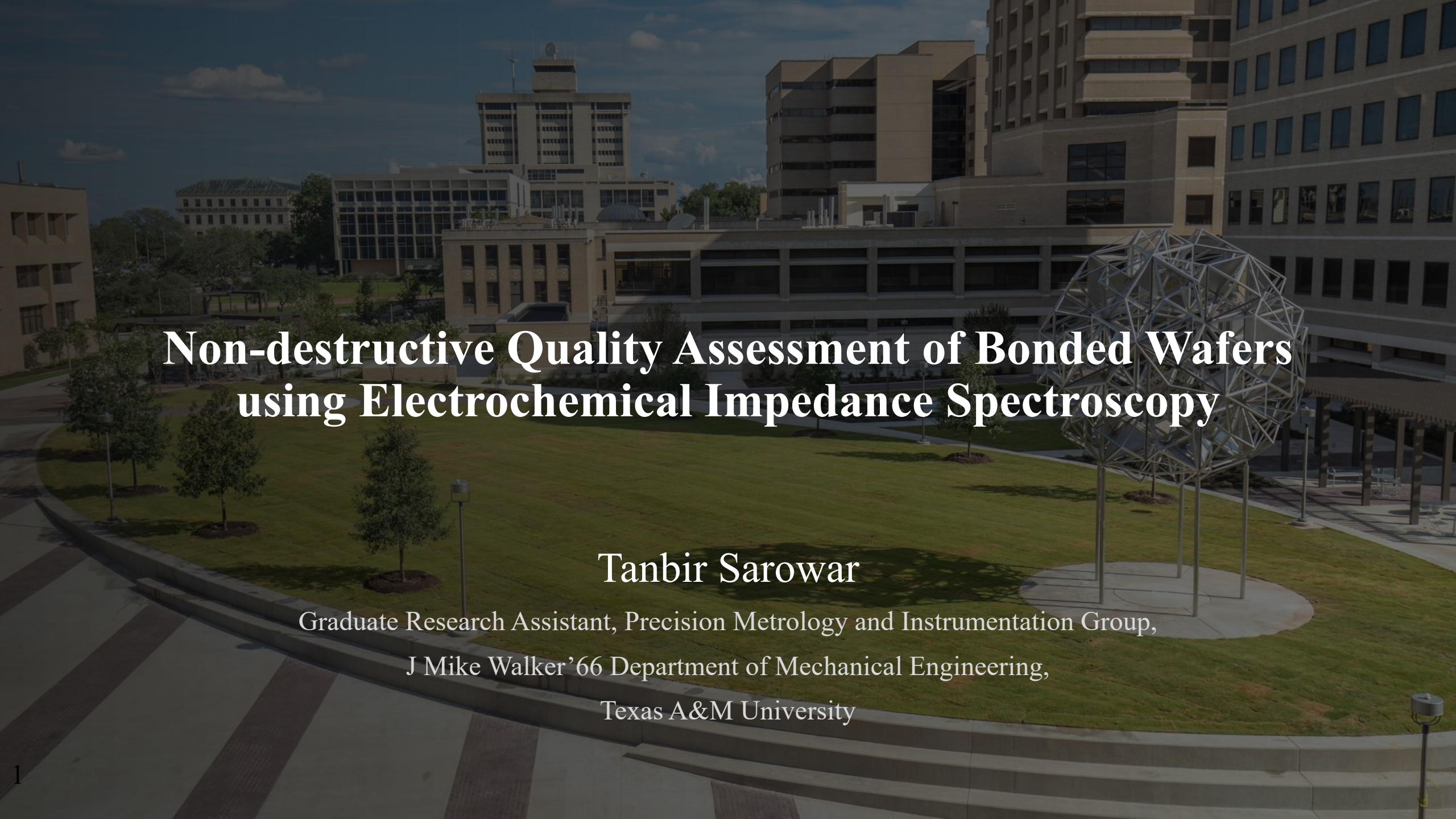




Non-destructive Quality Assessment of Bonded Wafers using Electrochemical Impedance Spectroscopy

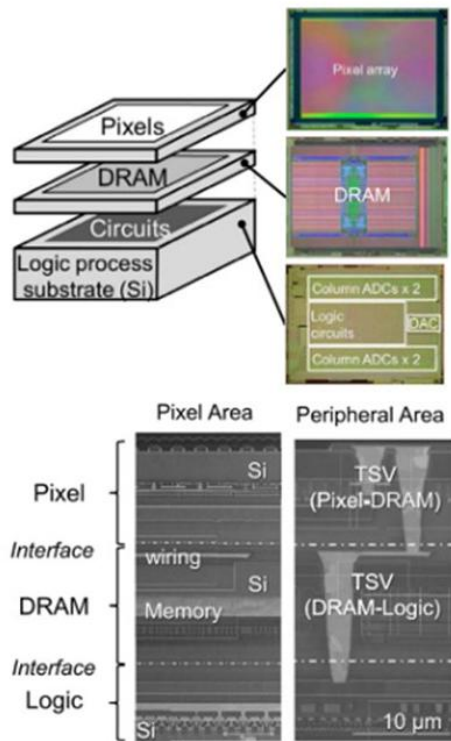
Tanbir Sarowar

Graduate Research Assistant, Precision Metrology and Instrumentation Group,
J Mike Walker'66 Department of Mechanical Engineering,
Texas A&M University

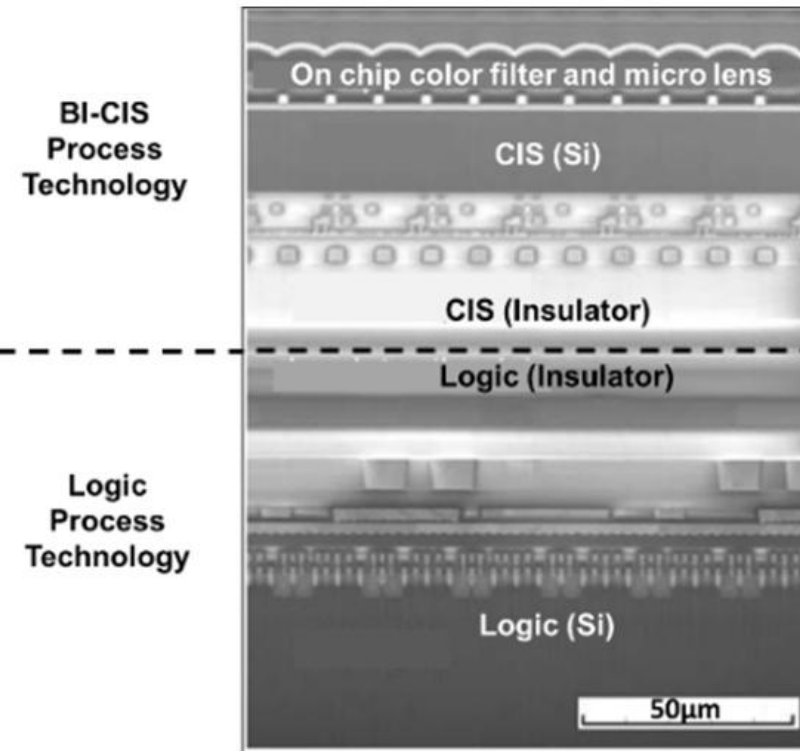
Wafer Bonding: Why?



