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Ultra-Sensitive Dynamic Piezoelectric Force Sensors that Improve Semiconductor Manufacturing

James Macy

Application Expert BU Advanced Manufacturing

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Name: **James Macy**

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Familiar Status: married, two sons

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Shaping the future together

Who are we, and what do we do?

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High Dynamic Measurement	**Measurement Results**	**Gained Knowledge**
Force, pressure, etc.	**Monitor and optimize production processes**	**New innovations**

Kistler at a Glance

Facts & Figures

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10,500+
active customers worldwide

60+
locations worldwide

2,050+
employees worldwide

300+
employees in R&D worldwide

9%
investments in R&D (given as a percentage of turnover)

800+
applied for and granted patents

30+
university and college R&D partners

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Ultra-Sensitive Dynamic Piezoelectric Force Sensors that Improve Semiconductor Manufacturing

Force is a critical process value in production

Outline

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- **Why:** Dynamic Force Measurements are Important
- **What:** Dynamic Force Sensors & “The Transduction Element”
- **How:** Share Insight & Solutions … 5 Semiconductor Processes
- Wrap Up Presentation and Address Open Questions

Why Dynamic Force Measurement

Piezo Electric Force Measurement

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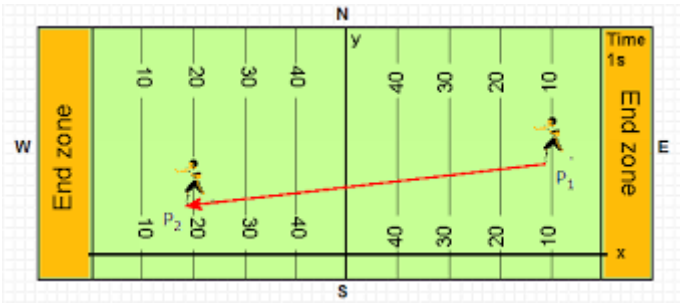
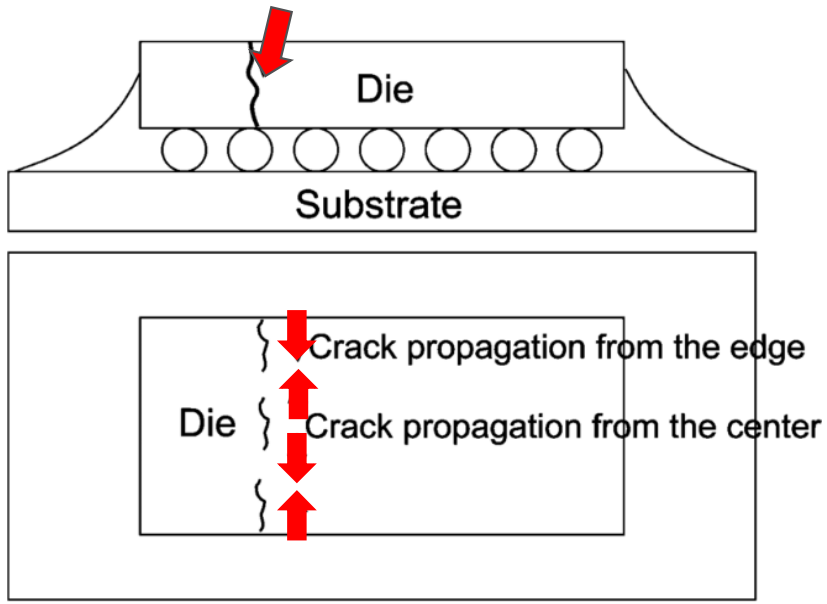
Today

Optical, Displacement and Electrical Testing



One does not directly detect the Mechanical Stress generated

Crack during Die Bonding Process



Stress is a physical value based on Force ($\sigma = F/A$)

What: Dynamic Force Sensor

HIGH RIGITY MEANS HIGH LINEARITY

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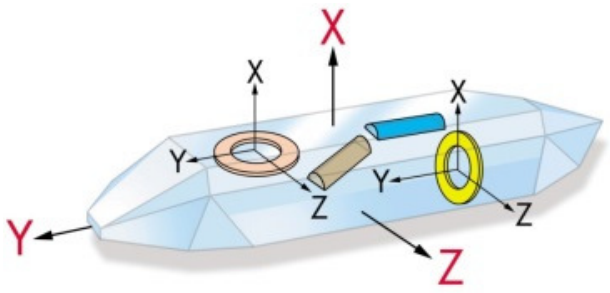

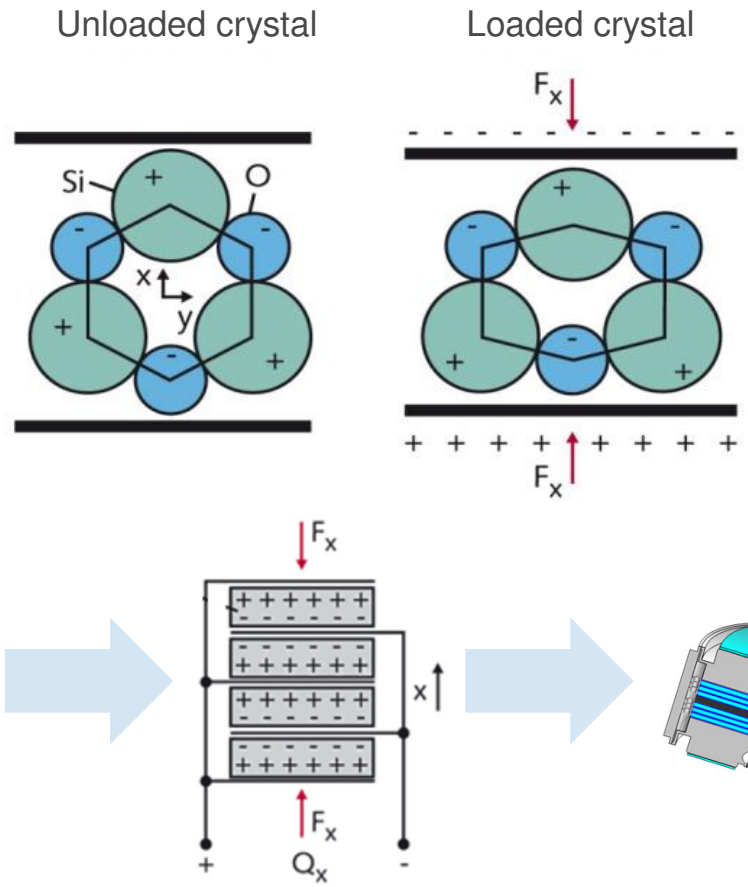

“The Transduction Element”

Unique Advantages (GIGO)

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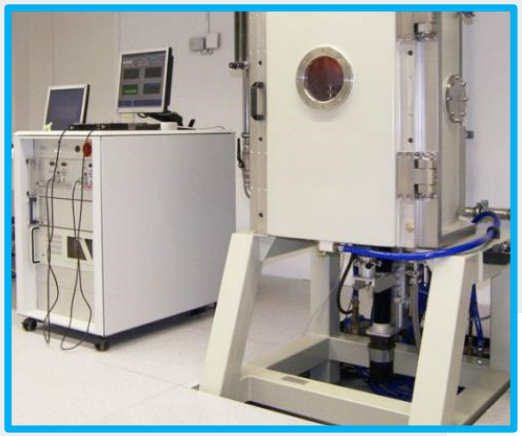
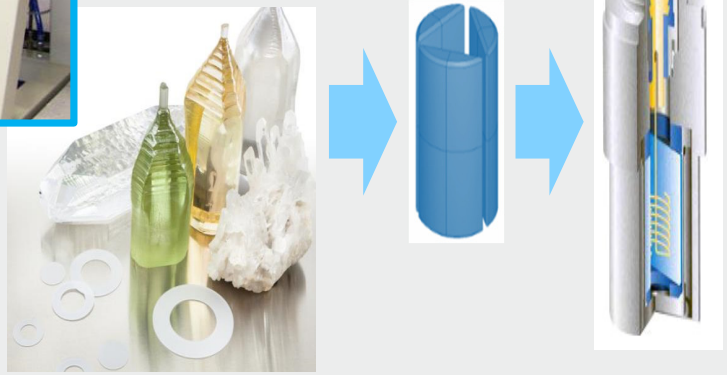
Kistler’s own Crystal-growing facility.



