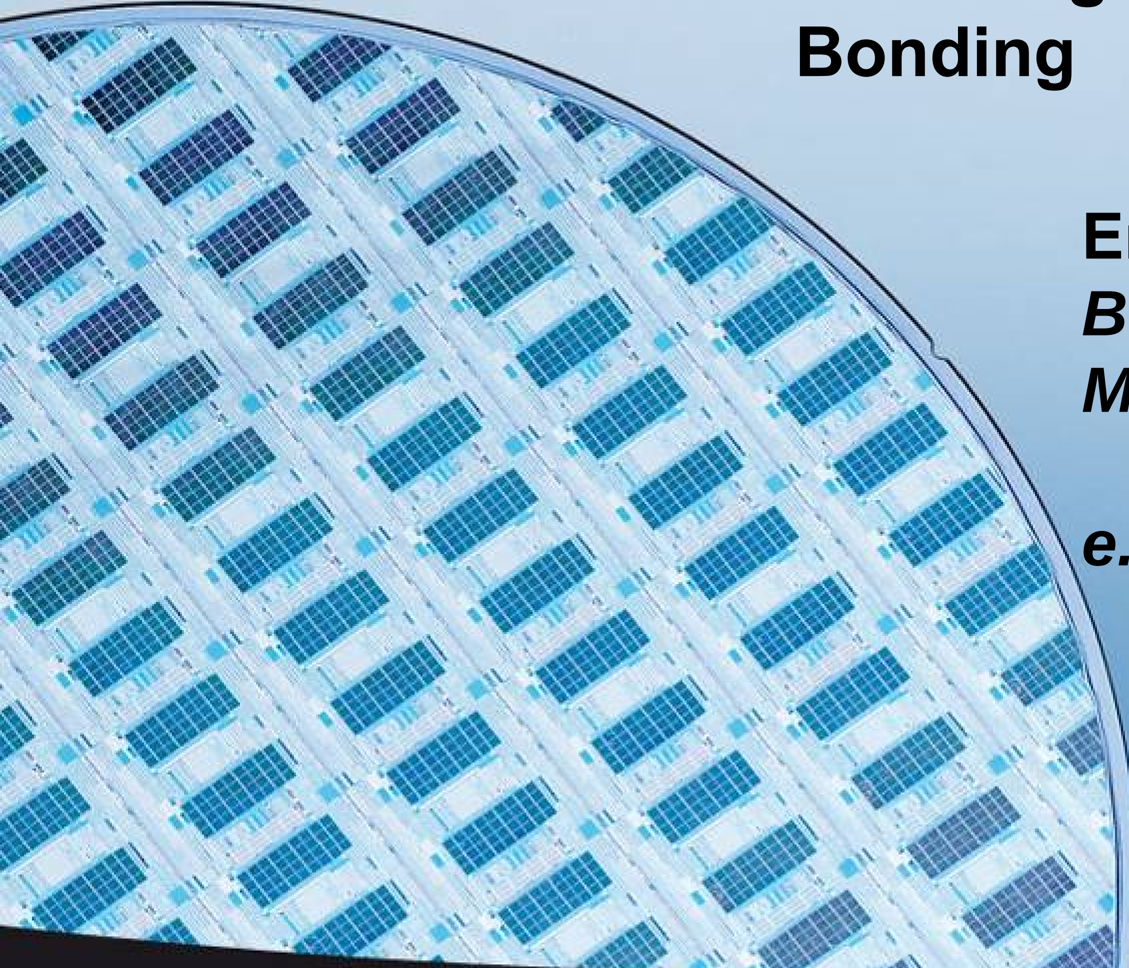
EV Group

Plasma Activation – An Enabling Technology for Wafer Bonding



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PAG
Semicon West 2010

EVG

Outline

- **Why Bond – driving forces**
- Bonding Processes
- Alignment Processes
- PA (PLASMA Activated) Bonding

Why Bond?

Bonding allows

- Combining
  - Materials
    - Si
    - Glass
  - Processes
    - CMOS
    - MEMS
  - Functions
    - Mechanical
    - Sealing / Isolation (hermeticity or micro channels)
    - Electrical
    - Thermal
    - Acoustic
- Parallel Processing
  - Up to 15,000 parts processed in one time
- Repartitioning
  - Cost / Performance
  - Decoupling of chip revisions
- Performance
  - Decreasing signal path length
  - Form factor
- Increased integration – easier for customer to design in (customer has digital I/O)

This has enabled

- MEMS Devices
    - Accelerometers & Gyroscopes
      - Automotive
      - Gaming
    - Pressure sensors
  - SOI wafers
  - Microfluidics
  - etc
- Increase Device Performance
  - Special substrates
  - Use the Z dimension
    - 3D ICs
- Combine Techologies
  - Combine techologies (Image sensor & processor)
- MOEMS Devices
  - Parallel assembly of image capture assemblies
  - Parallel assembly of image emitting devices
  - (Sensor/Emittor/Modulator with Optics)
- MEMs packaging
  - Decrease Cost
  - Hermetic packaging by WLP

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Plasma Activation – An Enabling Technology for Wafer Bonding

Outline

- Why Bond – driving forces
- **Bonding Processes**
- Alignment Processes
- PA (PLASMA Activated) Bonding

Types of Bonding

- Wafer Bonding (1)
  - Intermediate Layer
    - Metal
      - Thermocompression (6)
      - Solder
        - Eutectic
        - TLP (4)
    - Polymer (2, 3)
      - Thermoset
      - Thermoplastic
      - UV Set (7)
    - Glass
      - Glass Frit
  - No Intermediate Layer
    - Fusion (5)
    - Anodic

NOTES
1. May be mechanically or optically aligned. Bonding process will effect final alignment results
2. May be used for permanent or temporary bonding.
3. Inludes adhesive bonding
4. TLP – Transient Liquid Phase
5. Also called direct bonding or molecular bonding. Has strict requirements for flatness, surface finish, and contamination.
6. Also called metal diffusion
7. Requires special bond chamber.