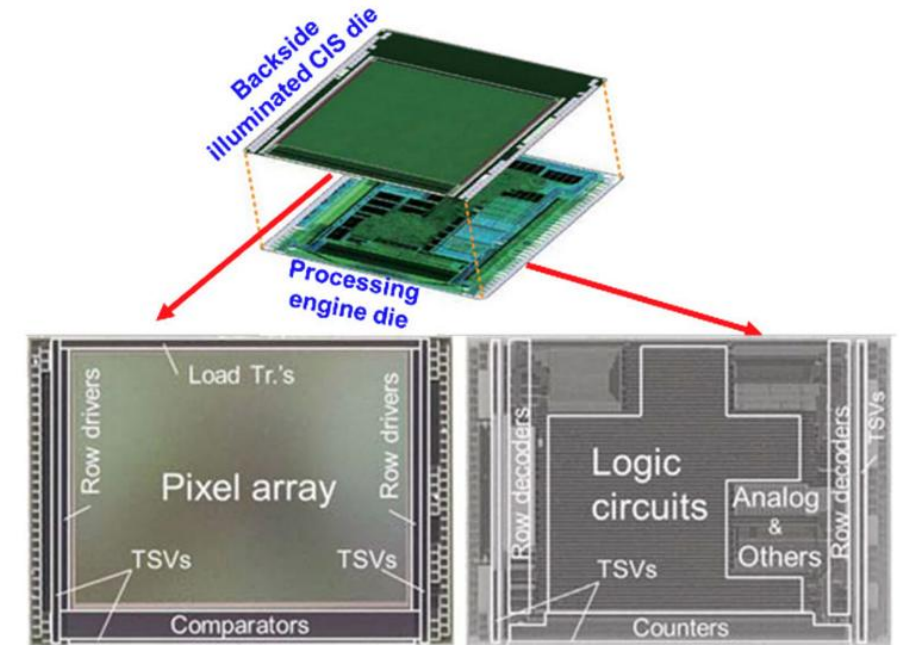
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3D Stacked CMOS Image Sensor



Back-Illuminated (BI) CIS Process



CIS and Logic Chip-on-Chip Integration

Bonding Technology

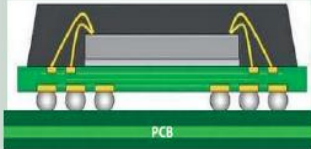
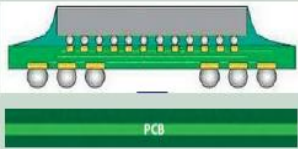
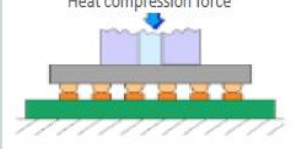
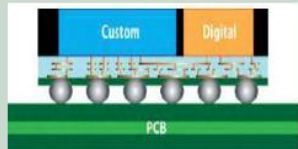
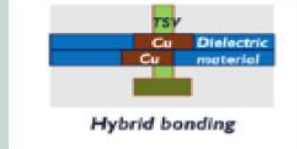
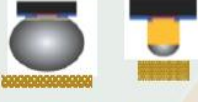
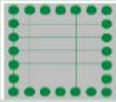
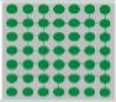
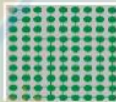
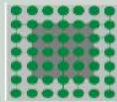
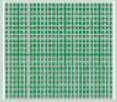
	Wire Bond (1975)	Flip Chip (1995)	TCB Bonding (2012)	HD Fan Out (2015)	Hybrid Bonding (2018)
Architecture					
Contact Type	 Wire	 Solder ball or copper pillar	 Copper pillar	 RDL or copper pillar	 Copper to copper
Contact Density	 5-10/mm ²	 25-400/mm ²	 156-625/mm ²	 500+/mm ²	 10K-1MM/mm ²
Substrate	Organic/leadframe	Organic/leadframe	Organic /Silicon	None	None

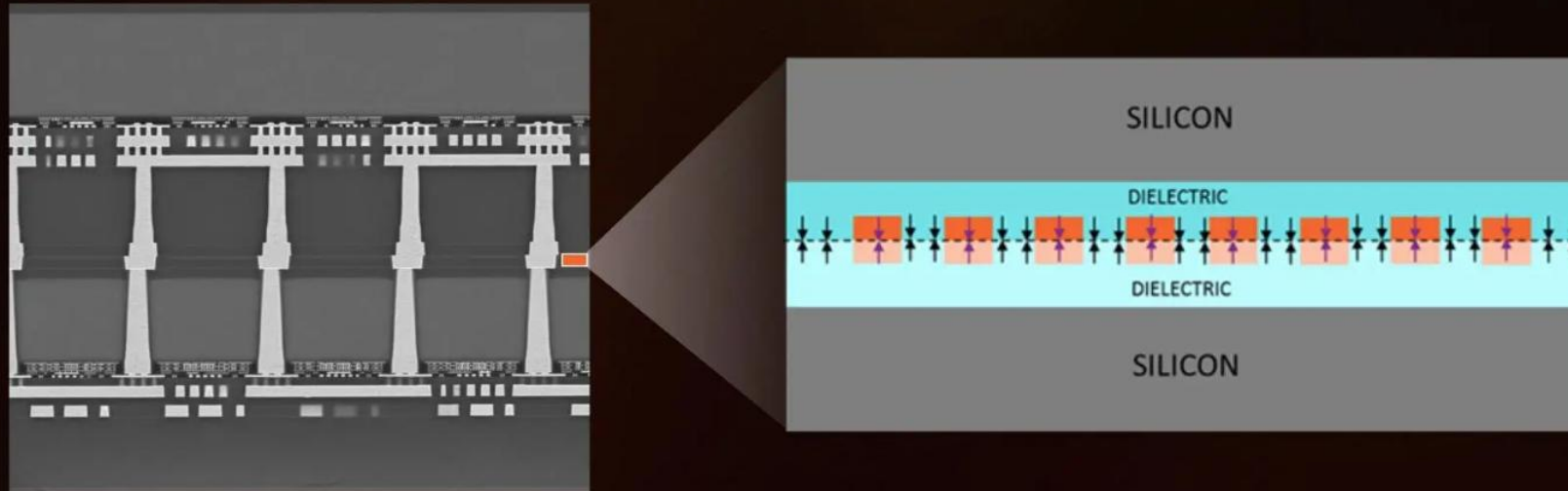
Figure 1. Bonding Technology Evolution [figure adopted from semi analysis]

Hybrid Bonding



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AMD 3D V-CACHE™ HYBRID BONDING

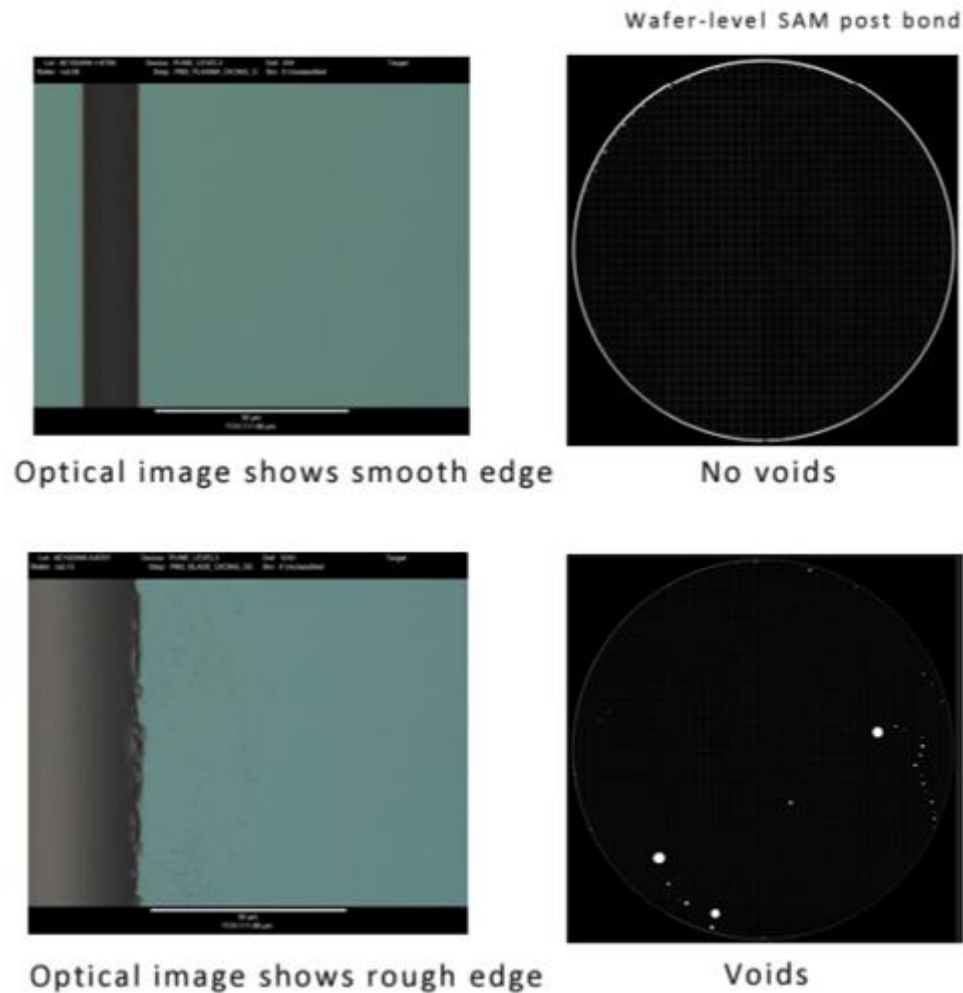


Direct Copper –Copper Bonding

Wafer to Wafer Bonding

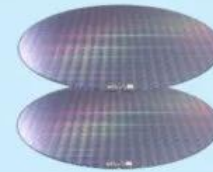


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Wafer to Wafer Hybrid Bonding