Unique KI Sensing Crystals under the hood of our sensors



Materials for Sensing Elements: Quartz

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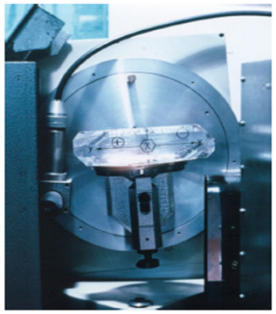
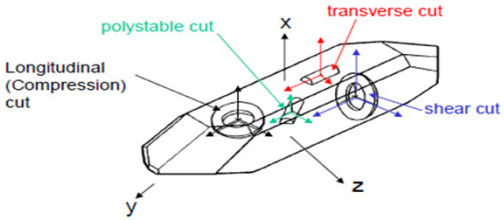


Quartz

- Prior to the cutting, a x-ray goniometer is used to determine the orientation of the major crystal axes



- Piezoelectric Effect: under mechanical force, piezoelectric materials produce electrical charges on their prism surfaces

FIA , March 10, 2014, page 18

Plus, our Specialized In-House Machining (Unique Transverse & Polystable cuts)

Dynamic Force Sensor offers Unique Performance

HIGH RESOLUTION AND WIDE MEASUREMENT RANGE

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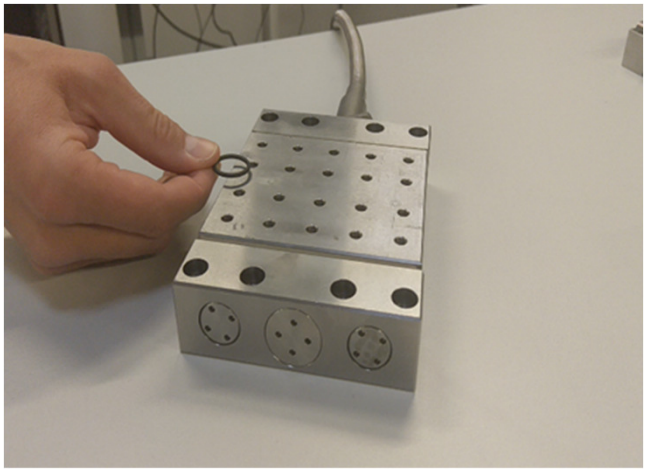
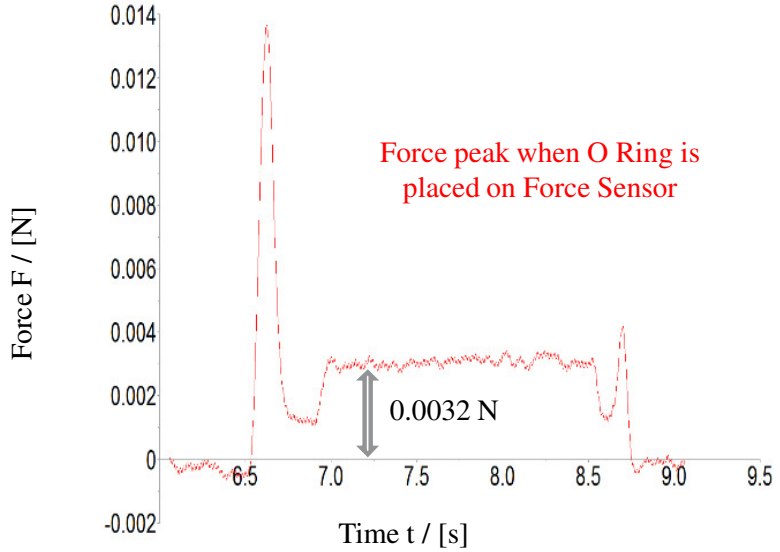
10 kN (2248 lbf) Piezo Force Sensor



O ring is ≈ 0.33 gram (0.00073 lbf)



Piezo Sensor detects O-Ring force impact and dynamics

Dynamic Piezo Electric Force Technology

Key Takeaways

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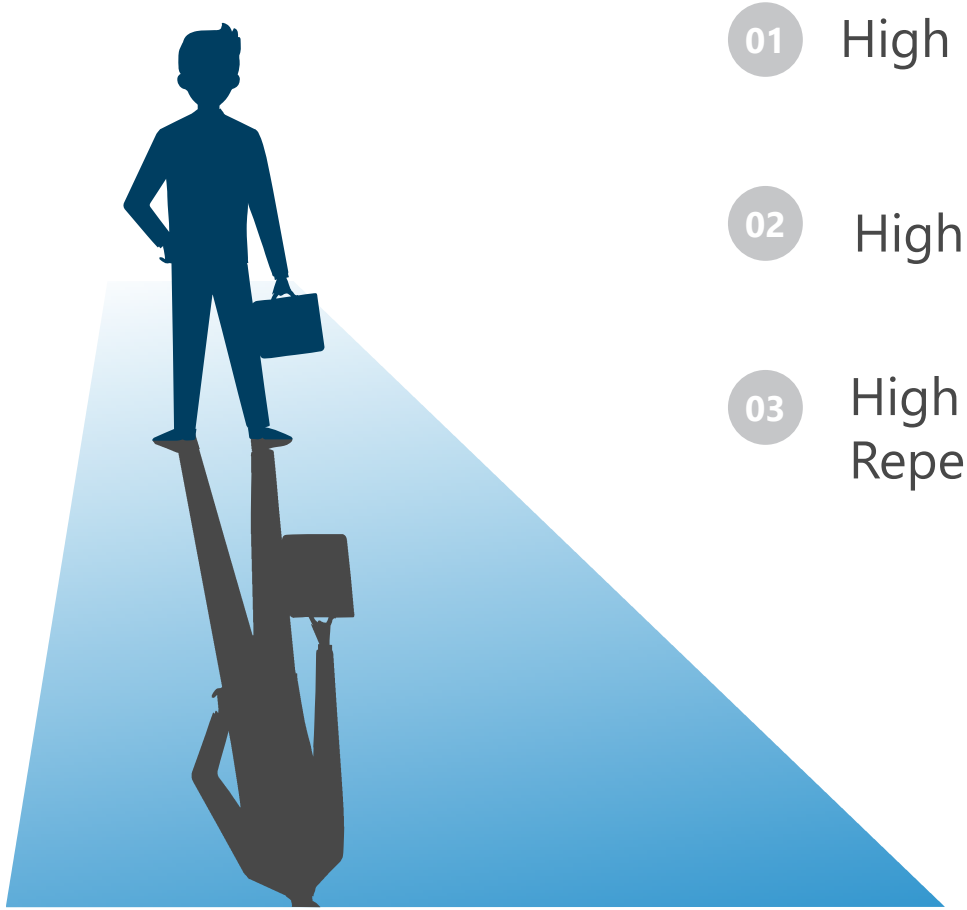

01 High Rigidity

02 High Linearity

03 High Resolution and Repeatability

04 Wide Measurement range

05 Long Life span

06 Very Compact Size

Market Demand for Ultra Thin Wafers

Ultra Thin Dies are utilized in Cell Phones, stacked 3D Packages…

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SOLUTION:
Φ300 mm Silicon Wafers are reduced to
5 µm Thickness by Grinding

Photo 1: t5 µm, Φ300 mm Silicon Wafer(Supplied by Renesas Technology Corp)

5 µm Thickness?

ISSUE:
Decreased Wafer Thickness, results in Decreased Die Strength and Increased Die Warpage.