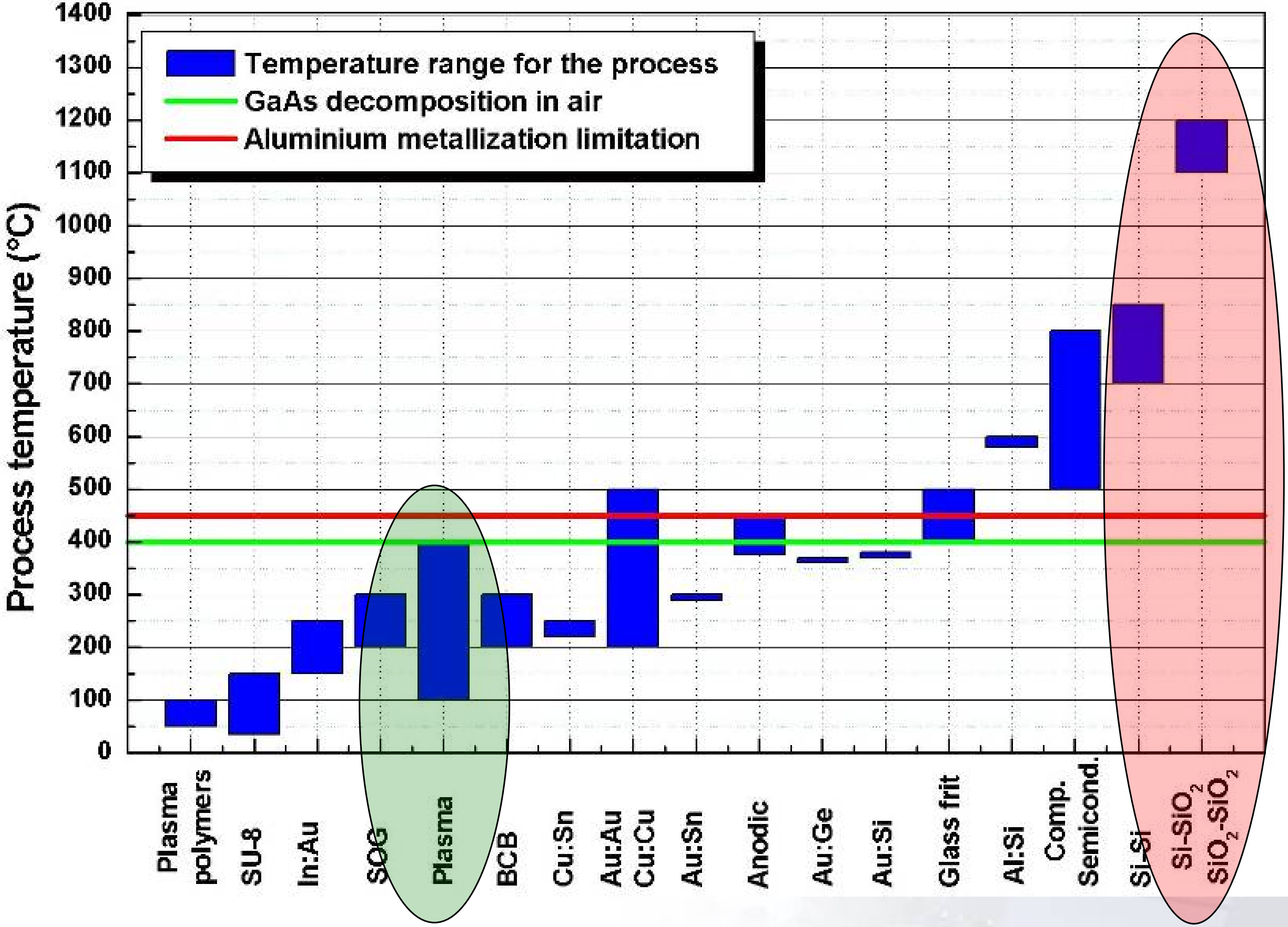
Bonding Process Requirements

	No Intermediate Layer			Intermediate Layer					
	Anodic Bonding (Electric Field)	**Direct Bonding**	**Plasma Activated Direct Bonding**	**Glass Frit**	**Thermo Compression**	**Solder / Eutectic / TLP**	**Adhesive**	**Epoxy (thermally cured)**	**Epoxy (UV cured)**
Surface Roughness	< 20 nm	< 0.5nm	< 2 nm	< 1000 nm	< 2 nm	< 1000 nm	< 1000 nm	< 1000 nm	< 1000 nm
Layer Thickness	NA	NA	NA	Determined by silk screen process	~ 1000 nm each side	~ 1000 nm each side	?	?	?
Process Temperature	400 - 500 C	1000 C (anneal)	Room Temp & 200-300 C anneal	400 - 500 C	300 - 500 C depending on metal	200 -500 C depenting on metal	< 200 C depending on adhesive	< 200 C depending on adhesive	~ Room Temperature
Cleanroom Environment (FS209E)	100	10 or 1	10	1000	10	100	100	1000	1000
Sensitivity to Particles	Medium	High	High	Low	Medum	Medium	Low	Low	Low
Sensitivity to Surface Contamination	Medium	Very High	Very High	Medium	High	High	Low	Low	Low
Na present	Yes	No	No	No	No	No	No	No	No
Cycle Time (minutes)	45 - 90	Bond ~ 1 Anneal - hrs	Bond ~ 1 Anneal hrs	45 - 90	30 - 90	30 - 60	5 - 45	15-30	5 -15

Bonding Process Performance

	No Intermediate Layer			Intermediate Layer					
	Anodic Bonding (Electric Field)	Direct Bonding	Plasma Activated Direct Bonding	Glass Frit	Thermo Compression	Solder / Eutectic / TLP	Adhesive	Epoxy (thermally cured)	Epoxy (UV cured)
CMOS Compatible	No	No	Yes	No	Yes	Some	Some	Yes	Yes
Electrically Conductive	No	No	No	No	Yes	Yes	No	No	No
Vacuum Low < 1 mbar	Yes	Yes	Yes	Yes	Yes	Yes	No	No	?Yes
Vacuum High < 2 mbar	No	No	Yes	No	Yes	Yes	No	No	No
Current Manufacturing Volume;	High Mature	High Mature	Low Early	High Mature	Medium to High Mature	High Mature	High Mature	High Mature	High Mature
Mechanical Strength Sufficient for Backgrinding	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Max Post Bond Temperature	> 1000 C	> 1000 C	> 1000 C	350-450 C depending on Glass Frit	Limited by melting point of metal or eutectic	Limited by melting point of solder except for TLP is higher	Low, limited by adhesive	Low, limited by adhesive	Low, limited by adhesive

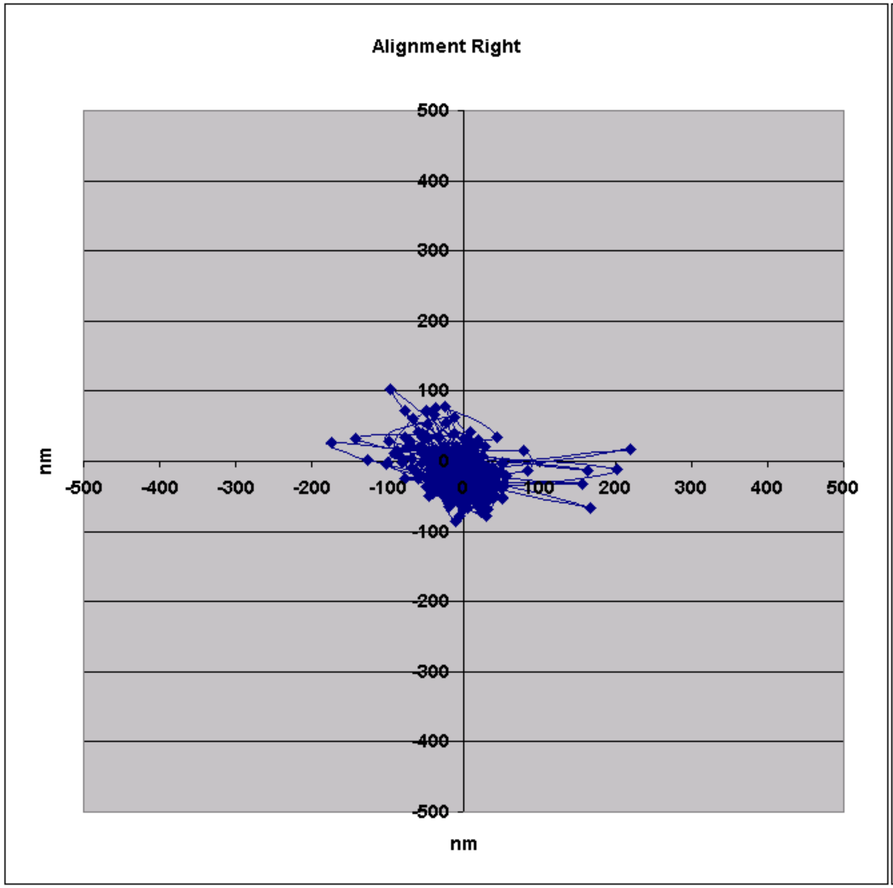
Maximum temperature ranges of common wafer bonding processes

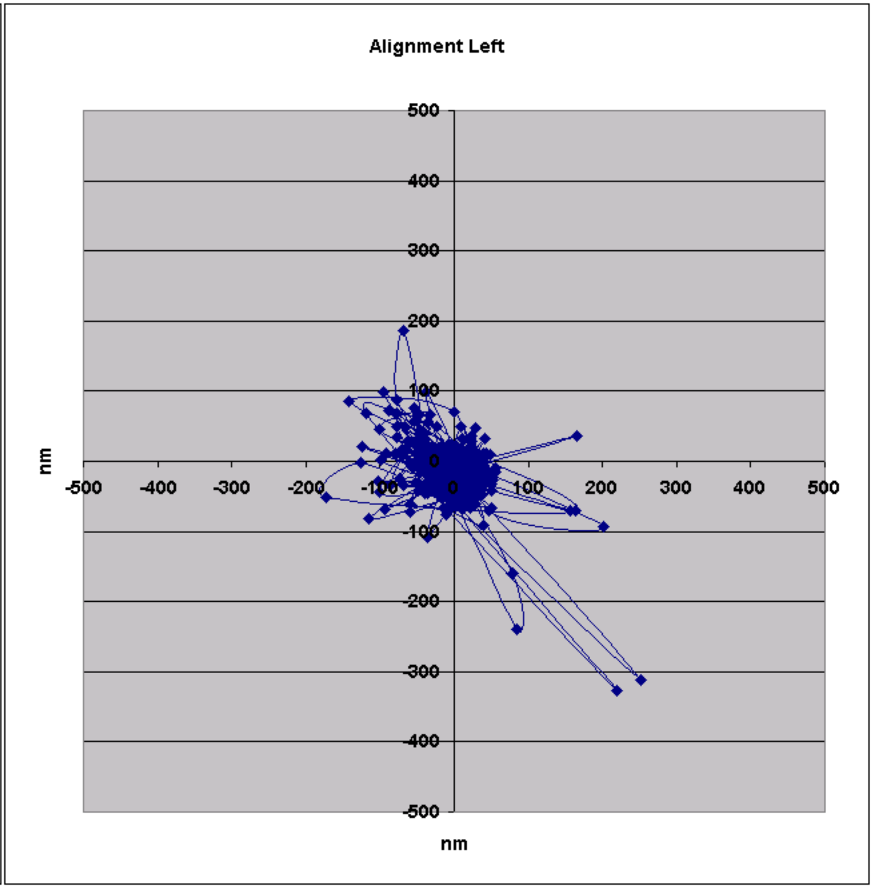


Outline

- Why Bond – driving forces
- Bonding Processes
- **Alignment Processes**
- PA (PLASMA Activated) Bonding

SmartView®NT Results





	XR	YR
Avg	-6,78663	-15,072
Std	38,00791	26,95548
3*Std	114,0237	80,86644

	XL	YL
Avg	48,415	30,91665
Std	61,07386	48,09172
3*Std	183,2216	144,2751

<200nm (3 Sigma) Alignment Capability

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SmartView®NT

Plasma Activation – An Enabling Technology for Wafer Bonding

- Wafer Growth During Bonding
  - Wafer Size 300 mm wafer
  - Silicon TCE ~3ppm
  - Alignment Temp 25C
  - Bond Process Temp 425C

  - Results in wafer growth of ~380 um

Outline

- Why Bond – driving forces
- Bonding Processes
- Alignment Processes
- **PA (PLASMA Activated) Bonding**