Die remain on wafer



Activation, cleaning
and then bonding

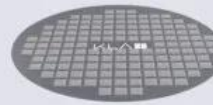


Grinding and thinning,
sent to packaging

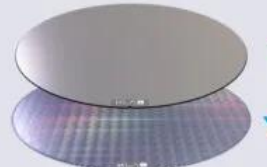


Die to Wafer Collective Hybrid Bonding

Die to be bonded are
prepared, diced,
then placed on
carrier wafer



Activation, cleaning
and then bonding



Remove carrier wafer,
leaving bonded die on
target wafer



Die to Wafer Sequential Hybrid Bonding

Singulated die are
transferred to carrier for
activation and cleaning



Direct placement of die
using a bonder tool



Problem Statement



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Bonding void

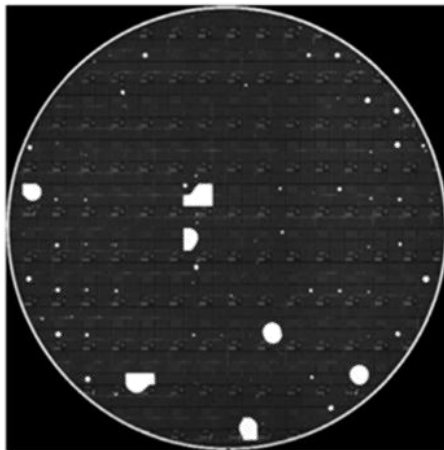
Directly affects Bonding process and Yield.

If void is big ($>100\mu\text{m}$), can not proceed next grind step

If void is small ($<5\mu\text{m}$), cause the bad bonding interconnection

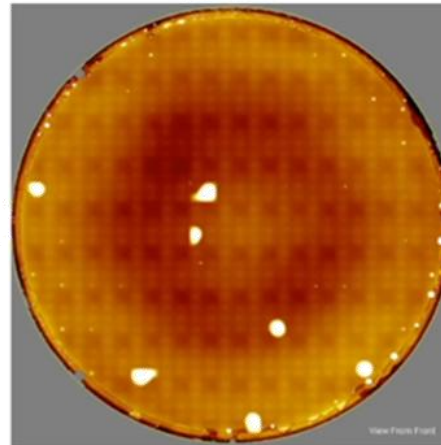
Big void

Scanning Acoustic Microscopy (SAM)



~20 - 40 min

Alternative Surface morphology



< 1 min

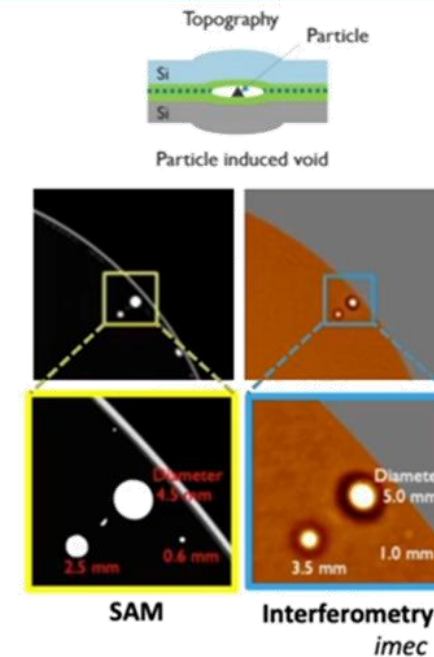


Figure 4. Defect identification in bonded wafers

Bonding Layer Inspection with EIS



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- Analyzer: 10-100MHz frequency sweep
- Pulse: Voltage induced current source
- Probe: Connected to magnets
- Magnetic force
 - Consistent contact force
 - Consistent alignment