Photo 5: t50 µm Φ8-Inch Silicon Wafer

Source: DISCO

How: Share Insight & Solutions

5 Semiconductor Process Areas

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1. **Machining** Thin Wafers
2. **Producing** Thin Dies
3. **Handling** Thin Dies
4. **Assembling** Thin Dies
5. **Testing**

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1. Machining Thin Wafers (CMP Polishing)

Improving Press Force Accuracy

The Benefits of Force Control

Chemical-Mechanical Planarization (CMP) / Wafer Polishing

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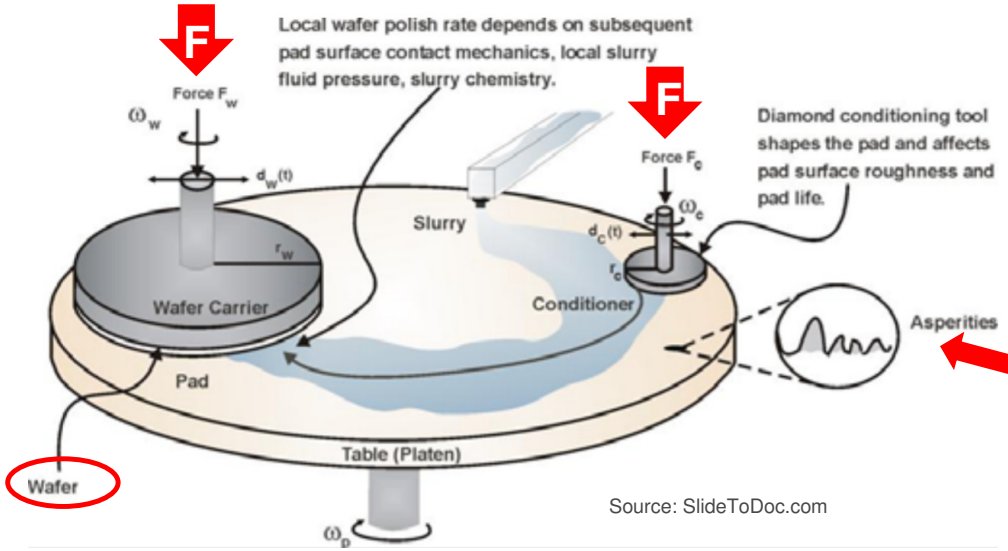
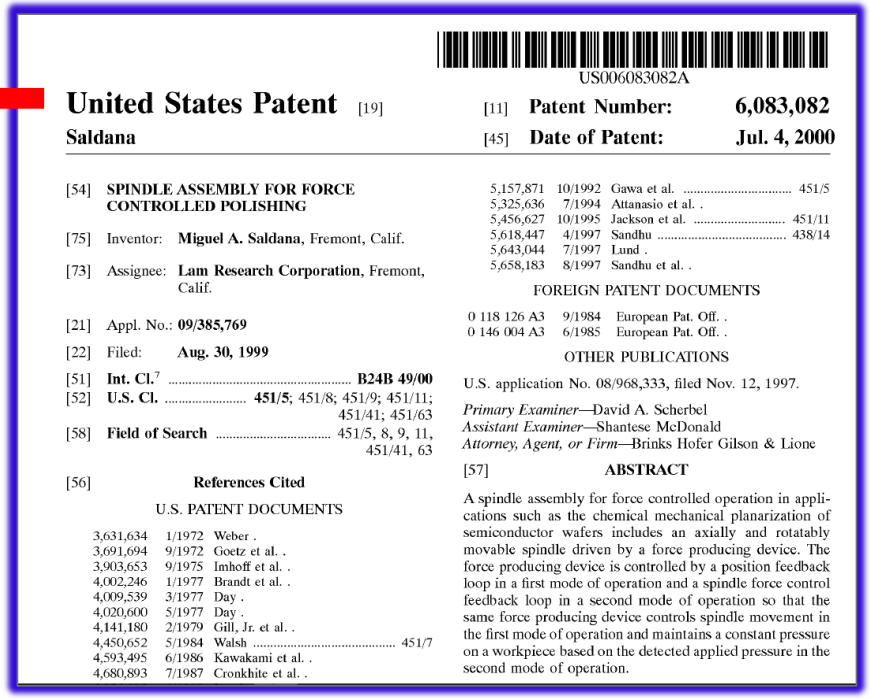
CONCERN:
"Improving the Accuracy of prior systems in by providing The Actual Down Force on a workpiece in a polishing environment"

Filed by: Lam Research Corp (Fremont, CA)
Patent Assignee: Applied Materials Inc



Source: SlideToDoc.com



US006083082A

United States Patent [19]
Saldana

[11] **Patent Number: 6,083,082**
[45] **Date of Patent: Jul. 4, 2000**

[54] **SPINDLE ASSEMBLY FOR FORCE CONTROLLED POLISHING**

[75] Inventor: **Miguel A. Saldana**, Fremont, Calif.

[73] Assignee: **Lam Research Corporation**, Fremont, Calif.

[21] Appl. No.: **09/385,769**

[22] Filed: **Aug. 30, 1999**

[51] **Int. Cl.**[7] **B24B 49/00**

[52] **U.S. Cl.** **451/5**; 451/8; 451/9; 451/11; 451/41; 451/63

[58] **Field of Search** 451/5, 8, 9, 11, 451/41, 63

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0 146 004 A3	6/1985	European Pat. Off. .

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U.S. application No. 08/968,333, filed Nov. 12, 1997.

Primary Examiner—David A. Scherbel
Assistant Examiner—Shantese McDonald
Attorney, Agent, or Firm—Brinks Hofer Gilson & Lione

[57] **ABSTRACT**

A spindle assembly for force controlled operation in applications such as the chemical mechanical planarization of semiconductor wafers includes an axially and rotatably movable spindle driven by a force producing device. The force producing device is controlled by a position feedback loop in a first mode of operation and a spindle force control feedback loop in a second mode of operation so that the same force producing device controls spindle movement in the first mode of operation and maintains a constant pressure on a workpiece based on the detected applied pressure in the second mode of operation.

Kistler Piezo-Technology: Greatly Improves the Force Measurement… Resolution at the Wafer to Pad Interface

Wafer Grinding and Polishing

Advancing Semiconductor Manufacturing

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Dynamic Force Sensors provide:

1. Initial Wafer Contact
2. Actual Pressing Down Force
3. Live Feedback for Monitoring and Control

Force Sensor 9132B

High Resolution
0.1 gram

Conditioner 5074

Fast Cycle Time
< 0.1mS

PLC Connection
via
Industrial Fieldbus

Your Benefit's includes…

Higher Precision & Documentation

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2. Producing Thin Dies (Dicing & Lamination Process)

Die Tension Control

Wafer Dicing Process

Semiconductor Manufacturing

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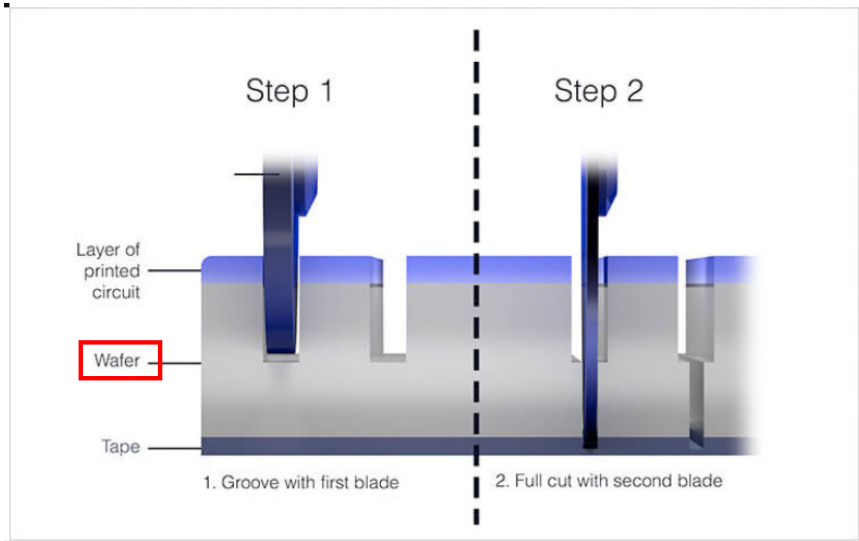
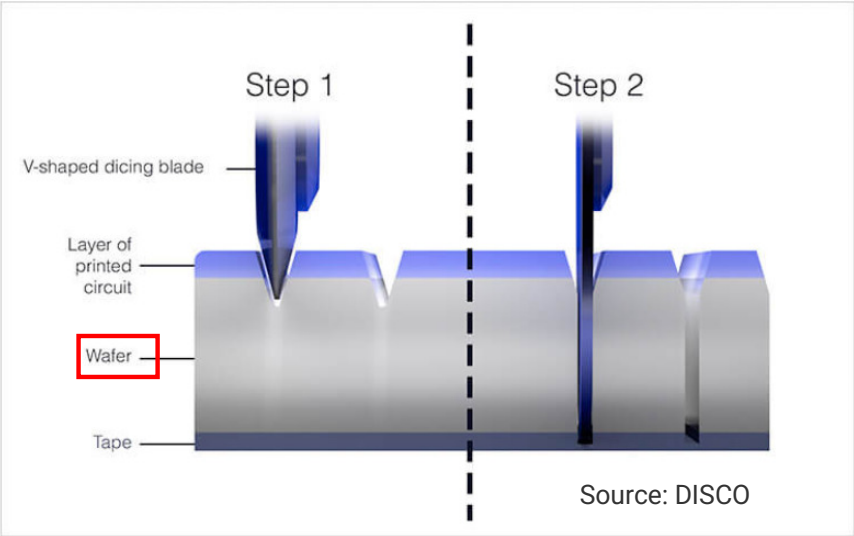
Traditionally, Silicon Wafers are **1st Thinned by GRINDING & 2nd CUT into Dies**