Plasma Chemistry

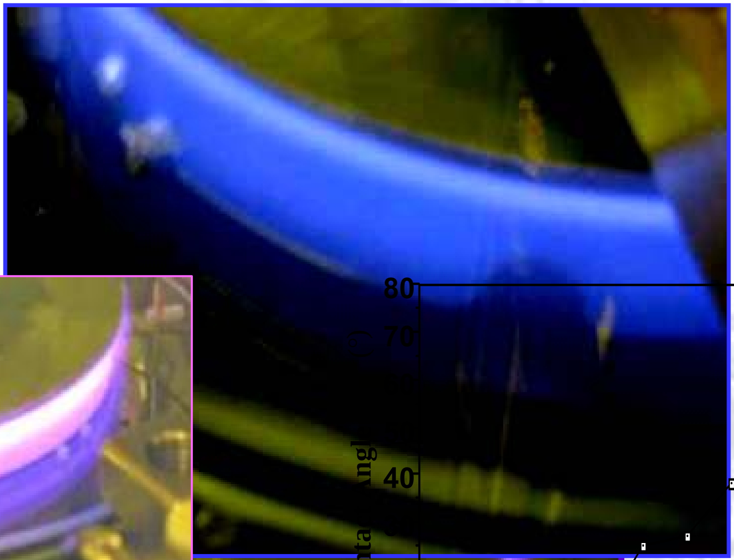
Custom

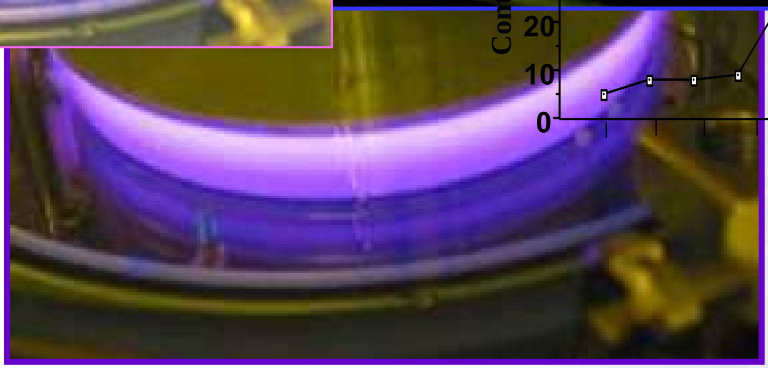
Hydrogen

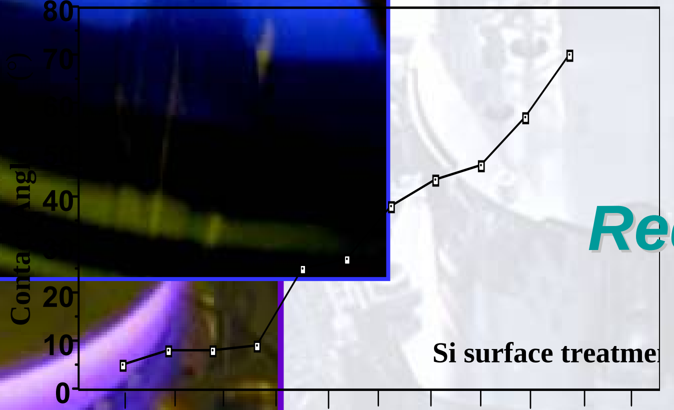
Oxygen

Reactive

Reducing







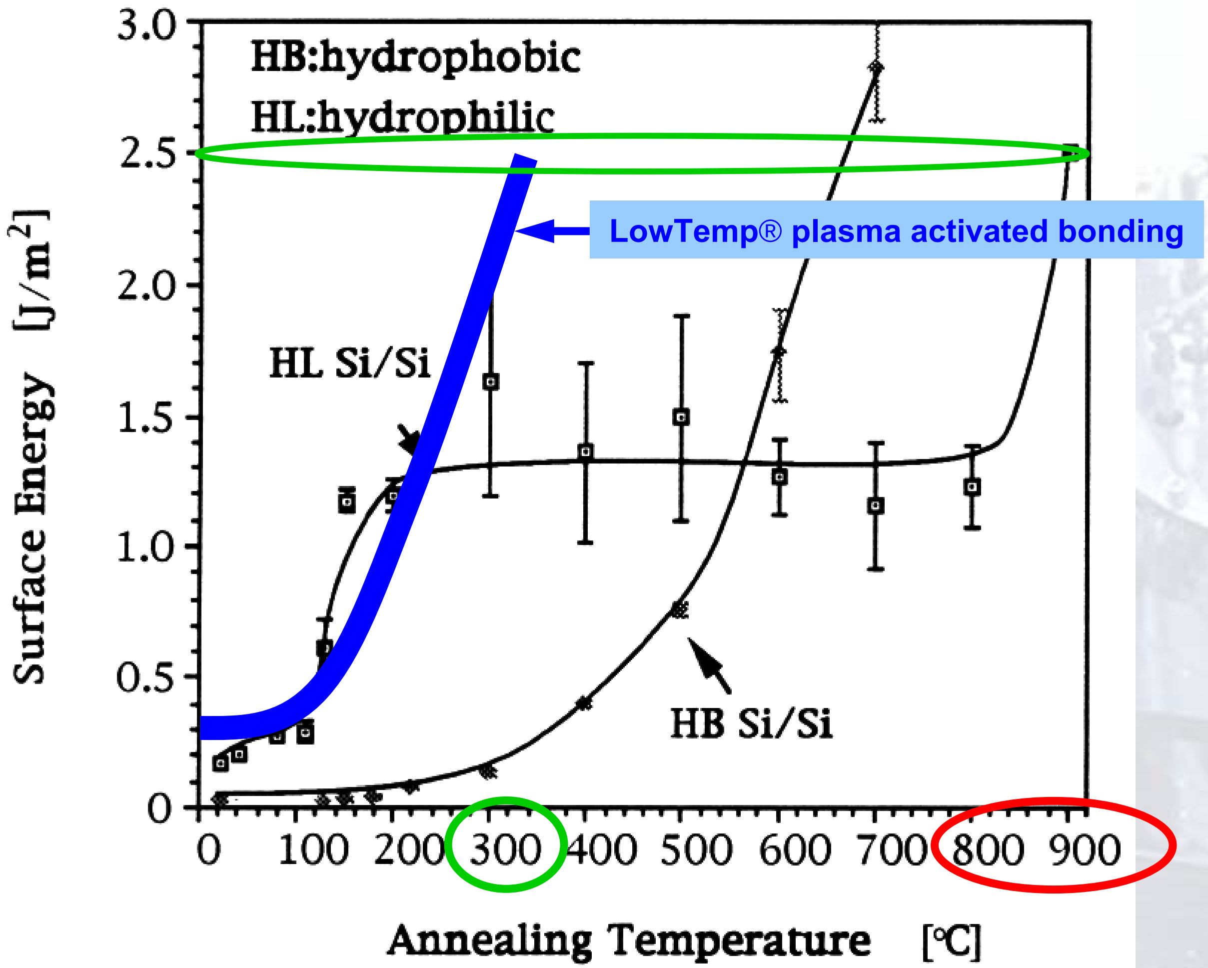
Nitrogen

Helium

Argon

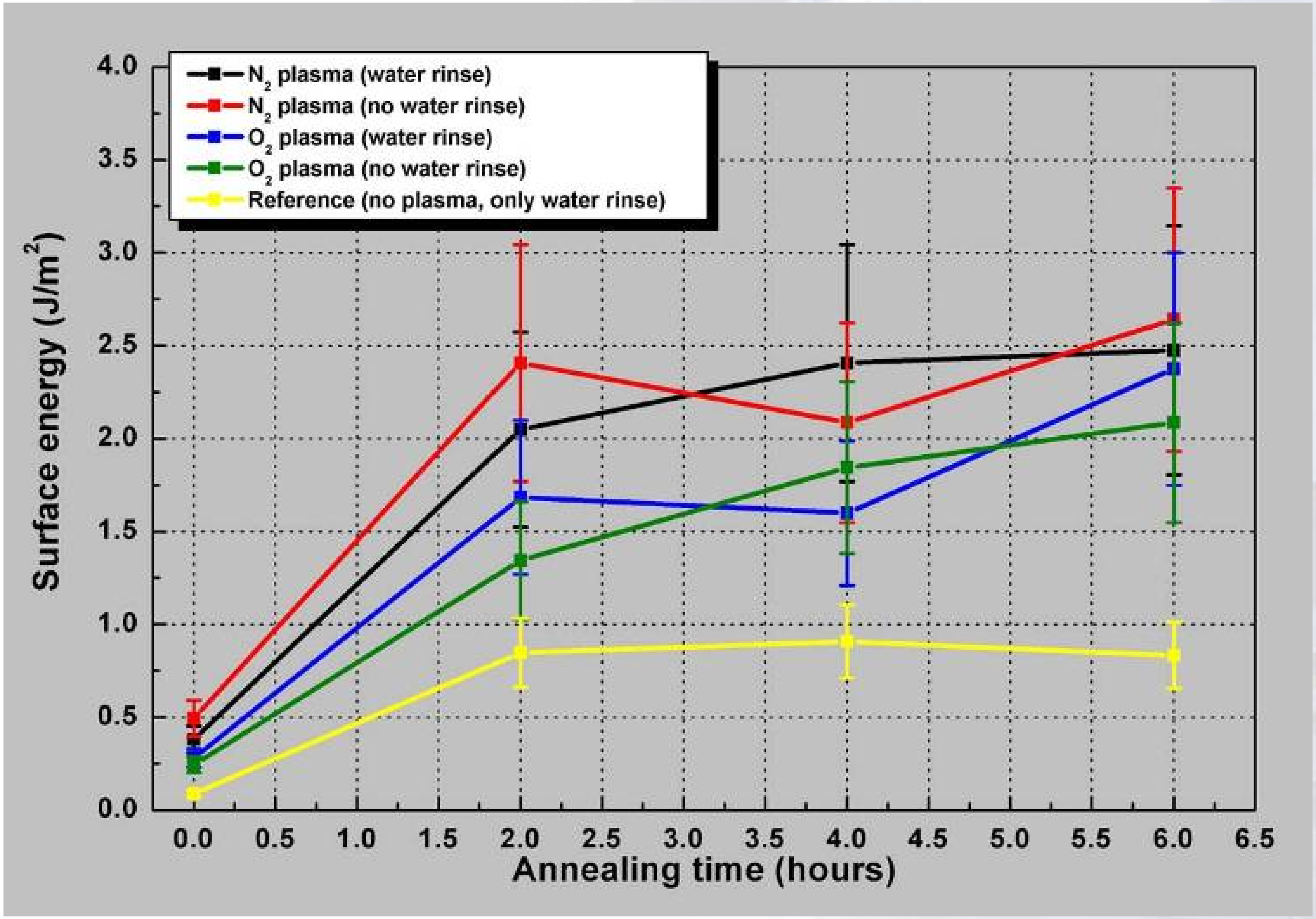
Non-Reactive

Silicon Direct Bonding