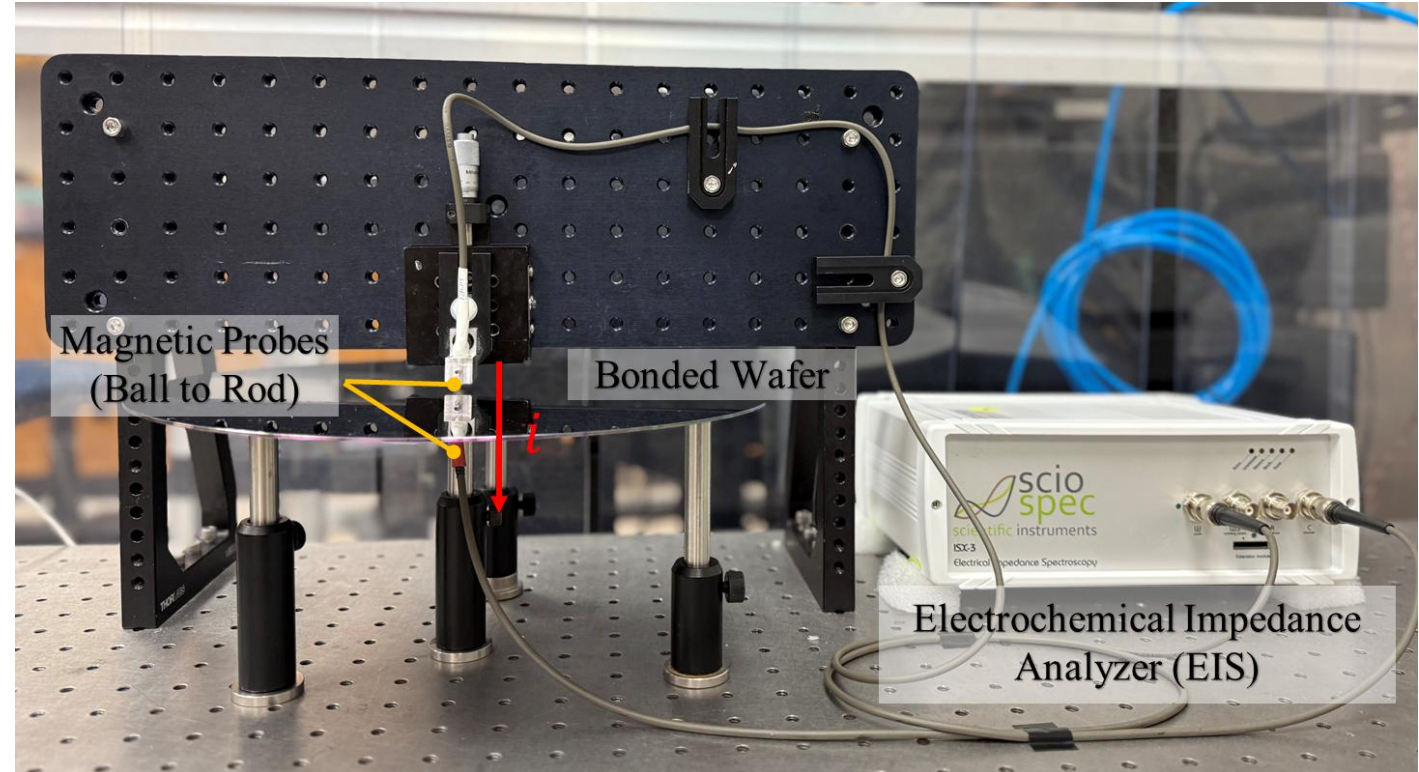
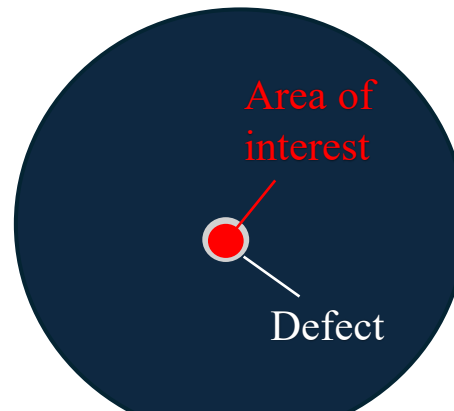
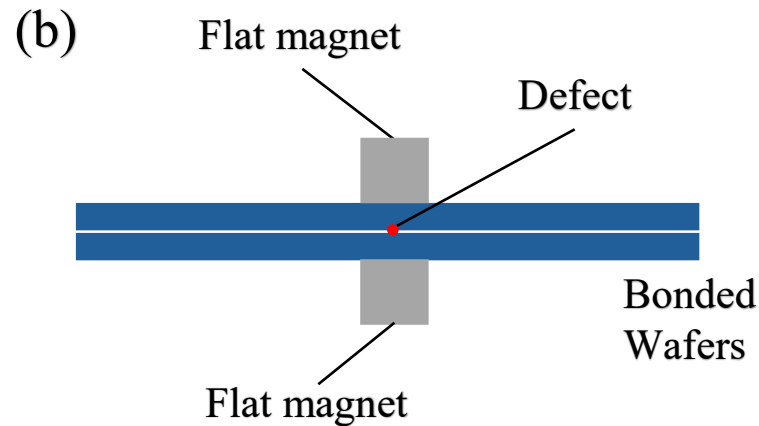
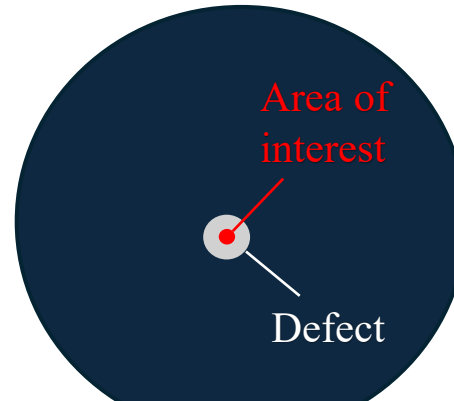
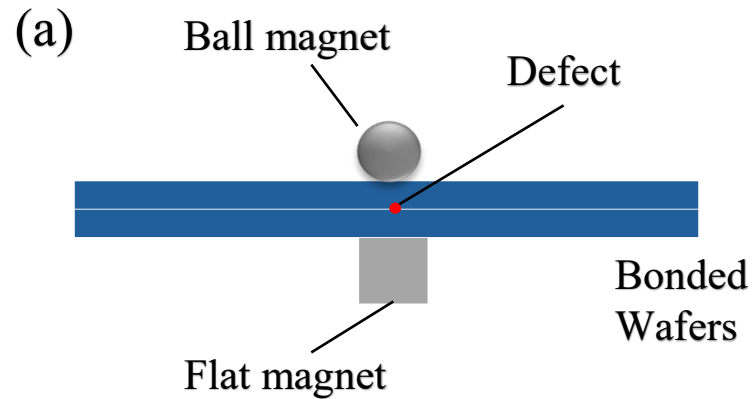


Figure 5: Experimental set up for EIS measurements

Probe Design



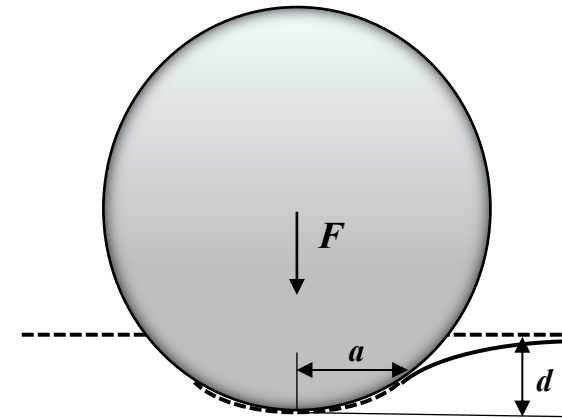
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Hertzian contact theory

$$a = \sqrt[3]{\frac{3FR}{4E}}$$

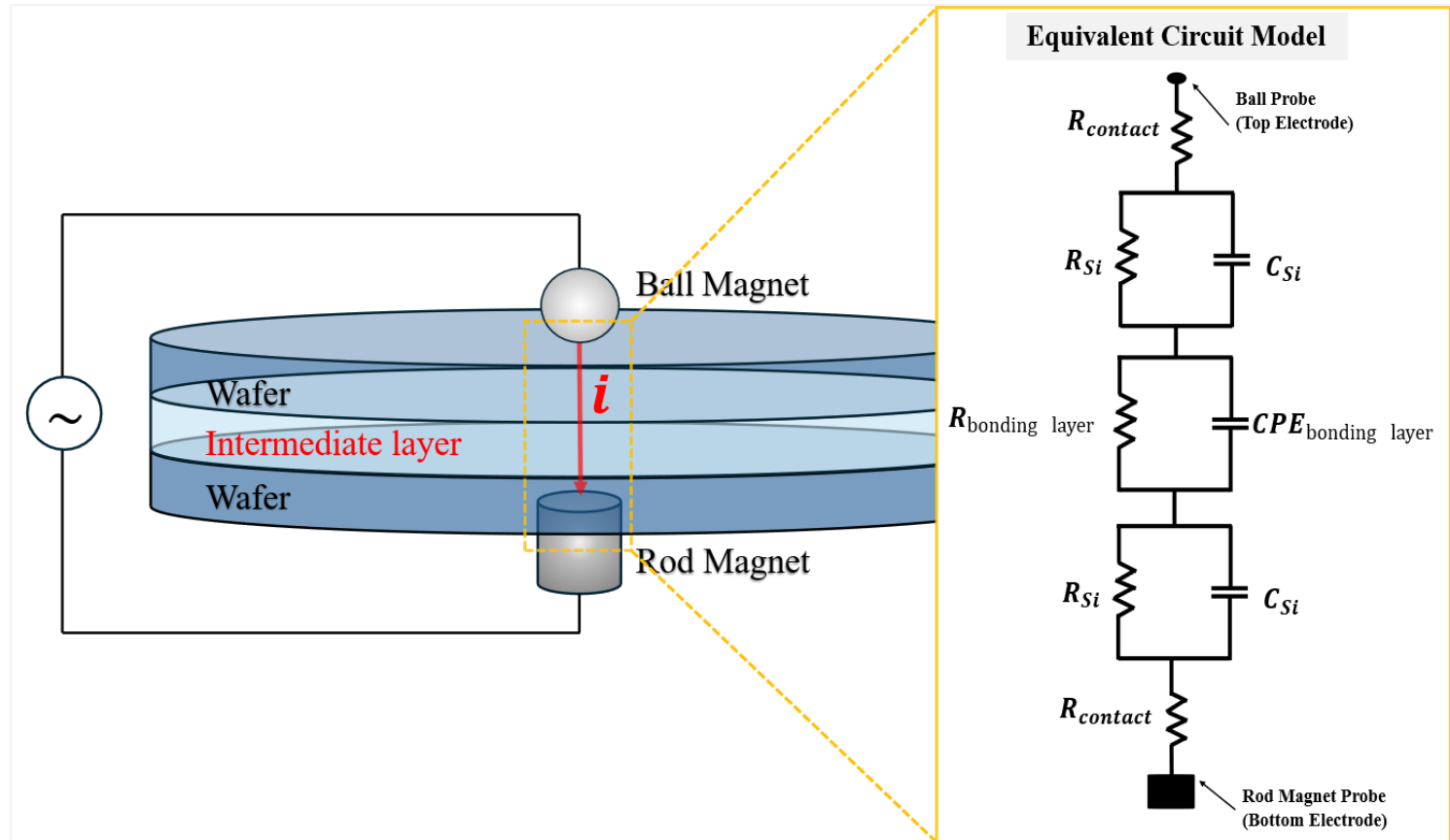
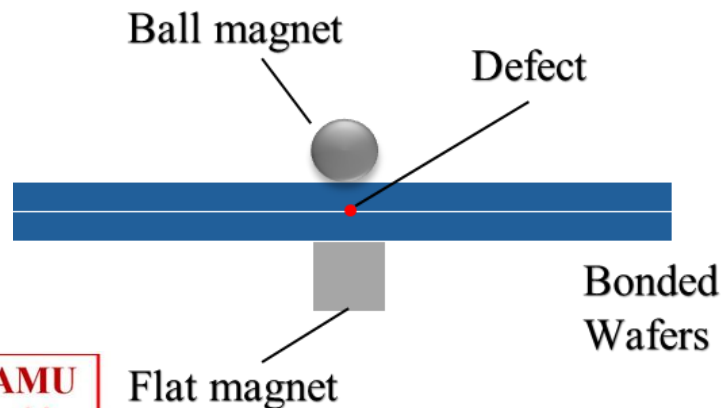
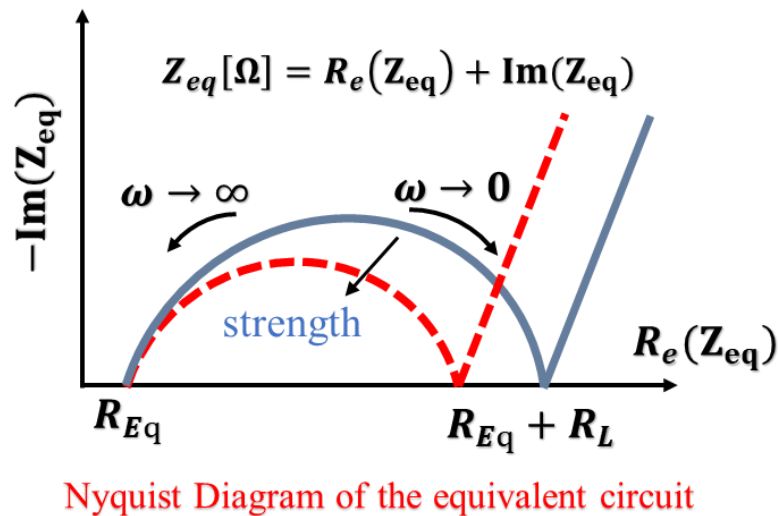
F: magnetic force
R: radius of the ball