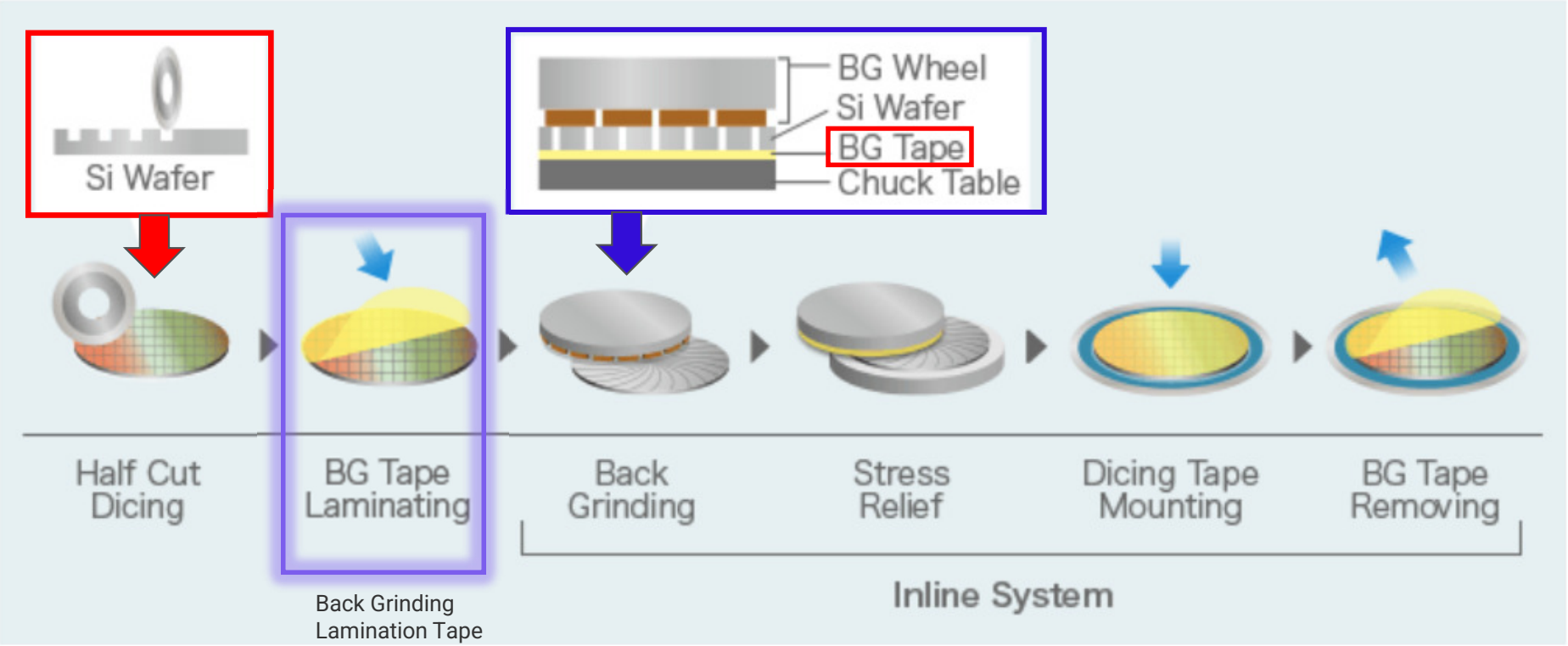
CONCERN:

Risk of Wafer-Level Breakage, which increases with Larger Diameters and Thinner Wafers

So, let's examine another approach …

Dicing Before Grinding (DBG) Process

SOURCE: DISCO Technology Advancing the Cutting Edge



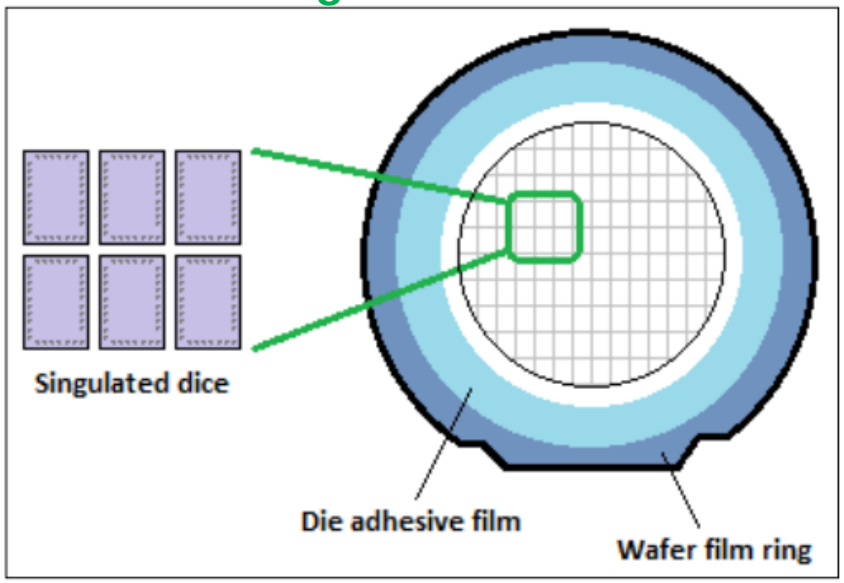
(DBG process)

SOURCE: https://technology.discousa.com/method/dicing-before-grinding/

CONCERN: Proper Lamination Tape Requirement

Critical characteristic in handling of Thin Wafers

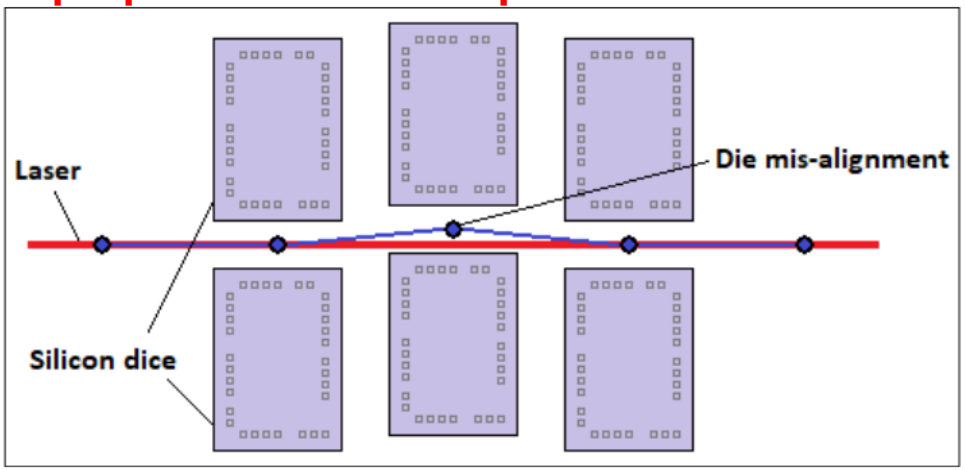
After Back Grinding:
Desired Die Alignment