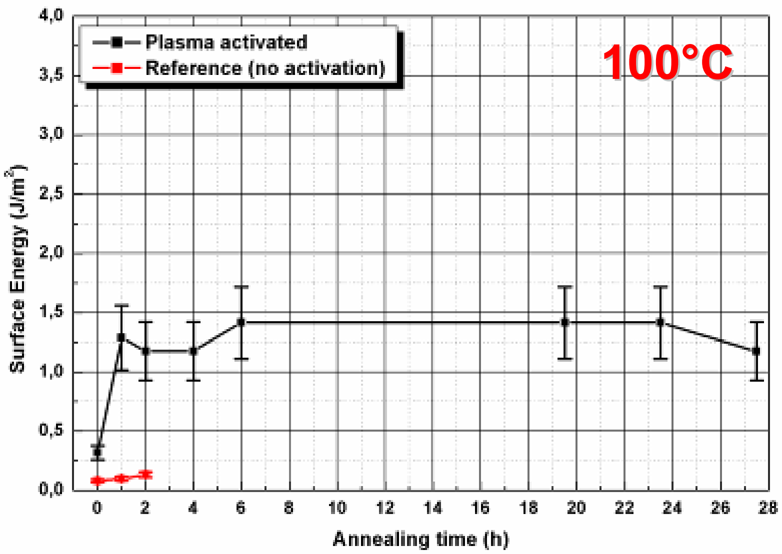
Q.-Y. Tong and U. Gösele, *Semiconductor Wafer Bonding: Science and Technology* (Wiley, 1998).

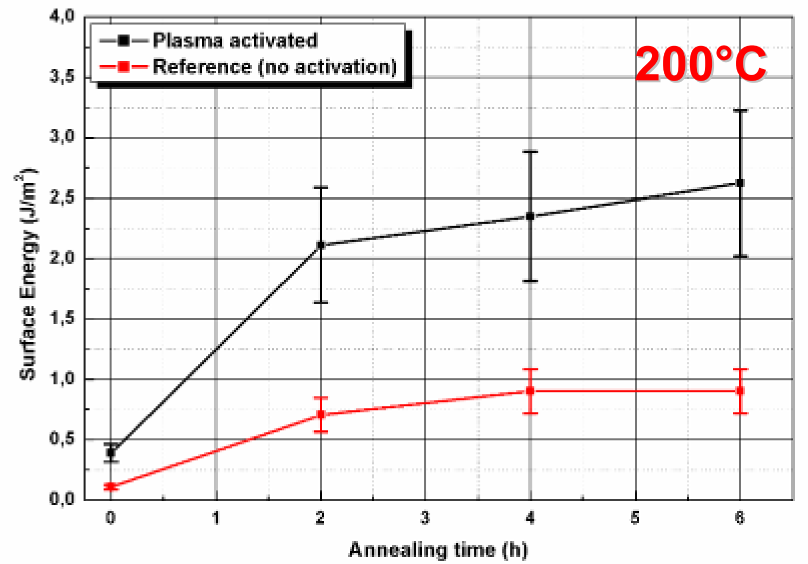
Test 1: annealing at 200°C

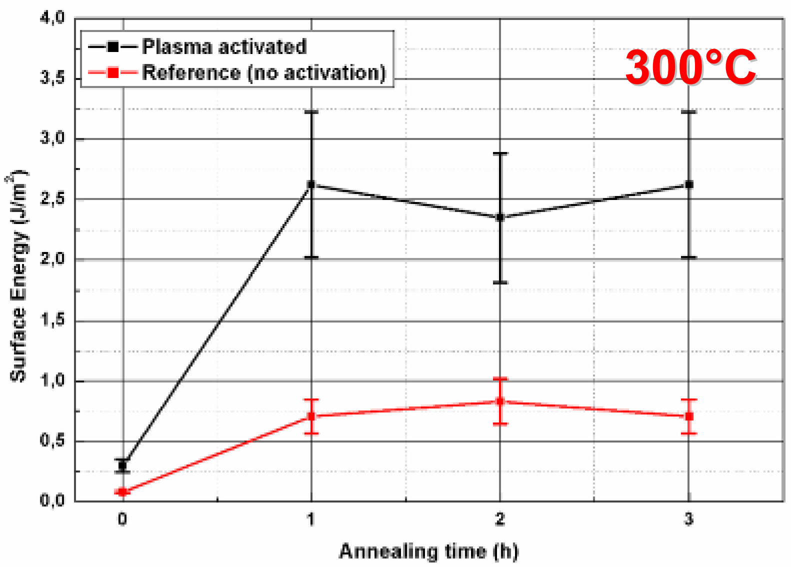


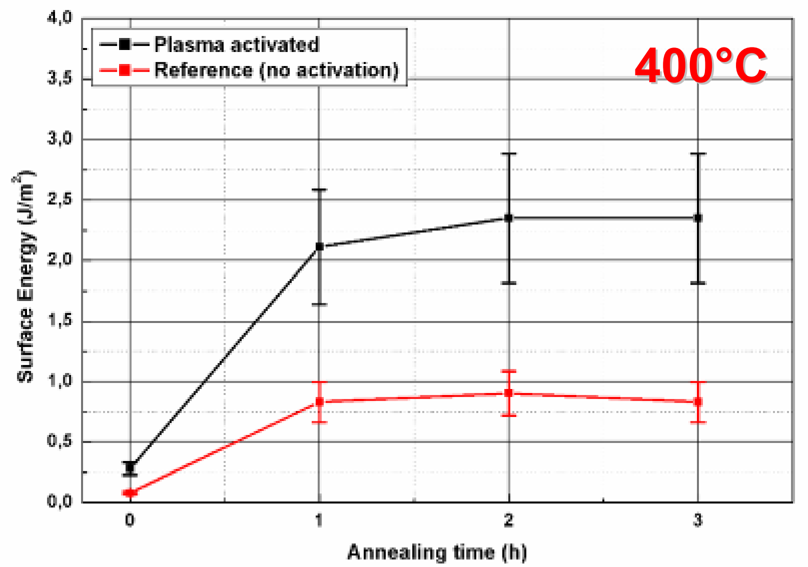
Surface energy vs. annealing time at 200°C.