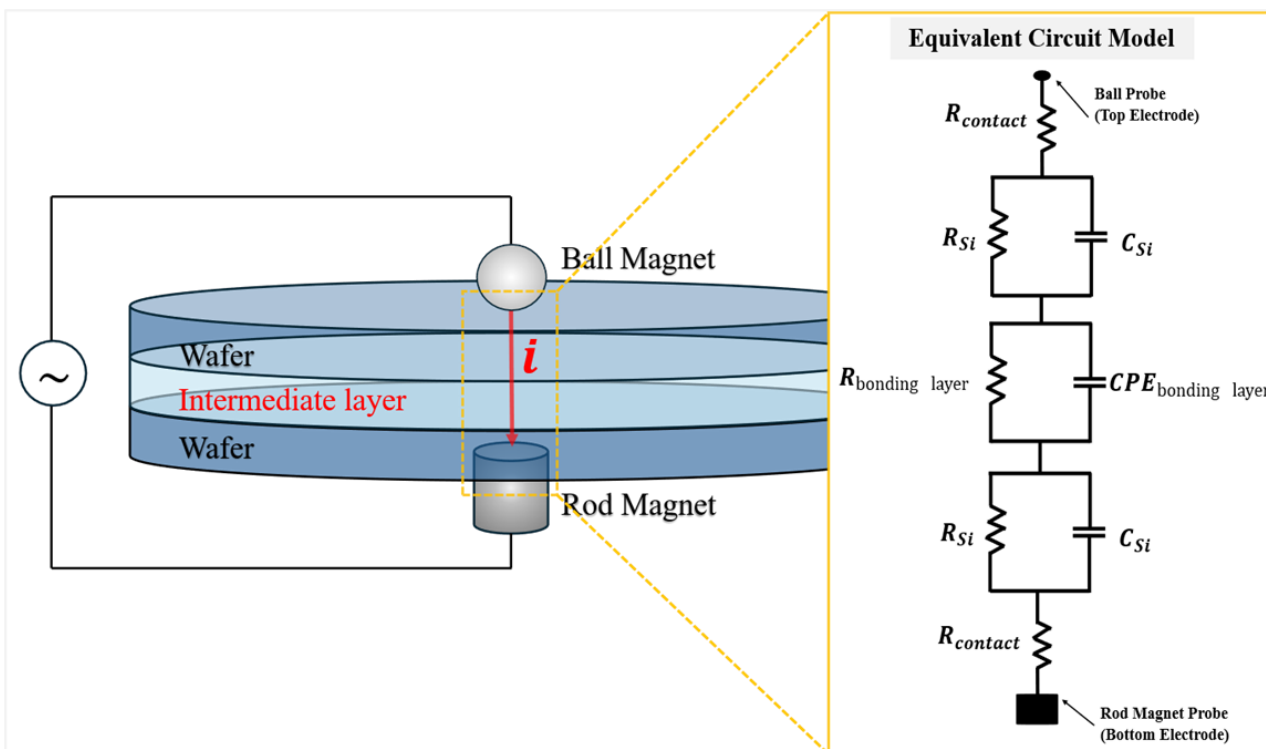
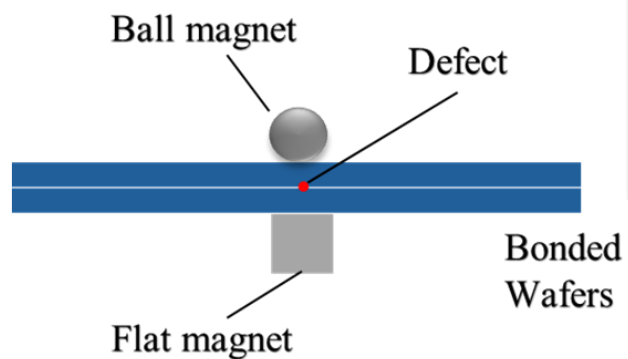
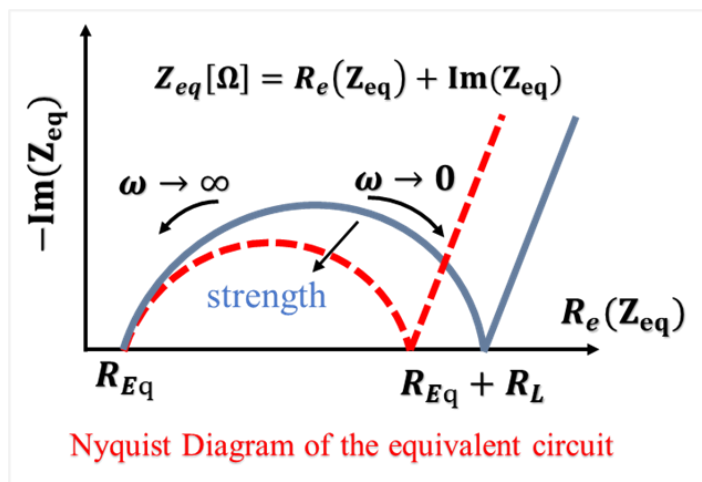
$$\frac{1}{E} = \frac{1-\nu_{ball}^2}{E_{ball}} + \frac{1-\nu_{substrate}^2}{E_{substrate}}$$

$$a = \sqrt[3]{\frac{3FR}{4E}} = \sqrt[3]{\frac{3 * 0.1N * 0.002m}{4 * 36.6GPa}} = 16 \mu m$$