Wafer representation

SOURCE:
STMicroelectronics Philippines

After Back Grinding:
Tension-Effect from
Improper Lamination Tape Process



Die mis-alignment manifestation

Evaluation on backgrinding tape lamination

Type of lamination	Die mis-alignment	Remarks
With tension	Manifested	Fail
Tensionless	No manifestation	Pass

Retrofit Solution: Indirect Force Piezo Sensor Pin

Advancing the Wafer Lamination Process

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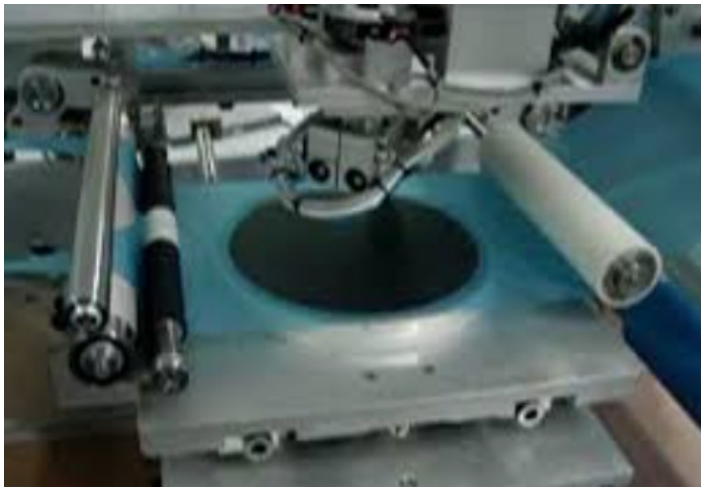
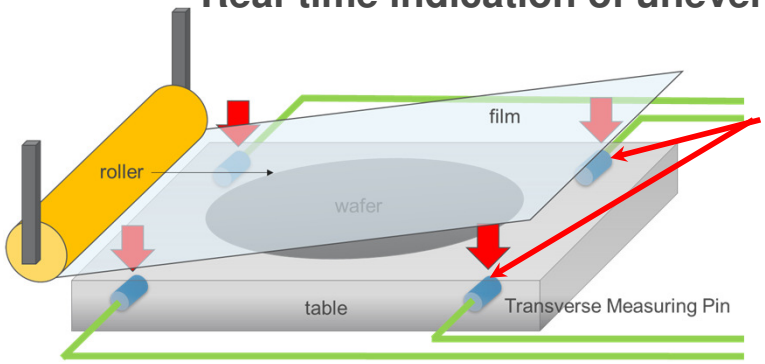


Source: youtube.com

Measurement Solution:

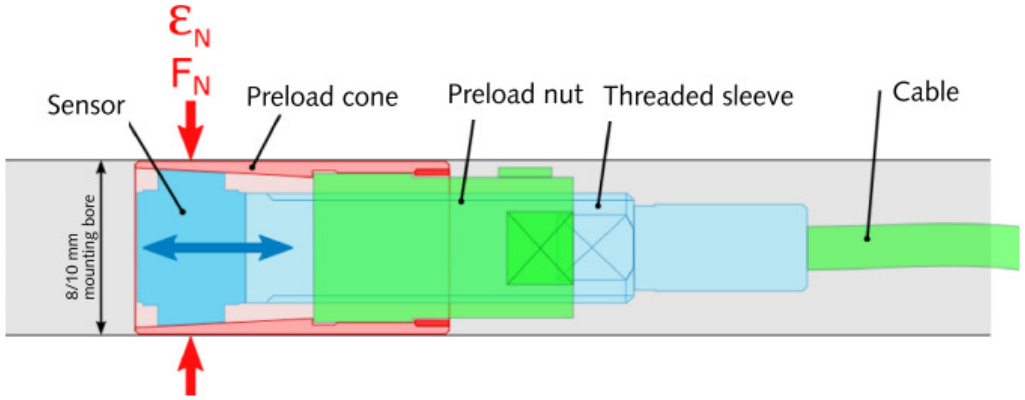
Real-time indication of uneven loading conditions



4 each Sensors

- **Installed in Wafer-Support Structure**
- **Individual Dynamic Output Signals**

Mounting Bore Sensor Options: 8 or 10mm



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3. Handling Thin Dies (Pick & Place / Die Sorting / Chip Removal)

Die Stress Control & Peeling Energy

Die Sorting & Chip Removal

Process Concerns

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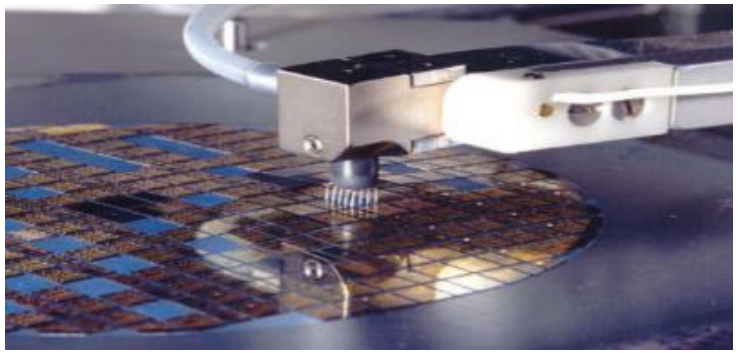
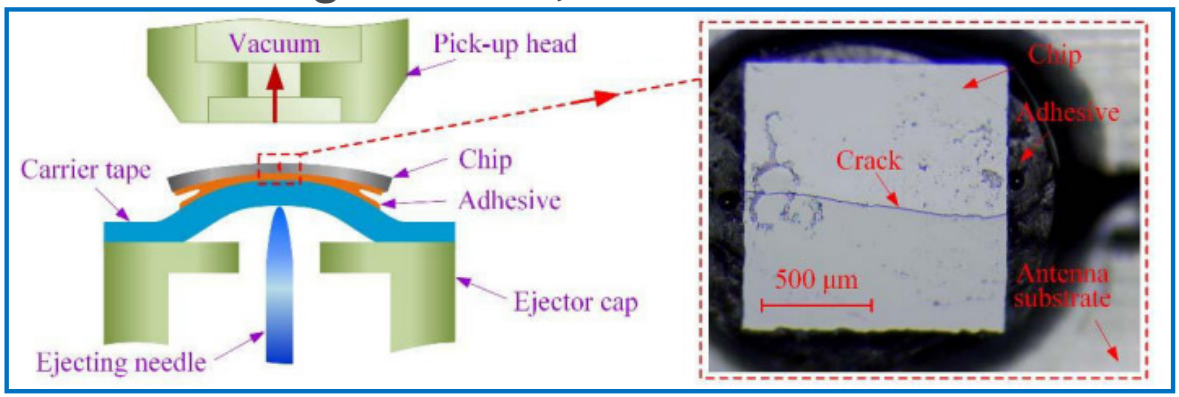
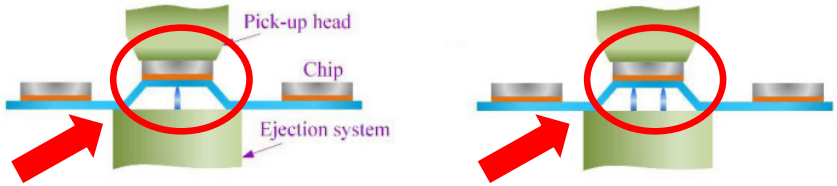


Thinner and larger wafers, result in more flexible dies



SOURCE: IEEE.org/publications

CONCERN: Reliable & Traceable Chip Removal from carrier membrane/tape



***Dynamic Force** monitoring provides a means for:*

- ***Direct Detection** of **Die Cracking Stress***
- ***Determination** of **"The Peeling Energy"**, required for Proper Die Removal from the Carrier Membrane …*

Sensing “Die Peeling Energy”