Surface Energy vs. Thermal Annealing Time

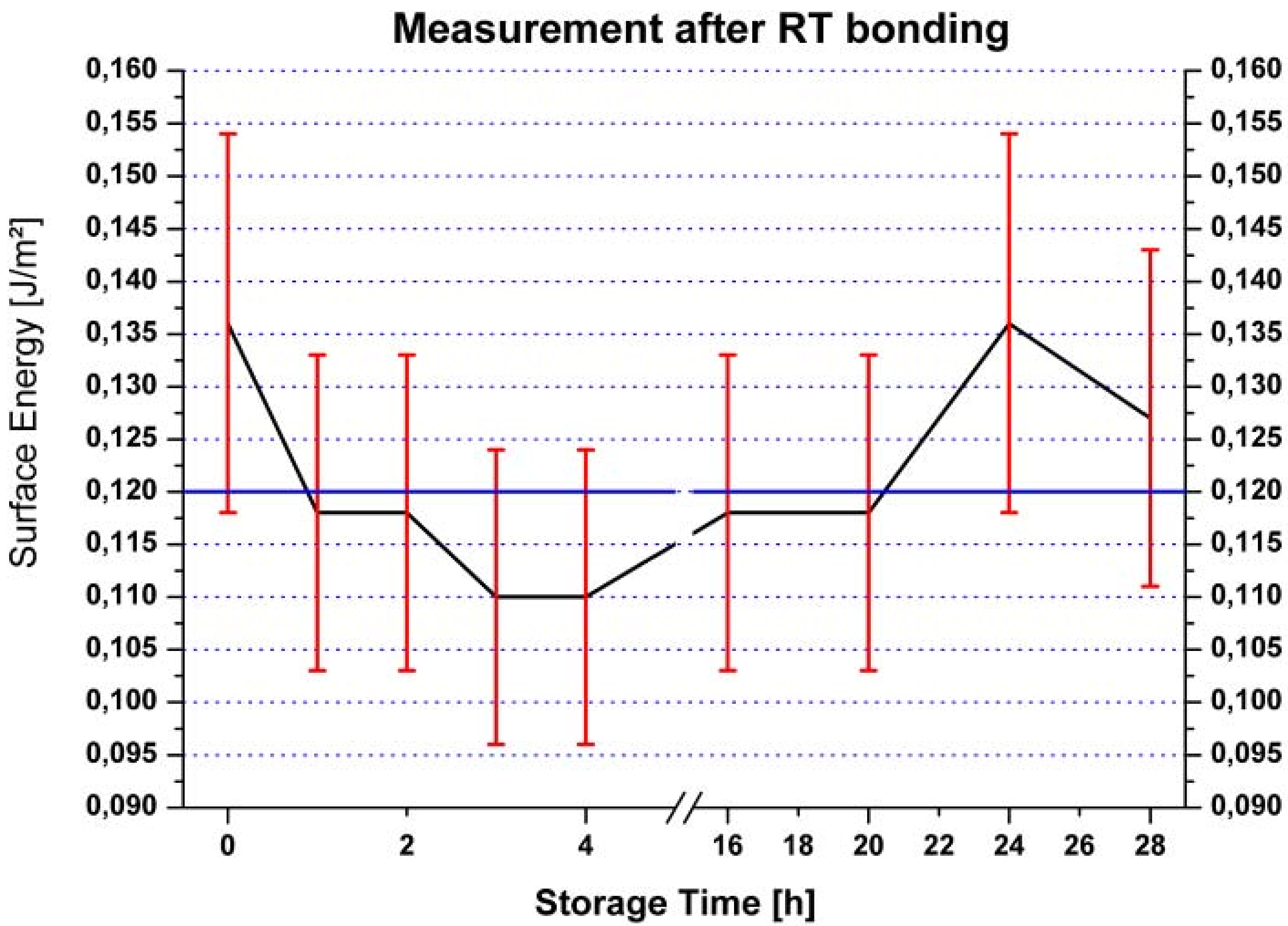








Activation Lifetime

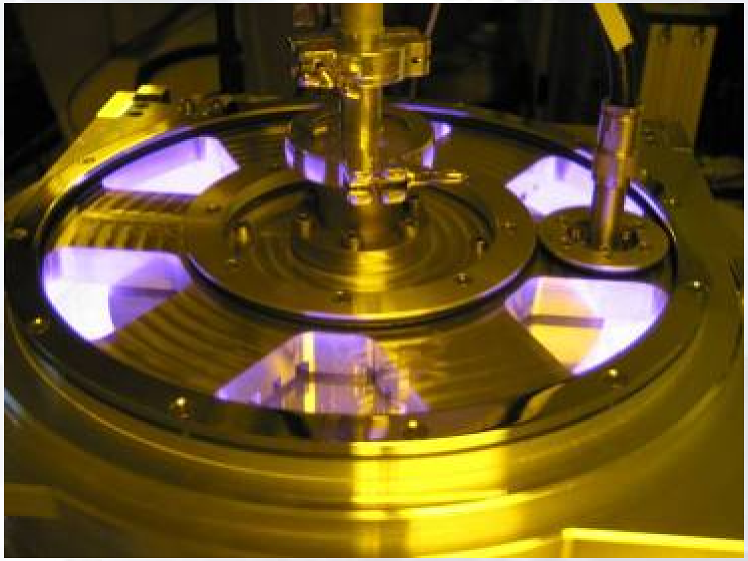


Plasma Activation

Principle:
Tailoring the surface chemistry

Result:
Increased bond strength at low temperature

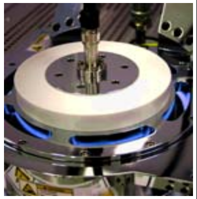
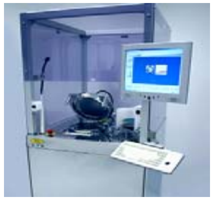
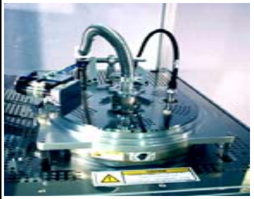
Flexibility:
Compliant with various materials
(not only semiconductors)!



Technology:
Fully compliant with state of the art wafer-to-wafer alignment and bonding equipment

Benefits:
Expand wafer bonding applications field
Bring bonding processes at industrial level

Economic:
Equipment costs decrease
Cost decrease per device (e.g. MEMS)

LowTemp® Plasma Chambers:	EVG810LT Chamber (150 mm)	EVG810LT Chamber (200mm)	EVG810LT Chamber (300mm)	Full Gemini Platform	EVG850LT Platform (200mm)
					
Short Description:	Manual load dry activation chamber	Manual or auto load dry activation chamber	Manual or auto load dry activation chamber	Auto-load Dry Activation Cluster Tool w/ Alignment and Compression Bond Chamber	Auto-load Dry Activation Cluster Tool w/ Pre-Bond Chamber
Max. Wafer Diameter	150	200	300	200	200
Min. Wafer Diameter	pieces	auto load: 100 (opt. 50) man. load: pieces	auto load: 200 man. load: pieces	auto load: 50mm-100mm or 100mm - 200mm	auto load: 50mm-100mm or 100mm - 200mm
Rack	yes	yes	yes	yes	yes
Automated Cover	optional	yes	yes	yes	yes
SmartView Integration-*ex situ*		yes	yes	yes	
In situ Compatible		yes	yes	yes	yes
Ex situ compatible	Standard	Standard	Standard	Standard	yes
Metal Ion Free	optional	optional	optional	optional	Standard
Supports Vacuum Packaging	only with *in situ* option	only with *in situ* option	only with *in situ* option	yes	yes
Supports (anodic, eutectic, glass fritt, polymer...)dependent on configuration				yes	
Supports optically aligned wafer bonding	yes	yes	yes	yes	

Global Wafer Shape

Specifications:

- **TTV ≤ 3 µm**

- **Bow/Warp**

  ≤ 30µm 100mm

  ≤ 40 µm 200mm

  ≤ 50 µm 300mm

- **Microroughness (measured by AFM, 2 x 2µm^2):**
  < 0.5 nm (all wafer diameters): excellent results
  < 1.0nm: good results
  < 1.0-2nm: possible under some special conditions

Accepted Contamination Levels

- **Particles:**
  - **Incoming wafers:**
    - Si: <0.1 LPD/cm2, size >0.15µm
    - Oxide: <0.1 LPD/cm2, size >0.2µm

    (0.1LPD = 8p/100mm, 12p/125mm, 18p/150mm, 31p/200mm, 71p/300mm)

  - **Wafers handling (environment):**

    Added: <0.015 LPD/cm2

    (0.015LPD = 1p/100mm, 2p/125mm, 3p/150mm, 5p/200mm, 11p/300mm)

  - **Process stations (clean, plasma and pre-bond):**

    Added: - Si: <0.03 LPD/cm2, size >0.15µm

    - Oxide: <0.05 LPD/cm2, size >0.2µm

    (0.03LPD = 2p/100mm, 4p/125mm, 6p/150mm, 9p/200mm, 21p/300mm
    0.05LPD = 4p/100mm, 6p/125mm, 9p/150mm, 16p/200mm, 35p/300mm)

