High Temperature Wafer Probing of Power Devices

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June 2-5, 2019
Overview

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1. Introduction to Power Devices
2. Testing Requirements
3. Probe Card Solution

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4. Prober Chuck Improvement
5. Experiment: Chuck Thermal Stability
6. Conclusion, Follow-On Work
Power Devices - Applications

- Power supplies
- Air Condition
- Electric Vehicles
- Industrial Automation
- Trains, Wind Turbines, Photovoltaic
- Power Transmission

Power Devices - Applications in HEV/EV

- **Rectifiers**
  - Grid AC -> DC charger

- **Inverters**
  - DC 800V -> AC motor winding

- **Converters**
  - DC 24V -> HV bus
  - Generator -> HV bus
Power Devices - Types

• **Si-based devices:**
  – PIN, SBD
  – IGBT
  – GTO

• **SiC/GaN-based devices:**
  – MOSFET
  – BJT
  – JFET
Power Devices – Wide Band Gap

- Silicon Carbide
- Gallium Nitride

- Smaller Devices
- Higher Efficiency
- Less Cooling Effort

- Higher Operating Voltage!
- Higher Operating Temperature!
Test Requirements - Overview

- **Reverse Voltage (Breakdown Voltage)**
  -> Up to several kV

- **Reverse Voltage (Leakage Current)**

- **Forward Current (On-state resistance)**
  -> Up to several kA

- **UIS – Unclamped Inductive Switching (max power dissipation)**
  -> Up to several kA / kV

*Image source: Wolfspeed, SiC-MOSFET*

*Image source: ABB, 6.5kV-600A Si-IGBT*
Wafer Test

• **Current test applications:**
  – Bare Die
  – Engineering/Characterization

• **Potential test applications:**
  – Tri-Temp Automotive
  – Move from package to wafer test
  – Reduce test cost by 50%
High Voltage Wafer Test

- Vertical Device
- Wafer Bulk on HV
- Flash-over risk to dicing frame!
Flash-Over Suppression

Approaches:

- **Liquid**
  - high breakdown strength possible
  - immersion necessary
  - not useful for wafer test

- **Inert Gas**
  - flushing prober at ambient pressure
  - pure SF₆: 3-fold breakdown strength of ambient air
  - high cost, greenhouse gas

- **Pressure**
  - linear increase of breakdown voltage with pressure
  - works with any gas
  - compressed air
Flash-Over Suppression - Solution

- **Air under higher pressure (Paschen)**
  - whole prober under pressure
  - whole wafer under pressure
  - chip-scale chamber
  - contactless chip-scale chamber
Contactless chip scale pressure chamber
Contactless Seal Operation
HV-HT Probe Card

- Hot compressed air supply
- Dual hot-cold air stream to protect probe card
High Voltage – High Temperature

• Hot air has lower density
  -> reduced breakdown strength

• Pressure must be increased
  to get same breakdown strength

• At 125°C  ->  36% higher pressure needed!
HV-HT Probe Card

- production wafer sort
- hot wafer chuck 150°C
- hot compressed air 150°C
- non-contact Lupo seal
High Temperature Pressurized Air Supply

- Electrical heater
- Heats cold compressed air to 150°C
- closed-loop temperature control
- temperature sensor in probe card
- fast settling, stable operation
- integrated air cooling for probe card
High temperature test

Conventional high temperature test condition.

Chuck (wafer) temperature goes down!
Current issue and improvements

Condition: set temp.=150°C/0.5MPa/Die size=2.5㎜/Test time=1000ms

Chuck temp.(deg)

Time(sec)

Waiting temp. stability

Air blow start

Probing

Stronger heater with some sensors

Original heater with a sensor

Original heater with some sensors

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High temperature test with Hot air controller

Prober: UF2000
Hot air controller: LMH150
Probe card: ACTP001-HT
High temperature test enhancement

Blow hot air into probe card instead ambient air.

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Chuck Top

Probe Card

Wafer

Heater & Temp. Sensor (High temp.)

better Temperature stability

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Experiments

• Temp. test-1 :
  – Chuck temperature stability time after hot air blow start.