Characterization Technique

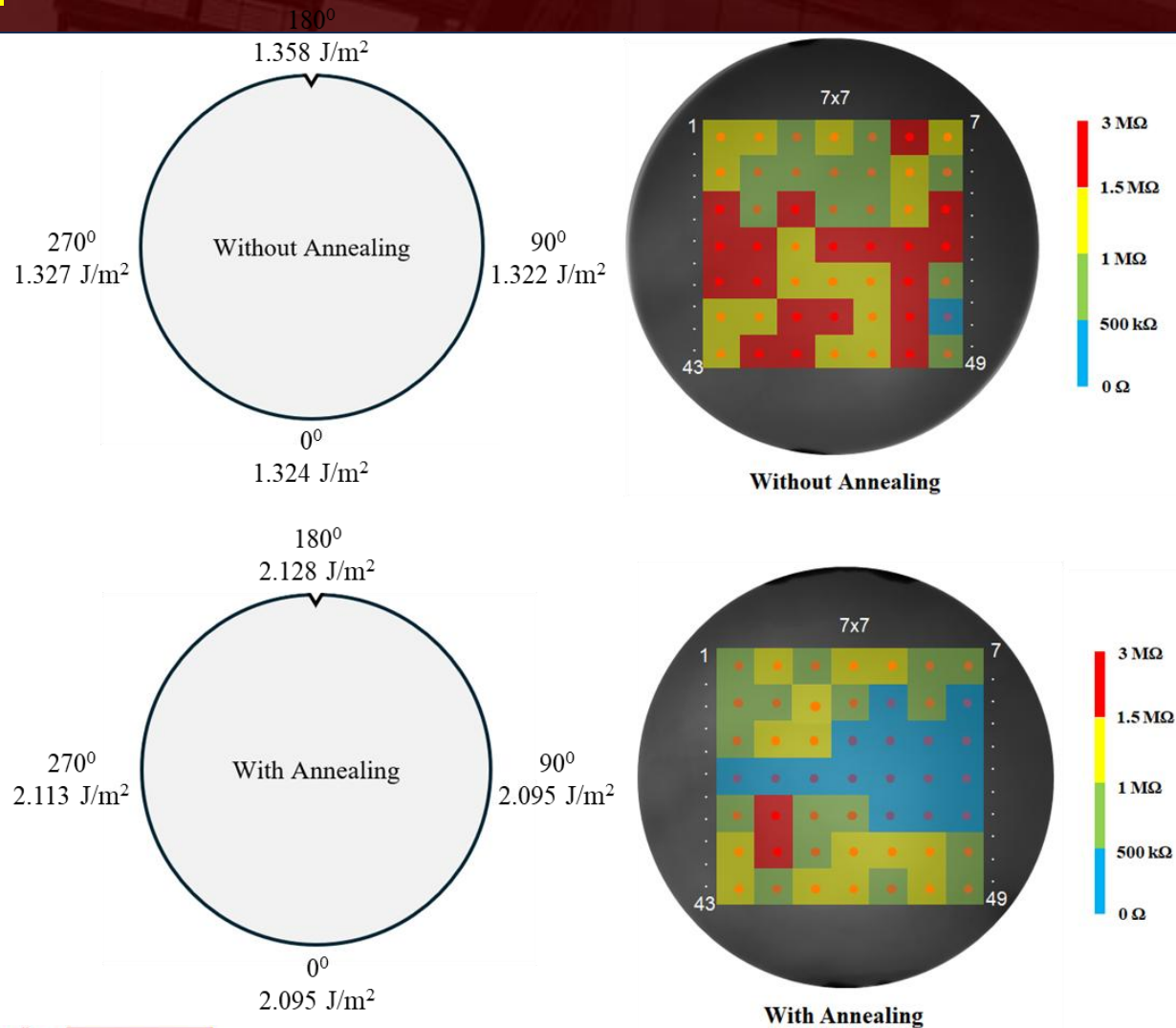


Magnets provide **consistent contact force** → **stable $R_{contact}$**

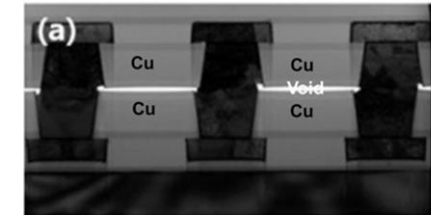


Magnets provide **consistent contact force** $\rightarrow$ **stable $R_{contact}$**

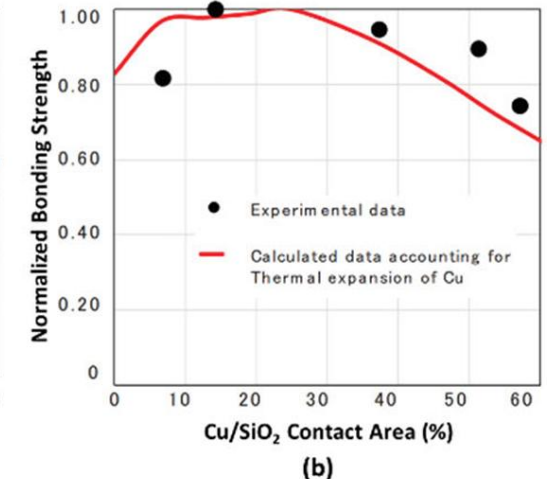
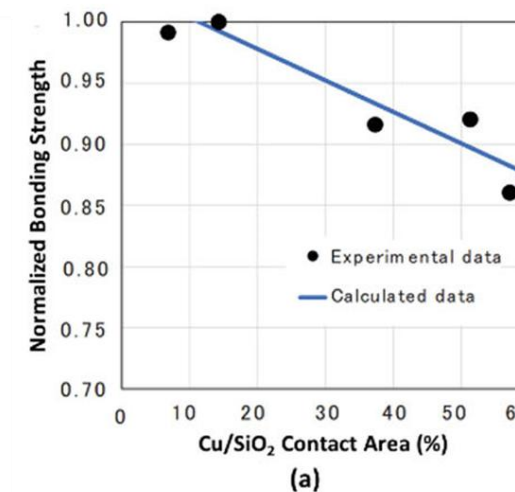
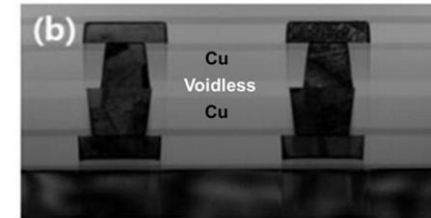
Annealing Effects on Bonding Layer