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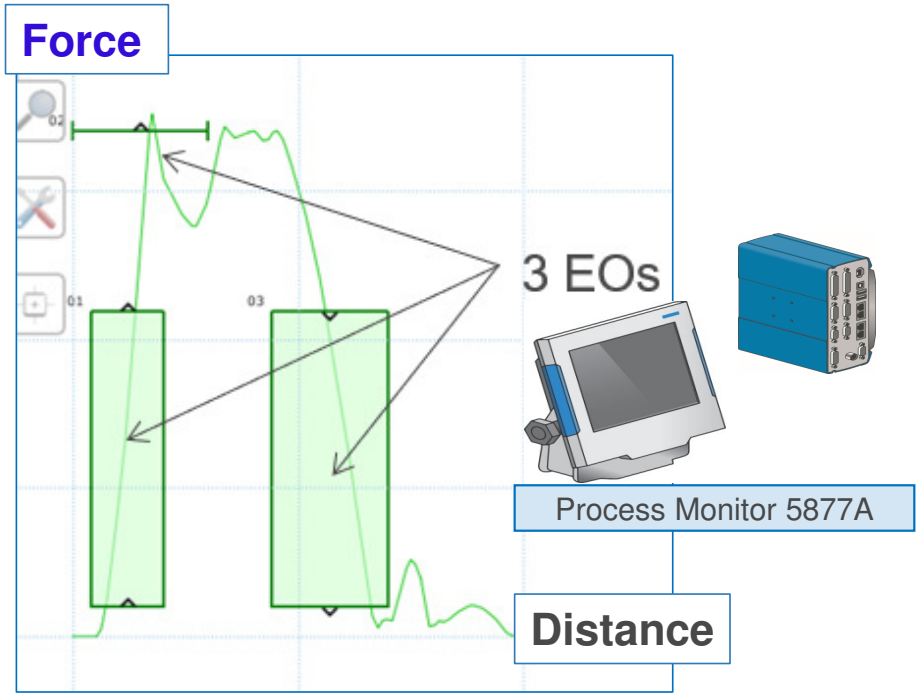
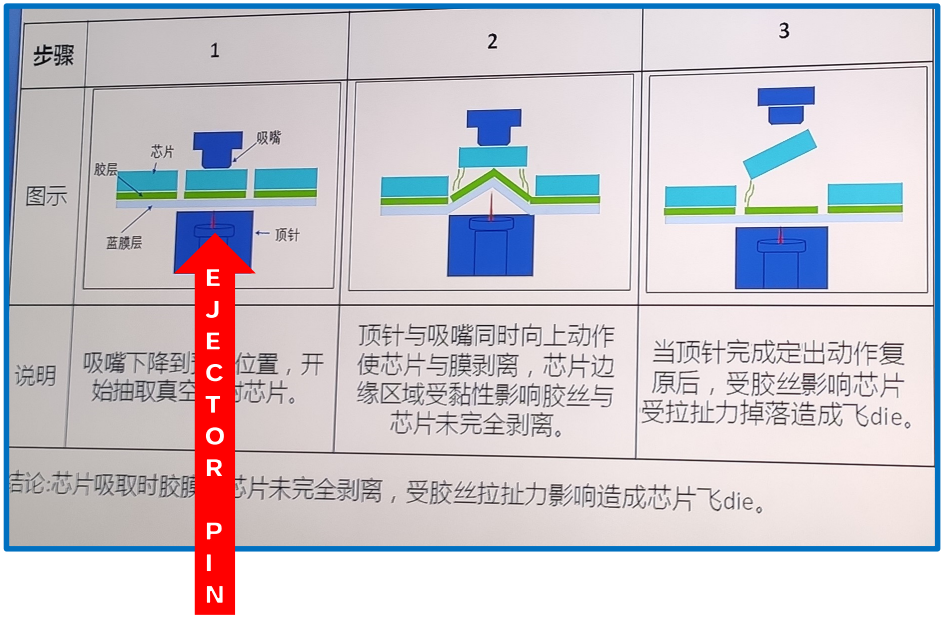
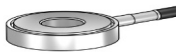
1) ENERGY is a measurement of the ability of something (The Ejector Pin) to do WORK.





Die Sorter – Sensor Placement

Force Sensor located within the Ejector Pin Shaft



Force Sensor 9132CD

2) WORK is defined as Force times Distance.

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4. Assembling Thin Dies (Thermal Compression Bonding)

Initial Contact &
Wetting of Bump Pads

Thermal Compression Bonding

Process Control of the **Temperature**, **Force** and **Z-axis travel** occur during this Die Bonding

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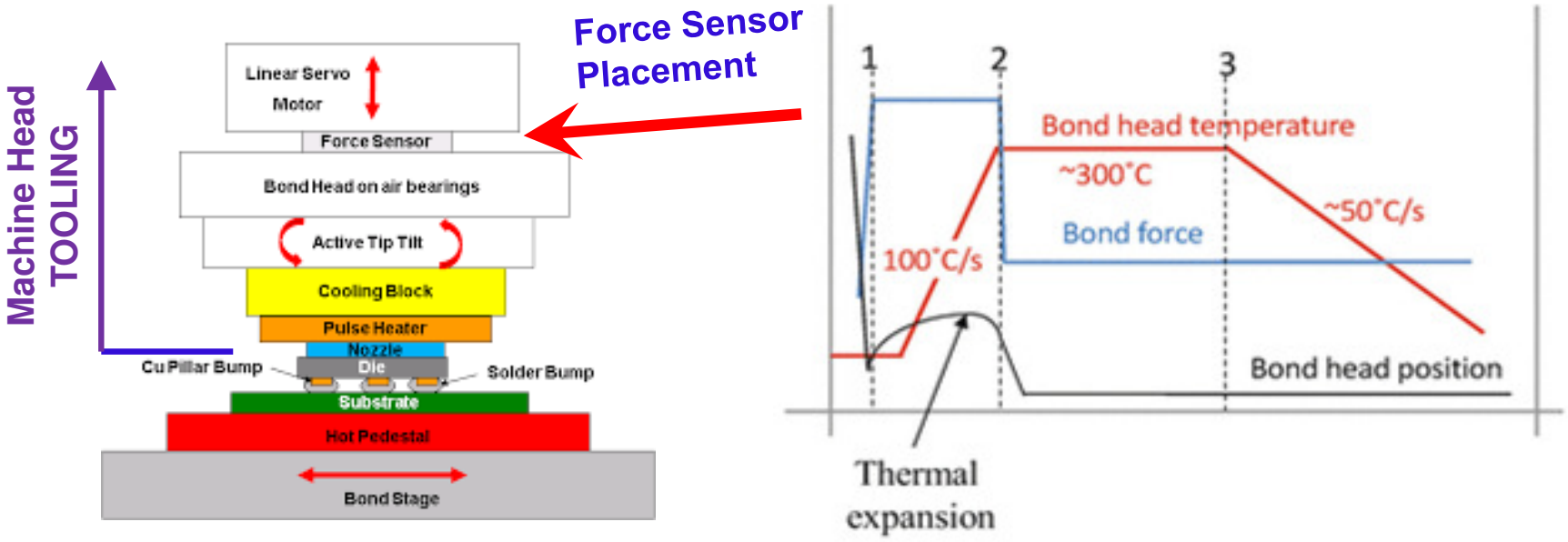

SOURCE: IEEE

SOURCE: Besi

Thermal Compression Bonding

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Detailed Control of 3 Process Parameters …

1. Bond Head Position moves down **until Force Senses Bump Pad Contact (Stack-Up Reached) Trigger #1** Position to be Held and Temperature Ramps-Up ***"Melting Solder"***