- **Metal ions (Fe, Cu, Ni, Al, Na, K, Ca, Mg):**

  Equipment installation: ≤ 5 x 10^{10} atoms/cm2

  SOI production: ~10^{9} atoms/cm2

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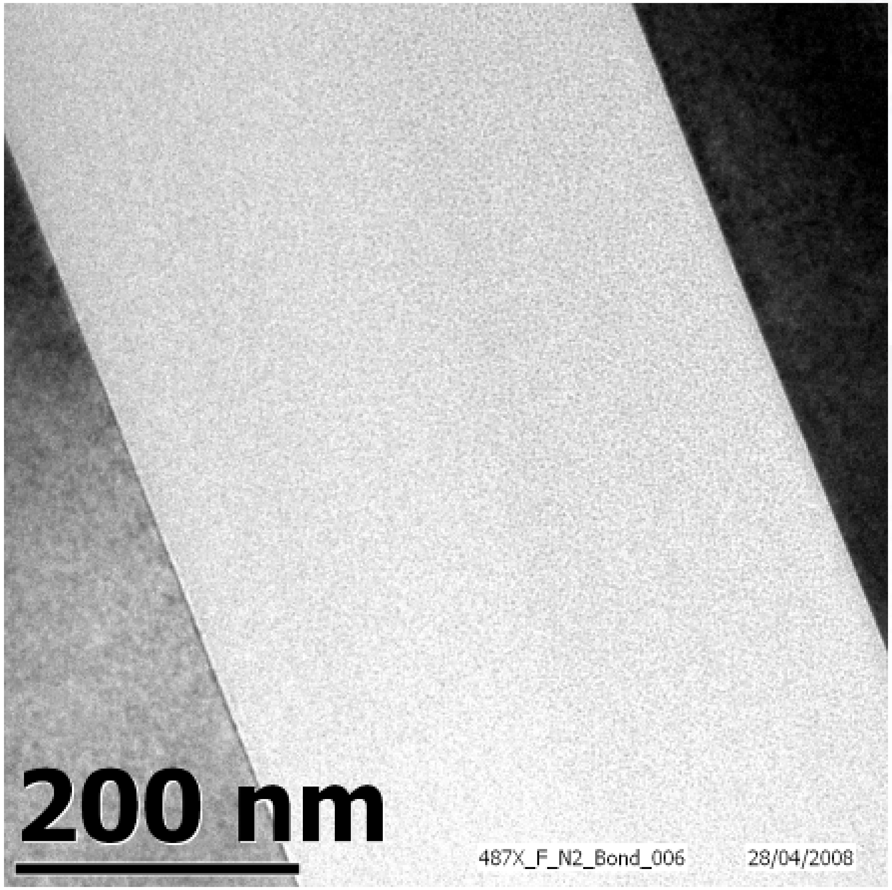
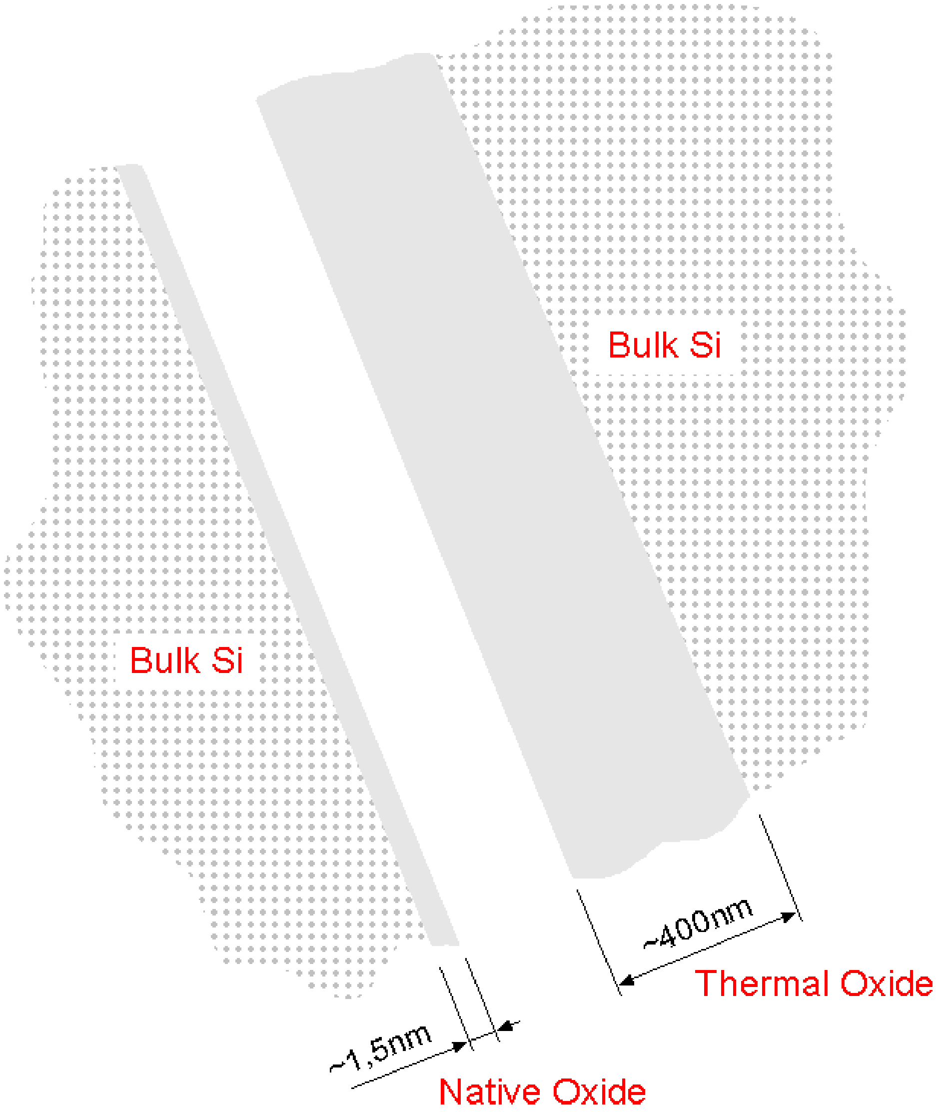
TEM Analysis





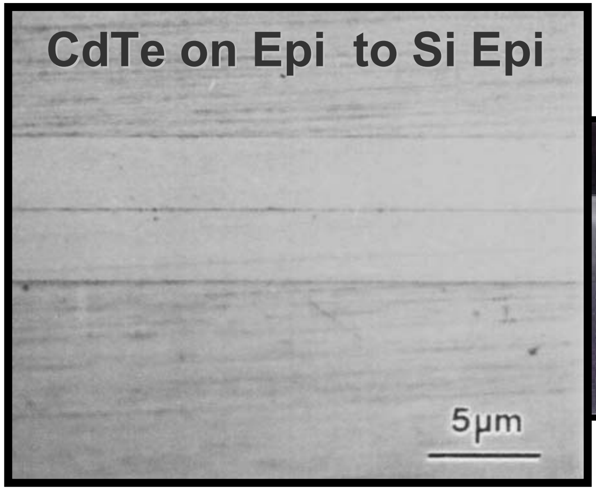
Conclusion

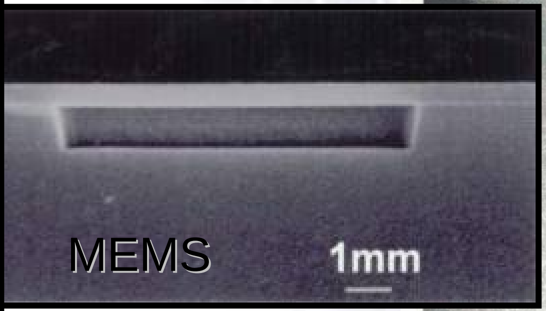
- Plasma activation of the surfaces overcomes the problem of high process temperatures needed for standard fusion bonding.
- Surface activation effect has a relatively long lifetime.
- Despite the long lifetime it is strongly recommended to pre-bond the substrates as soon as possible after activation for contamination reasons.
- Plasma activation doesn‘t increase surface microroughness.
- TEM investigation shows no visible bond interface line.

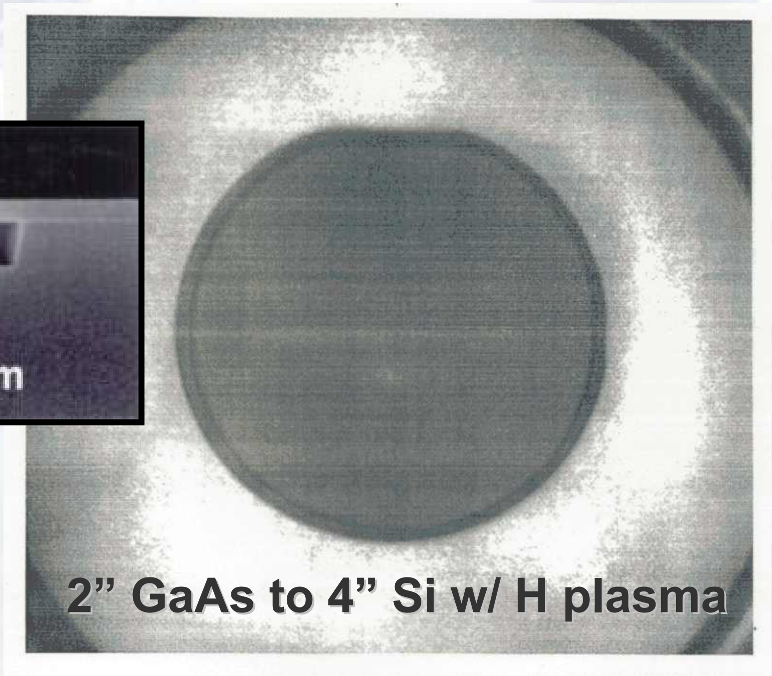
Plasma Activated Wafer Bonding Applications