Before Annealing



After Annealing



Center-to-Edge Bonding Quality Variation

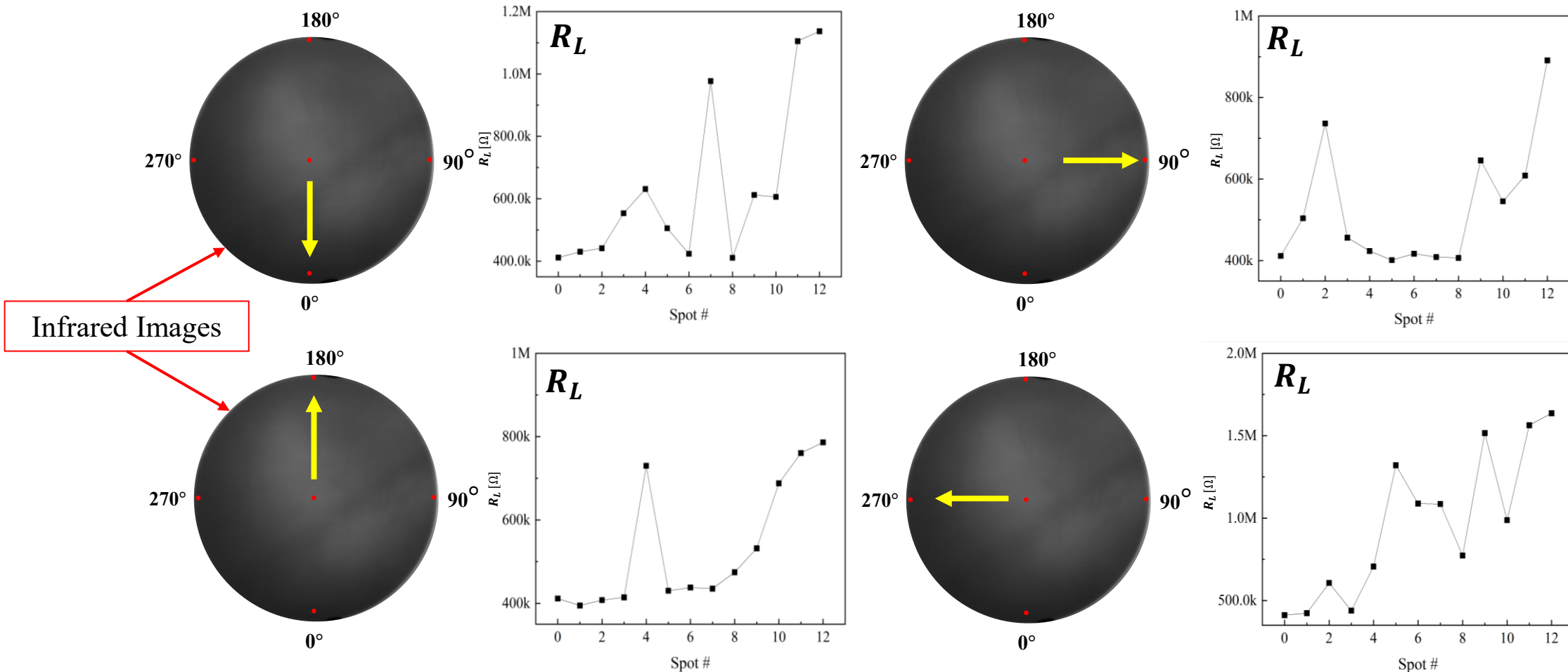
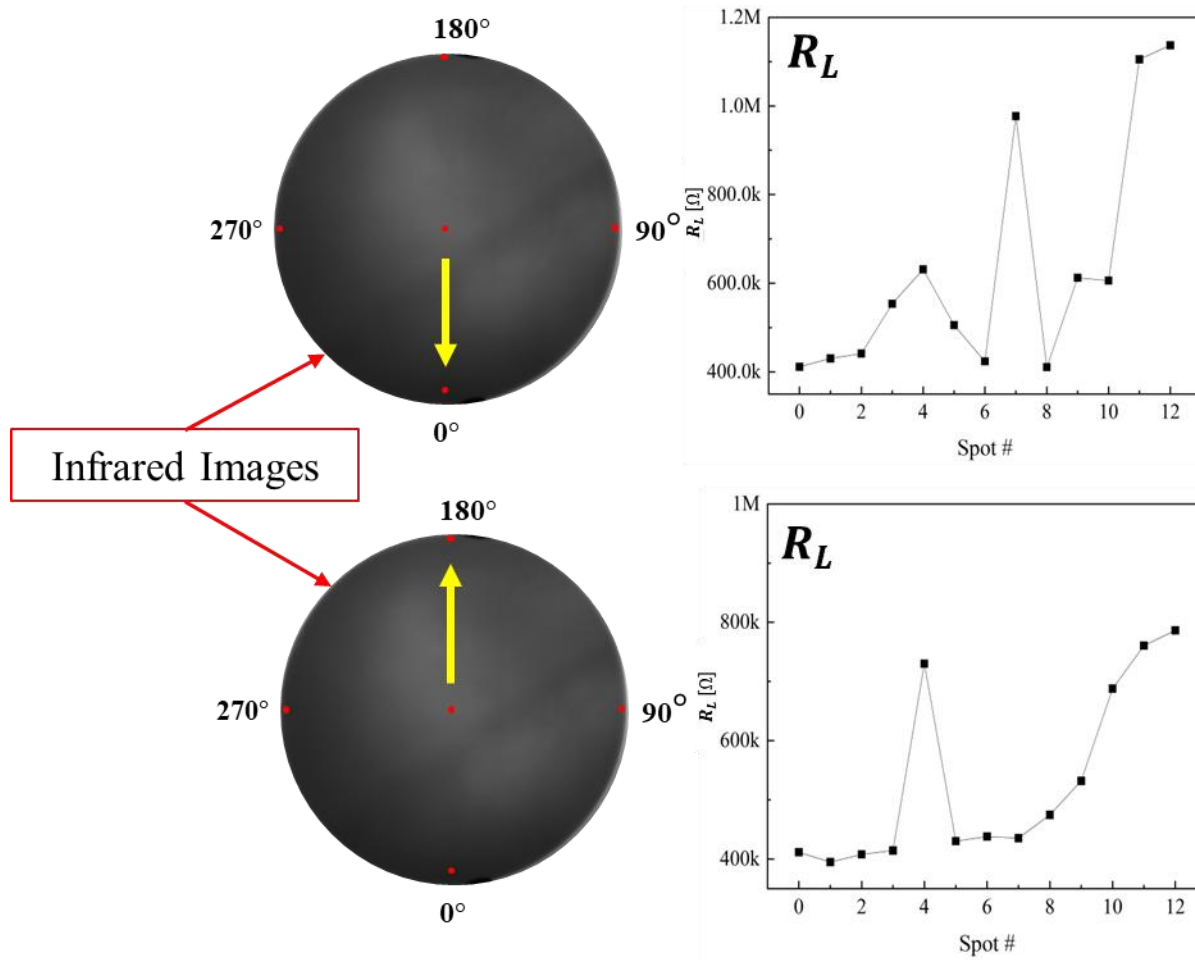
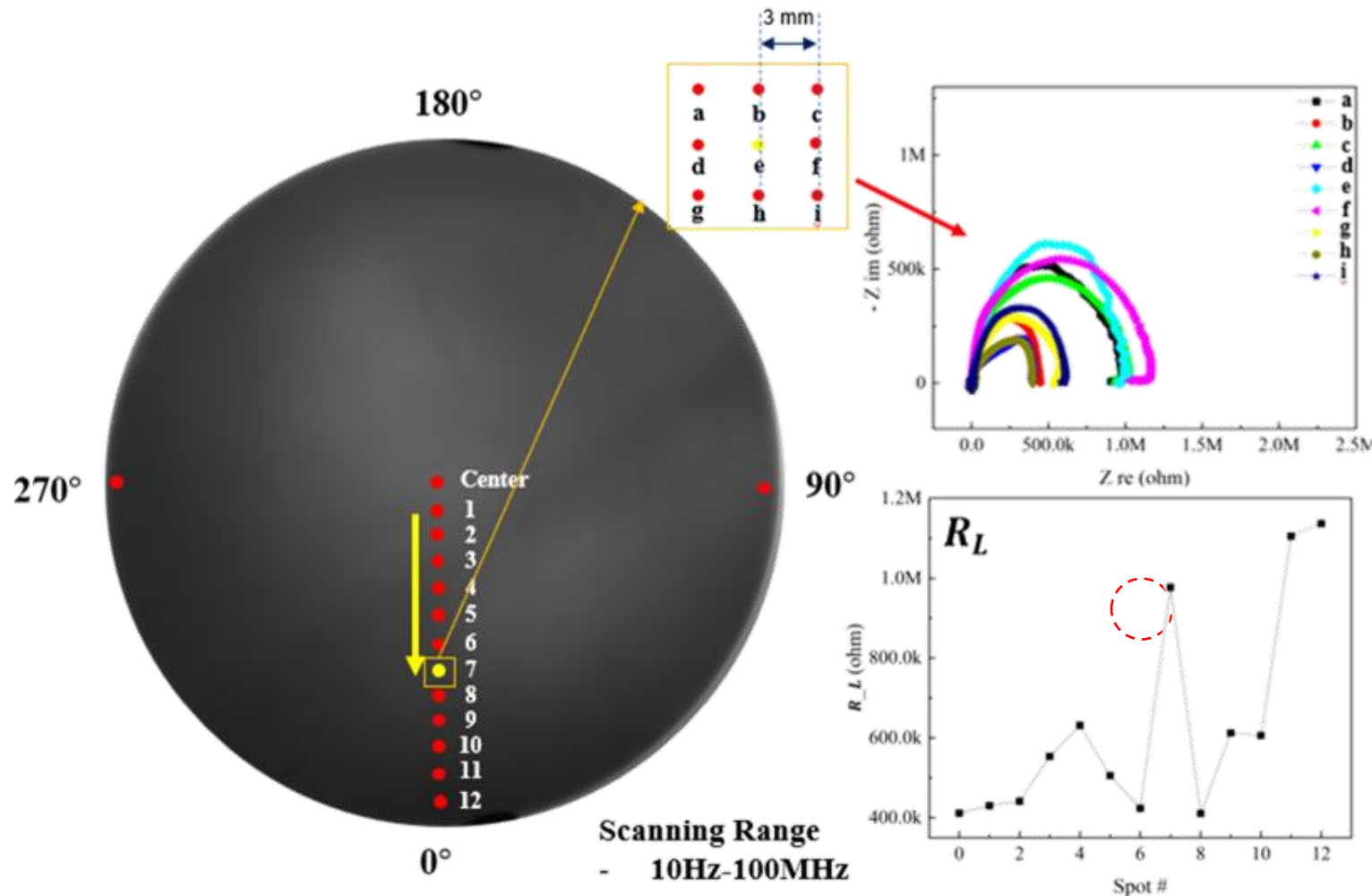