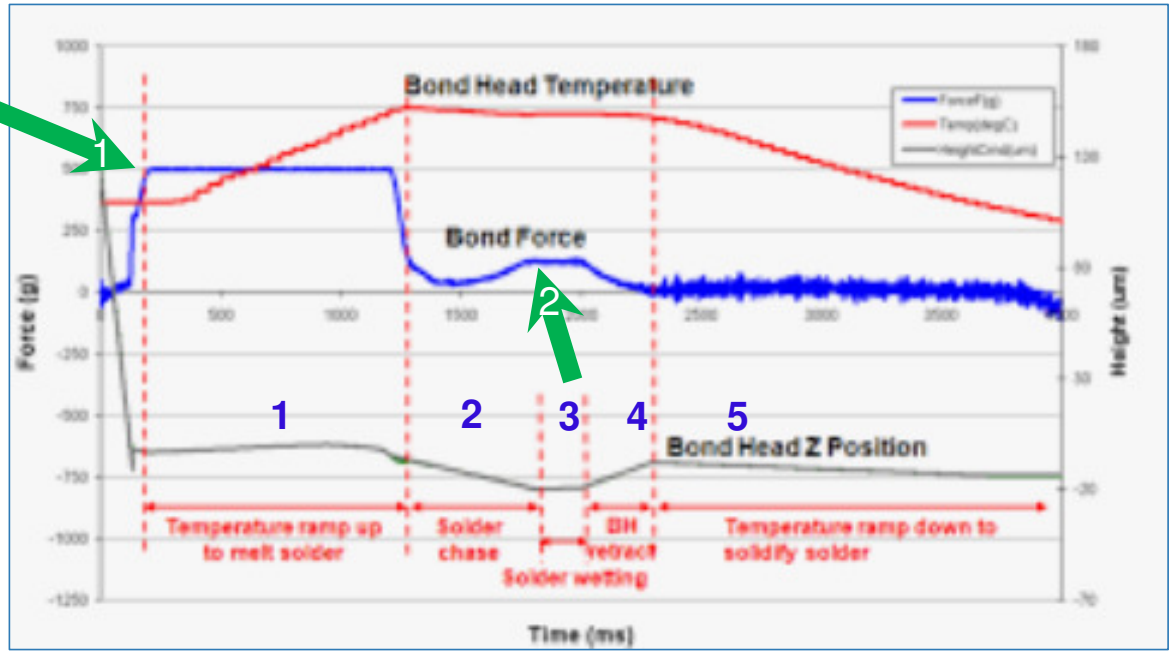
2. Temp. is Held, **Force Drops as Solder flows** and **Bond Head Blindly moves forward** ***("Solder Chase")***

3. **Force Signal Rises (Trigger #2) Sensing Liquid Solder Contact,** Position is then Held (**Assuring Solder Wetting of Bump Pads**)

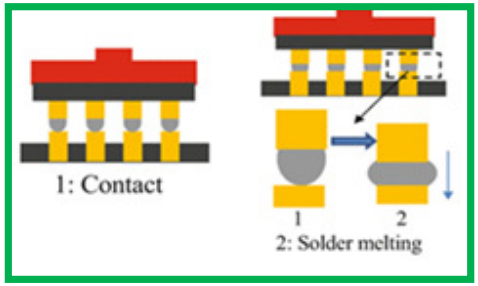
4. Bond Head Retracts Upward to ***"Desired Final Height Spec"***, **Force Signal Drops** ***(Height Control of Liquid Solder Joint)***

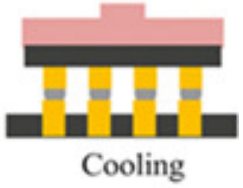
5. Temp. Ramps-Down, while Position remains Held ***(Locking in Cooling Solder at Proper Final Height)***

Sensing the Key Trigger Points



Source: ieeexplore.ieee.org





Source: link.springer.com

Thermal Compression Bonding

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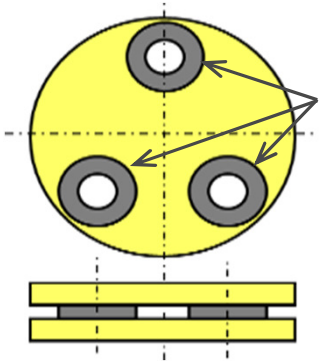
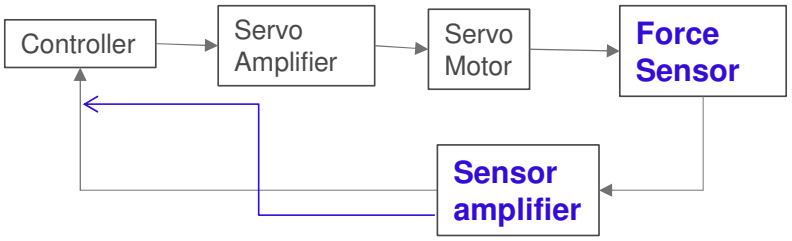
Machine Head Sensor



3 each Piezo-Force Sensors (Individual Output Signals)

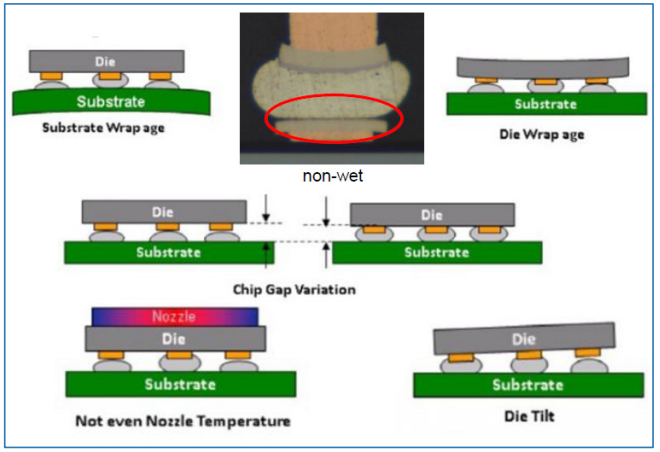
High Resolution 0.1 gram



Fast Cycle Time < 0.1mS

Benefits of Dynamic Force Integration

- **Control of Mechanical Contact & Parallelism, with an ability to sense component Warpage**



SOURCE: Besi

- **Increased Machine Speed & Performance**
- **Highly Rigid Force Sensor allows for Bonding the Thinnest & Most Brittle Materials (Improved Accuracy)**

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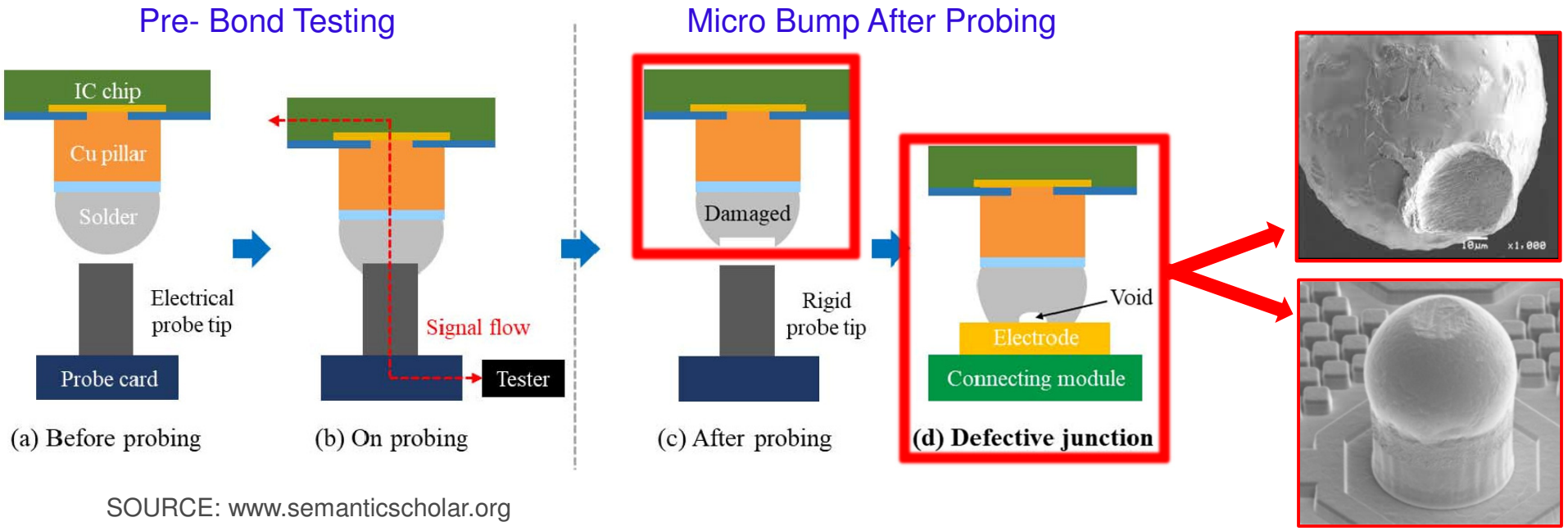
5. Testing (Micro Mini Bumps / Spring Probe Cards)