• Temp. test-2 :
  – Chuck temperature variation during probing.
    by changing compressed air pressure, Die size, Testing time, etc.

• Flash-over spark test :
  – With compressed hot air & T.I.P.S. HV demo wafer.
- Chuck temperature stability time after air blow start.
- Result: Return to chuck set temperature (150°C) within 3min using LMH150

![Diagram showing air blow start and chuck temperature after air blow]

- Air blow start (0.5Mpa)
- Chuck temperature after air blow
- ACTP001-HT with hot air blow.
- Approx. 3min
- Standard probe card (ACTP001) with room temp. air blow.

A : High temp air blow  Room temp air brow
Temp. test-2

Chuck temp. during probing with different conditions

<table>
<thead>
<tr>
<th>Chuck Temp. (°C)</th>
<th>Pressure (MPa)</th>
<th>Chip size (mm)</th>
<th>Test time (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.3</td>
<td>5.0</td>
<td>300</td>
</tr>
<tr>
<td>100</td>
<td>0.5</td>
<td>5.0</td>
<td>1000</td>
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<td>1000</td>
</tr>
</tbody>
</table>
Temp. test-2

- Chuck temp. variation during probing-1
- Condition: Set temp.=100°C/0.3MPa/Die size=5㎜/Test time=300ms
- Result: Chuck temp. is very stable. (Set temp. ±1°C during probing)
Temp. test-2

- Chuck temp. variation during probing-2
- Condition: Set temp. = 100°C/0.5MPa/Die size=5㎜/Test time=1000ms
- Result: Chuck temp. is very stable. (Set temp. ±1°C during probing)
- Chuck temp. variation during probing
- **Condition**: Set temp. = 150°C / 0.3MPa / Die size = 5 mm / Test time = 300 ms
- **Result**: Chuck temp. is very stable. (Set temp. ± 1°C during probing)
Temp. test-2

- Chuck temp. variation during probing-4
- Condition: Set temp.=150°C/0.5MPa/Die size=5㎜/Test time=300ms
- Result: Chuck temp. is very stable. (Set temp. ±1°C during probing)
Temp. test-2

- Chuck temp. variation during probing-5
- Condition: Set temp.=150°C/0.5MPa/Die size=5㎜/Test time=1000ms
- Result: Chuck temp. is very stable. (Set temp. ±1°C during probing)
Temp. test-2

- Chuck temp. variation during probing
- Condition: Set temp.=150℃/0.5MPa/Die size=2.5㎜/Test time=1000ms
- Result: Chuck temp. is very stable. (Set temp. ±1℃ during probing)
Temp. test-2

Chuck temp. during probing – Test result summary

<table>
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<th>Chip size (㎜)</th>
<th>Test time (ms)</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.3</td>
<td>5.0</td>
<td>300</td>
<td>+/-1℃</td>
</tr>
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Summary:
- When using standard probe card with ambient air at 150 ℃, the variation of chuck temp. is +5 to -14 ℃ max. It is mostly related to air pressure value, not to test time and die size. If using LMH150 with ACTP001-HC, the variation is +/-1 ℃ under all above conditions.
Flash-Over Spark Test

High voltage at 100°C

If the test area temp. (inside of Lupo-Ring) is going up, the flash-over voltage is dropped. In case of ACTP001 with ambient air even if chuck temp. is 100°C, the test area temp. must be lower. So the flash-over voltage is just a little bit dropped.

High Voltage – some Physics...

- Flashover Mechanism: Avalanche Ionization of Gas Molecules, "Arc Discharge"

Flash-over voltage comparison

- Drop flash-over voltage approx. 25%.
Flash-Over Spark Test

High voltage at 100°C

Test wafer

Check flash-over by camera & monitor.
Conclusion & Follow-On Work

Conclusion
– Proven Solution for High-Temperature High-Voltage Wafer Test
– Achieved the improvement by chuck design change and using hot air controller.

Follow-On Work
– More field test
– Integrate hot air controller into prober
– Extend Temperature Range
Thank you for your attention!

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