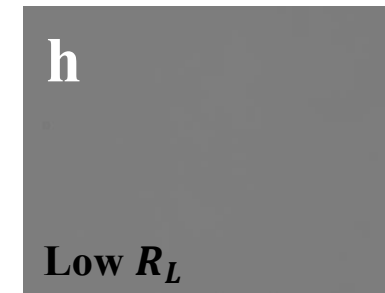
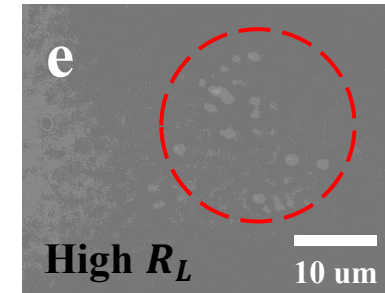
Figure 7: Bonding quality variation from center-to-edge with extracted resistance values along four different directions with 12 measurement points each direction.



Near Infrared Imaging



(b)



Wafer level bonding layer assessment

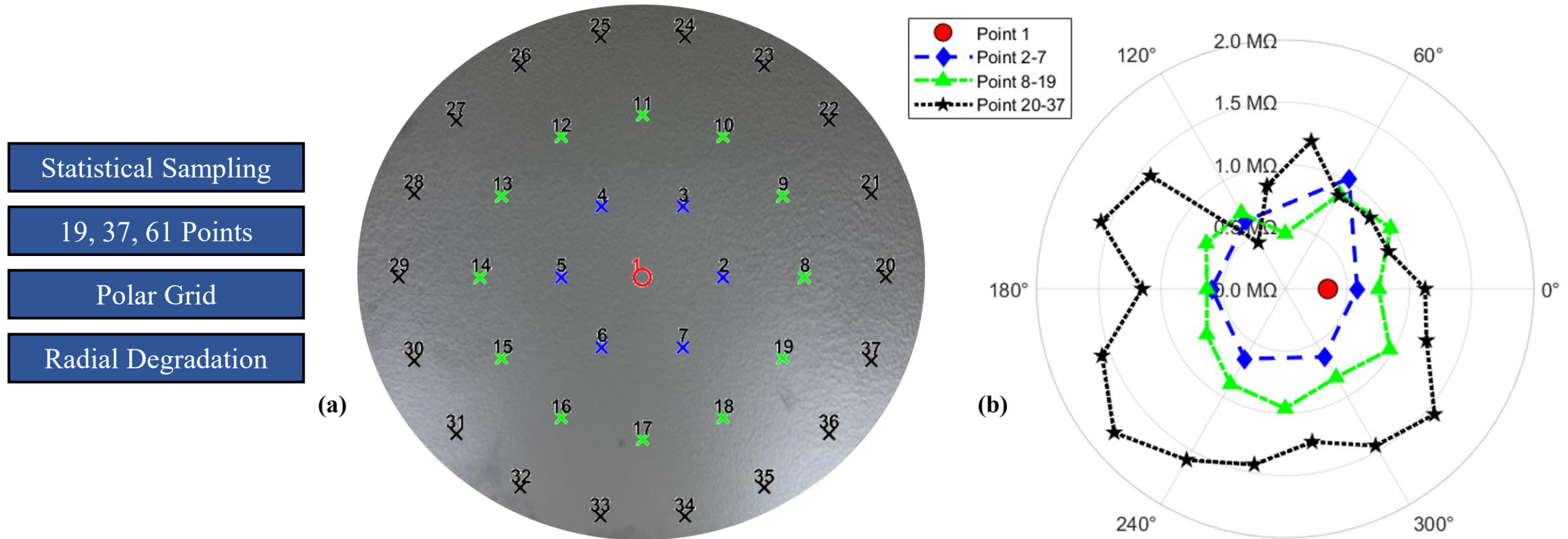


Figure 9: Bonding quality assessment through advanced sampling. (a) A 37-point testing scheme is adopted for better statistical accuracy in quality analysis and (b) Polar plots depicting bonding quality along the radial direction where theta (in degrees) and the radial parameter (in $M\Omega$) represent the angular position of the points respectively.

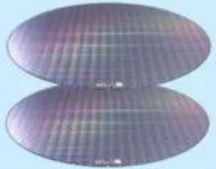
Summary



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Wafer to Wafer Hybrid Bonding

Die remain on wafer



Activation, cleaning
and then bonding



Grinding and thinning,
sent to packaging



Die to Wafer Collective Hybrid Bonding

Die to be bonded are
prepared, diced,
then placed on
carrier wafer



Activation, cleaning
and then bonding



Remove carrier wafer,
leaving bonded die on
target wafer



Die to Wafer Sequential Hybrid Bonding

Singulated die are
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activation and cleaning



Direct placement of die
using a bonder tool



Wafer-Wafer Bonding

Die-Wafer Bonding

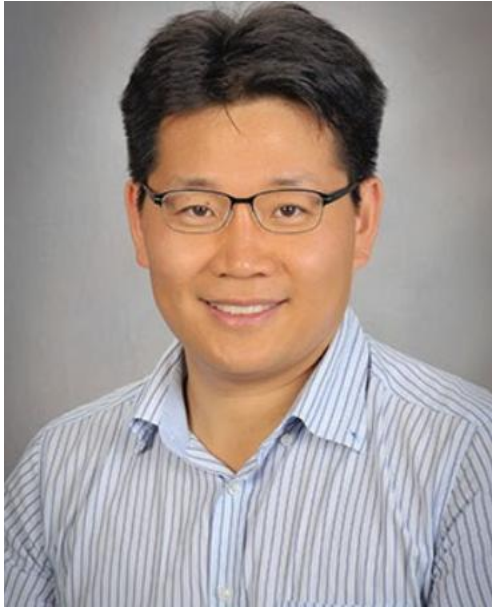
EIS
Testing

Defect
mapping

Process
Improvement

High Yield

Acknowledgement



Project Contributors

1. **Dr. Heebum Chun** (Field Application Engineer, KLA)
2. **Sean Kim** (PhD student, Purdue University)
3. **Hyun Jae Lee** (PhD student, Texas A&M University)

Sponsor:



Principal Investigator (PI)

Dr. ChaBum Lee

Associate Professor and Morris E. Foster Faculty Fellow II,
J. Mike Walker '66 Department of Mechanical Engineering, Texas A&M University



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Thank You

Appendix A