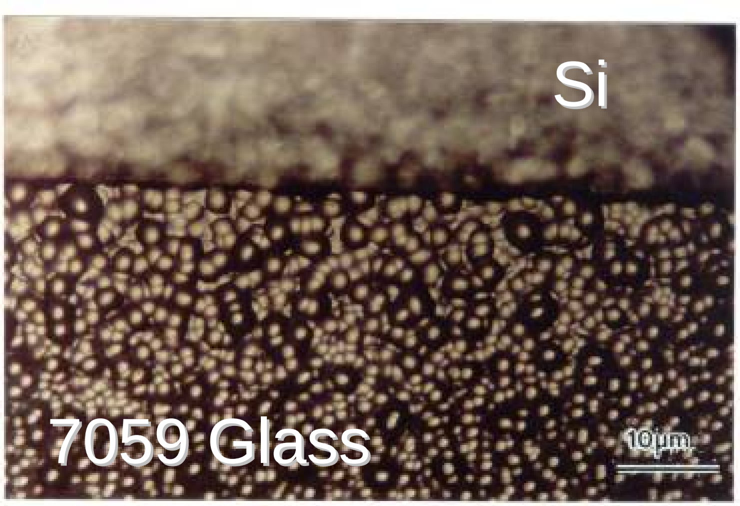
- SOI → maximum bond strength reached below cleaving temperature
- MEMS: sealing → vacuum sealing compatible
- MEMS: materials combinations → low temperature allows stress management
- MEMS on CMOS (e.g. backside illuminated image sensors)
- Polymer materials for bio-compatible applications

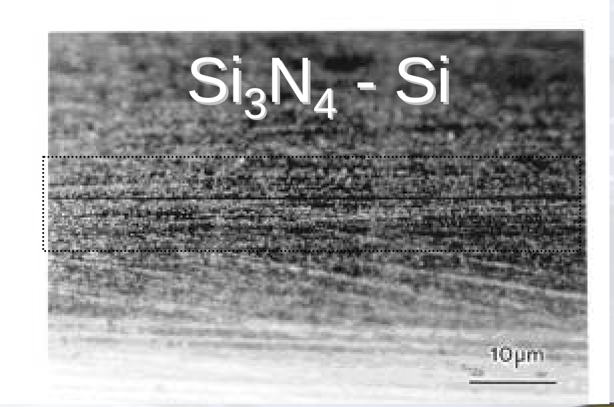
Low Temperature Plasma Bonded Gallery



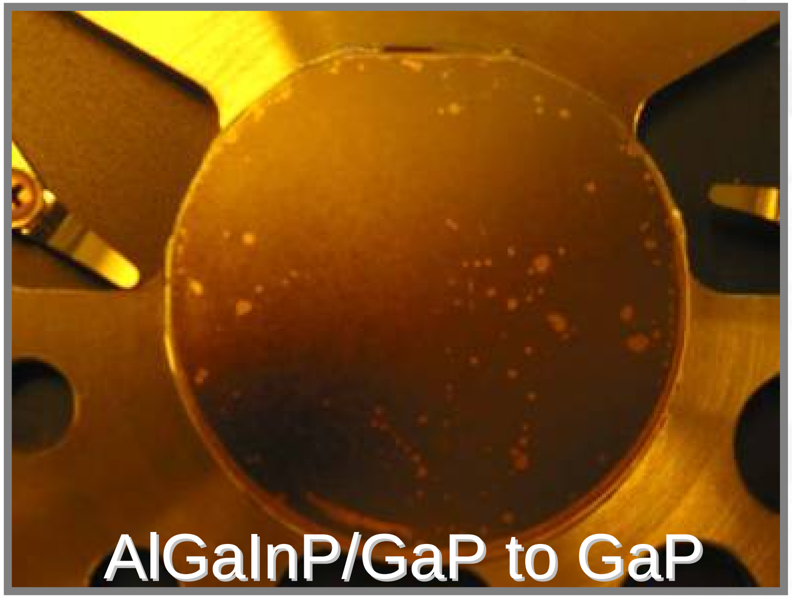


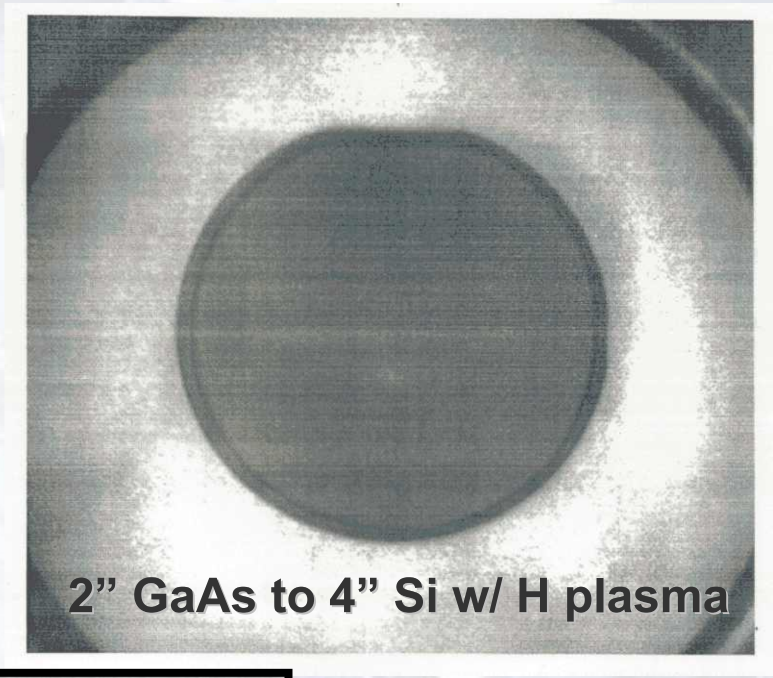


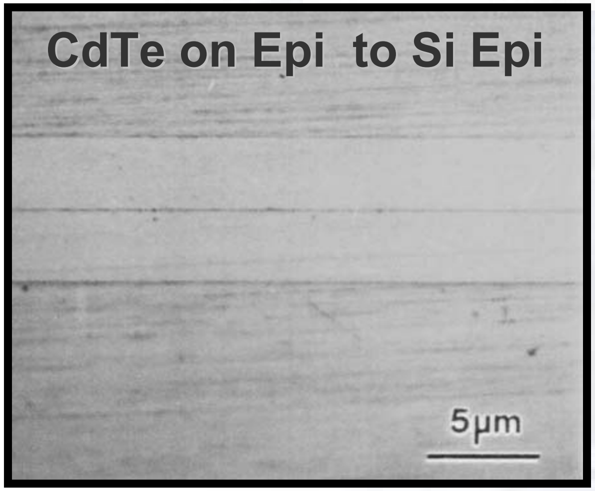




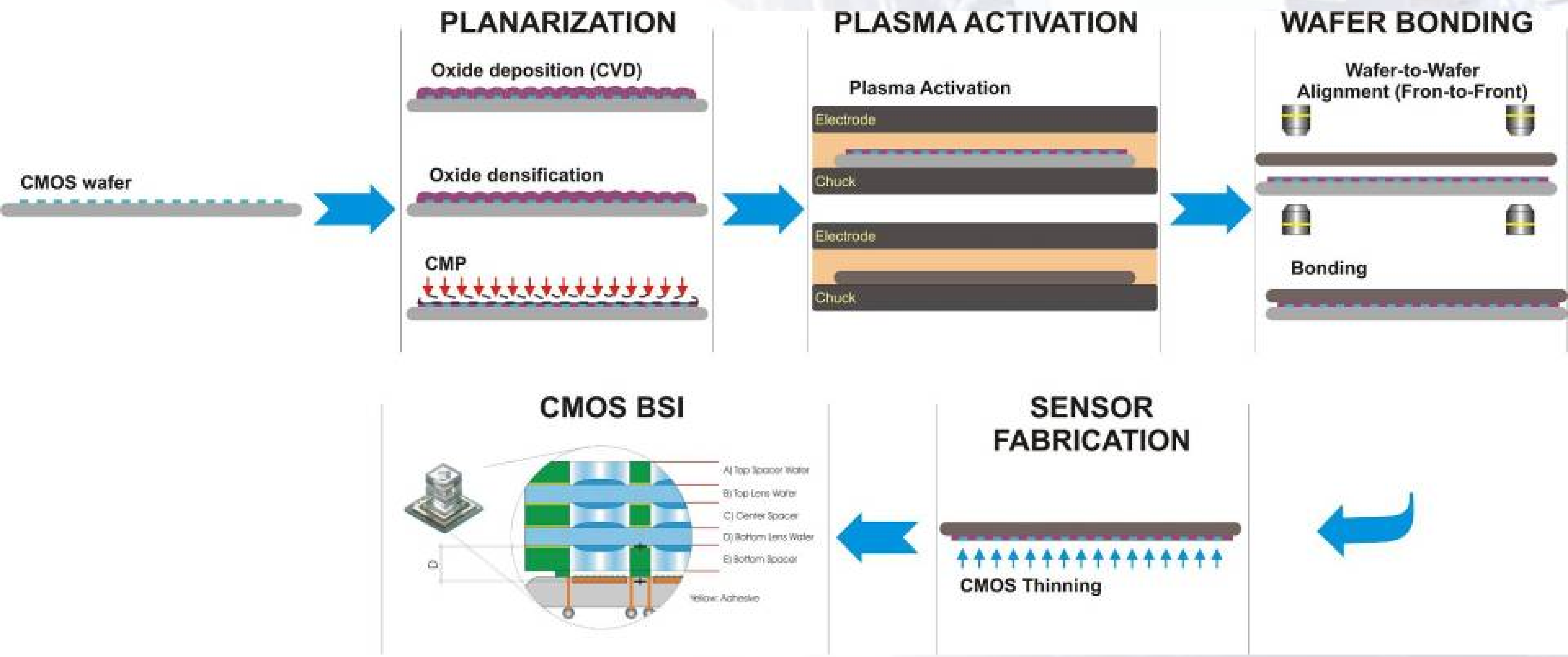
Examples: Compound Semiconductors







Wafer Bonding for CMOS BSI CIS: Fusion



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Thank You for Your Attention
Questions?