Verification & Traceability

Probing Micro Bumps

CONCERN: Defective Junction After Test Probing



SOURCE: www.semanticscholar.org

Verify Operational Probe Spring Force

Advancing Manufacturing Processes

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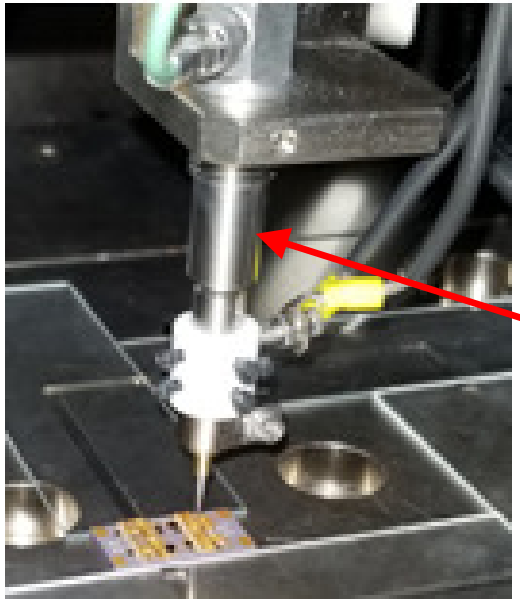
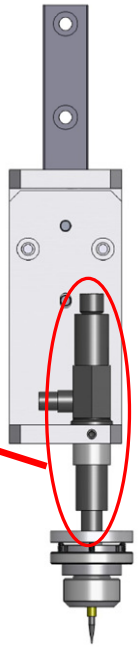
CONCERN: Probe Spring Force on DUT





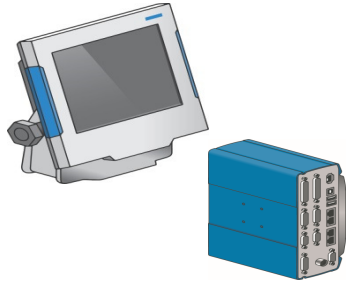
Tooling Directly Measures:
Force (F) and **Distance (X)**

The Spring Force (F) Applied equals **Spring Constant (k)** times the **Displacement of the Spring (Change in Length X)**

$$F = -k\,X$$

Hence, **k** = Test Probe's Spring Constant

Force



Displacement

In-process testing of Spring-loaded Probes

Advancing Semiconductor Quality Testing

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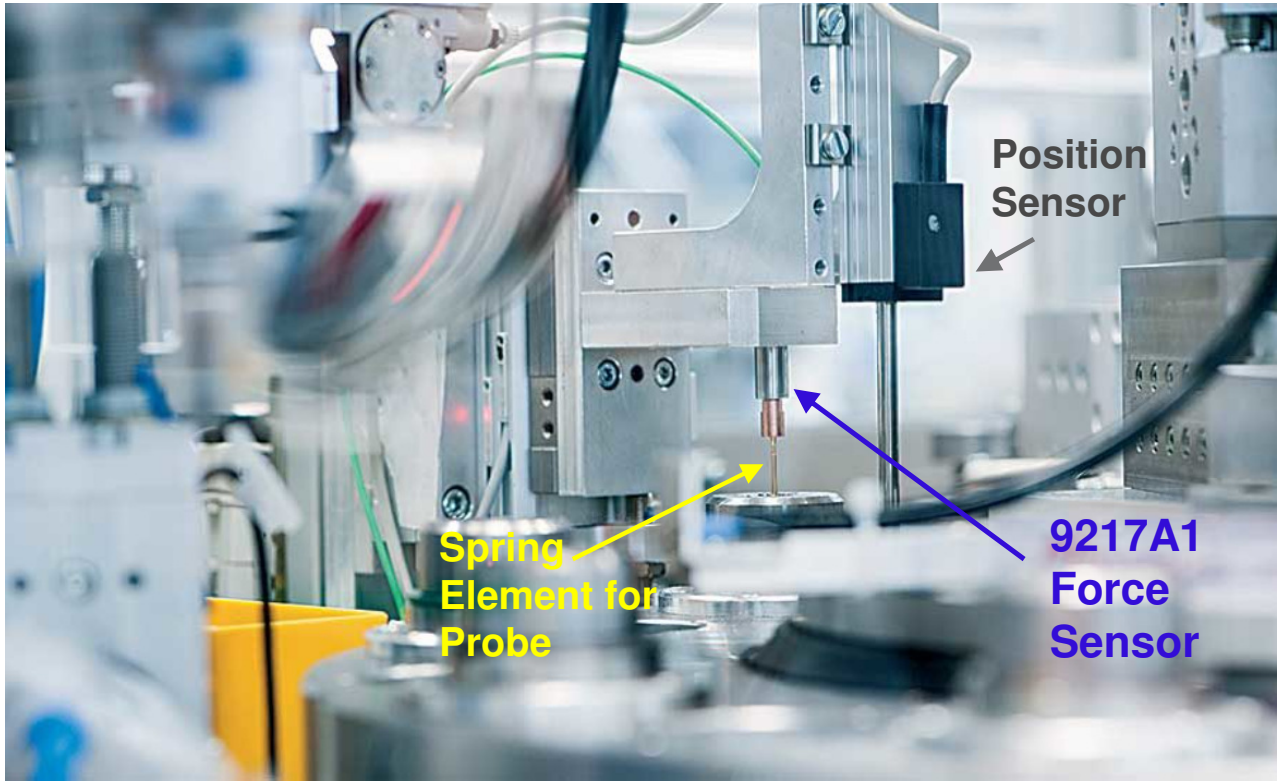

Source: Assembly Magazine - InGun

Force-Displacement Monitoring:

- Verifies the Functionality (EOL)
- Provides a means for Traceability
- Ensures the delivery of only Precise and Reproducible Probes

NOTE: This Machine can produce between 3 to 8 Million Probes per year

In-process testing of Wafer Probe Cards

Advancing Semiconductor Quality Testing

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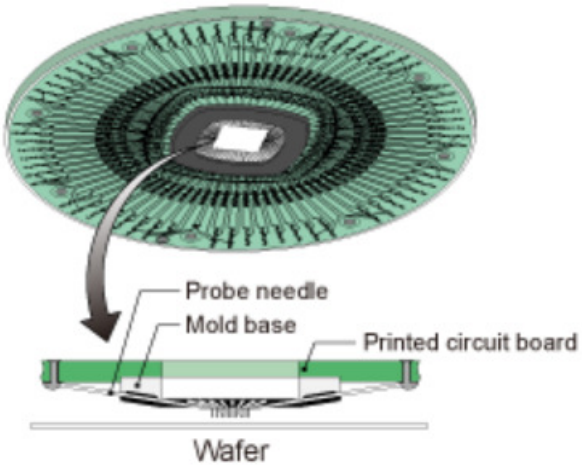
Probe Card



SOURCE: MICRONICS JAPAN CO.,LTD.

Functionality verified, includes:

✓ **Ultra-low probe contact force**

✓ **Assurance of gram-level force contact per probe**, even when operating at over travel conditions.

SUMMARY

Ultra-Sensitive Dynamic Piezoelectric Force Sensors Improve Semiconductor Manufacturing

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- ✓ *Chemical-Mechanical Planarization (CMP):* **Improve Press Force Accuracy**
- ✓ *Wafer Lamination:* **Die Tension Control**
- ✓ *Die Sorting:* **Die Stress Control & Peeling Energy**
- ✓ *Thermal Compression Bonding*: **Initial Contact & Feedback for Wetting Bump Pads**
- ✓ *Testing Phase:* **Contact Force on Micro Bump Pads**

Dynamic Force is a Critical Process Value in Semiconductor Production.

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Goodbye

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