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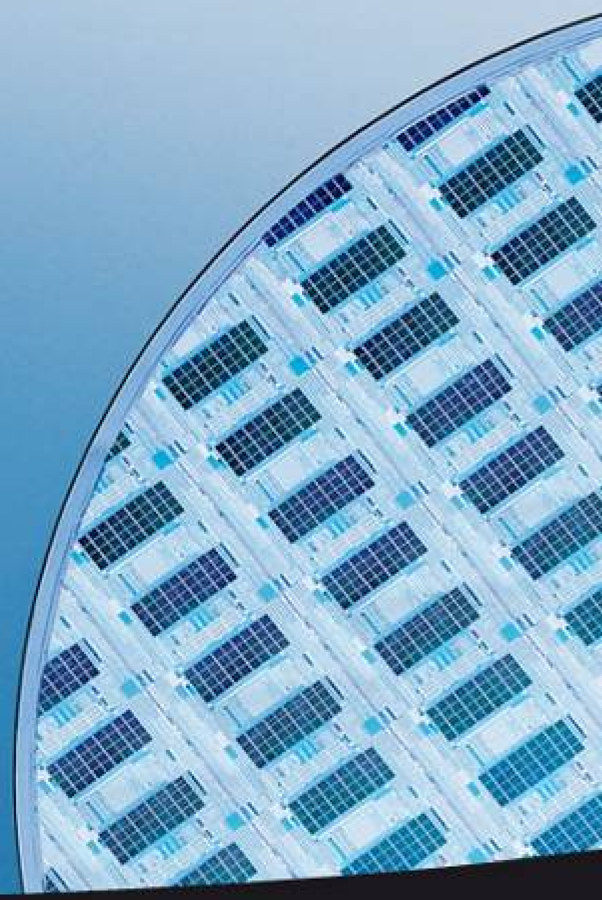
Triple i - The key to your success



E V G

Bonding Process Variables

Incoming	In Chamber	Outgoing
1.Wafer a.Size i.Diameter ii.Thickness b.Material i.CTE c.Bow & Warp d.TTV e.Vacuum integrity[1]	1.Wafer	1.Wafer a.Bow & warp b.TTV c.Breakage
1.Contact Layers a.Thickness b.TTV c.Roughness d.Bulk Composition e.Surface Compostion f.Surface Particles g.Surface Contamination h.Pattern	1.Standard Bond Chamber a.Time b.Temperature c.Force[2] d.Atmosphere[3] e.Wafer to wafer spacing (flags) f.Bow Pin g.Voltage / current 2.Special Bond Chamber a.UV energy b.Plasma 3.Materials a.Tg or Melting Point b.Outgassing c.Shrinkage d.Adhesion e.Flow	1.Bond Layers a.Percent bonded (voids) b.Thickness c.Strength d.Hermeticity e.Conductivity f.Pattern 2.Atmosphere in cavities if present a.Gas b.Pressure
1.Alignment 2.Spacing (gap between wafers)		1.Alignment 2.Wafer to wafer spacing

[1] Can the wafer be handled by backside vacuum or will edge handling or other special handling be required?
[2] Translates to pressure based on bond contact area
[3] Vacuum, forming gas, inert gas; no toxics or corrosive gasses.

Color Code
Items in RED are controlled by upstream process
Items in Green are controlled by alignment system
Items in BLACK are controlled by bond chamber
Items in BLUE are output variables

SmartView® - Benefits

- **Supports all bond alignment methods**
  - Transparent Alignment
  - IR Alignment
  - Backside Alignment
  - SmartView (Face-to-Face) Alignment
- **SmartView (Face to Face) Alignment Advantage**
  - Eliminates need for
    - IR transparent substrates which prevents high doping levels and requires metal line keep-outs around alignment targets.

    Or

    - Backside alignement marks
  - This reduces the cost and simplifies the design

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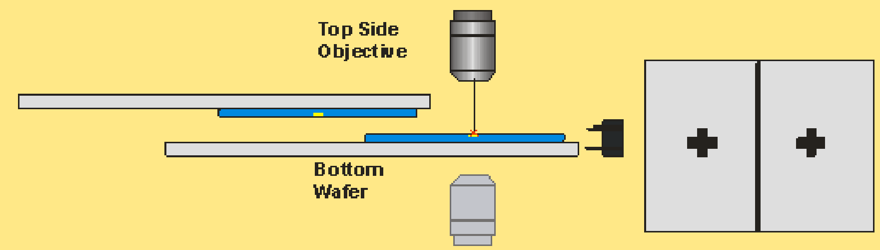
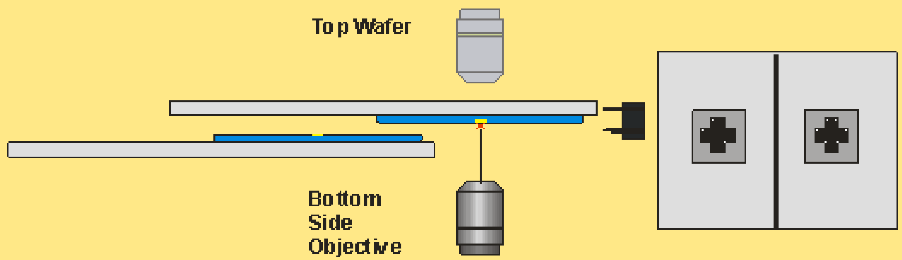
SmartView® Face-to-Face Bond Aligner

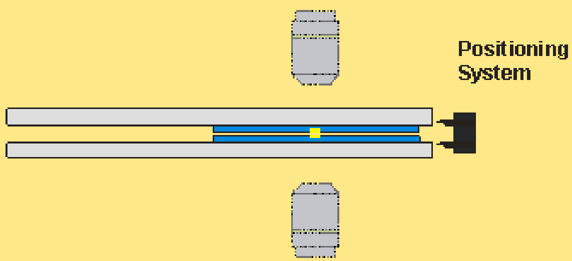
- Proprietary Alignment Technique that allows for high alignment accuracy as needed for high density interconnects with **non-IR transparent wafers.**



No Z-travel
- Locate bottom wafer alignment marks with top objectives
- Digitize image
- Store position



No re-focussing
- Align top wafer to digitized image

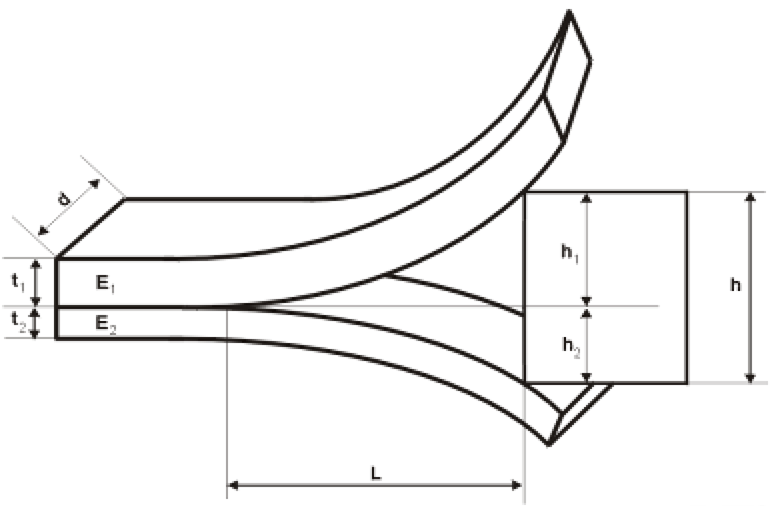


Perfect result
- Restore bottom wafer position
- Bring wafers in contact

US Patent: 6,214,692 B1

Bond Strength Quantification

Crack-opening method (Maszara, Razor blade)

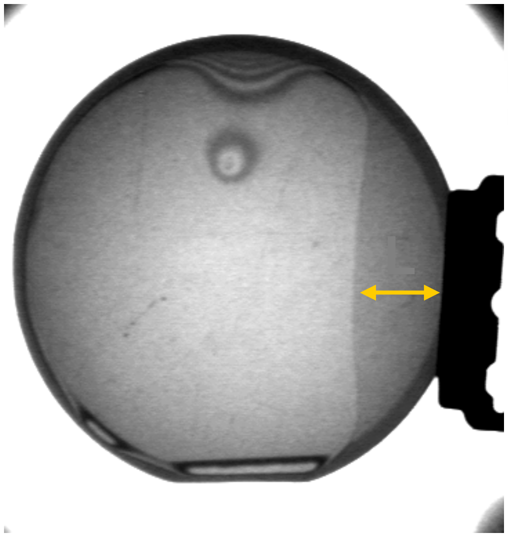


Dissimilar materials:

$$\gamma = \frac{1}{2}(\gamma_1 + \gamma_2) = \frac{3h^2}{16L^4} \frac{E_1 t_1^3 E_2 t_2^3}{E_1 t_1^3 + E_2 t_2^3}$$

Identical materials:

$$\gamma = \frac{3h^2 Et^3}{32L^4}$$



IR transmission image of a Si/Si bonded pair with a razor blade inserted at the bonded interface.

TEM Analysis

After 1h annealing @ 300°C!