Methodologies for Assessing On-line Probe Process Parameters

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  – ITS: Lab Capabilities
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Motivation

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Contact Resistance and Fritting Theory

Experimental Data

Production Data

Results & Future Work
Motivation

- Production sort floors are often manpower, materials, and financially limited for fundamental characterization studies which could lead to process understanding and improvement.
- Testing with “full-build” probe cards is expensive and often not feasible, particularly with large array probe cards.
- Assessing combinations of key parameters, such as current amplitude and directionality, probe needle materials, and FAB processing effects on bond pads, requires substantial resource allocation.
- Bench-top testing with a single probe or reduced probe count test vehicles can be performed quickly under known and controlled conditions.
Motivation

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Contact Resistance and Fritting Theory
Experimental Data
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Results & Future Work
Feinmetall ViProbe®
New Beam Material

• Beam material with improved performance:
  - high amperage (current carrying capacity, up to 800 mA)
  - low voltage/current applications
  - electrical resistivity: 0.12 $\Omega \cdot \text{mm}^2/\text{m}$

• Both materials (existing and new one) are palladium - silver alloys

• Mechanical behaviour of the new beams similar to the existing beams with 2.0 mil, 2.5 mil and 3.0 mil diameter
Feinmetall ViProbe®
New Beam Material

• Probe Force vs. Applied Current

Current Carrying Capacity
(3-mil ViProbe Beams at 100-um OT)

- Existing Material
  - CCC ~ 560 mA
  - ~ 6.50 g

- New Material
  - CCC ~ 780 mA

20% Reduction
~ 6.50 g
ViProbe® Testvehicle

- Smallest ViProbe® test head ever designed and built
  - 2mil, 2.5mil and 3mil ViProbe compatibility
Controlled Test Conditions

• Bench-top instrument for material characterization and probe performance testing.

• Testing System Details
  – Variable z-speed and z-acceleration.
  – Low gram load cell measurements.
  – Synchronized load vs. overtravel vs. CRES data acquisition.
  – High resolution video imaging and still image capture.
  – Current forcing and measurement with Keithley 2400 source-meter.
  – Micro-stepping capable to maximize number of touchdowns.
  – Multi-zone cleaning functionalities.
Test Vehicle

ViProbe Test vehicle installed onto 50 gram load cell

High resolution imaging system for video acquisition

Probe / Material Interaction and Buckling Visualization
NXP Testcenter Hamburg Production Environment

• Mass production and engineering site for Automotive and Identification business, digital and mixed signal
• Applications with high multisite factors and small pad pitch
• Capability to collect contact resistance data within production environment
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Contact Resistance and Fritting Theory
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Contact Resistance (CRES)

- Contact Resistance is a combination of two main parameters:
  - Localized physical mechanisms ... metallic contact
  - Non-conductive contribution ... film resistance

- Model for CRES has two main factors:
  
  \[ C_{RES} = \frac{\left( \rho_{probe} + \rho_{pad} \right)}{4} \sqrt{\frac{\pi H}{P}} \plus \frac{\sigma_{film}}{P} \]

  - \( \rho_{pad} \) : Resistivity values of pad
  - \( \rho_{probe} \) : Resistivity values of probe
  - \( \sigma_{film} \) : Conductivity of the film
  - \( H \) : Hardness of softer material
  - \( P \) : Contact pressure
  - \( P \) : Applied force normalized by true contact area

- Unstable CRES is dominated by the film contribution term due to the accumulation of non-conductive materials.
Key Factors that affect CRES

- Presence of contamination, e.g. debris, oxides, residues, etc.
  - Film resistance eventually dominates the magnitude and stability of the CRES

- Probe tip shape plays an important role in displacing the contaminants from the true contact area
  - True Contact Area = $F$ (Tip Shape, Applied Force, Surface Finish)
    - True contact are is “large” $\Rightarrow$ applied pressure and a-Spot density are “low”
    - True contact area is “small” $\Rightarrow$ applied pressure and a-Spot density are “large”

- Probe tip surface characteristics affect the “a-Spot” density
  - Asperity density depends on the microscopic surface roughness
    - Smooth surfaces have a high asperity density
    - The increase in asperity density decreases the electrical CRES
    - A “rough” finish facilitates material accumulation on contact surface

- Amplitude and directionality of the voltage or current applied.
  - Voltage or current must be sufficient to breakdown the oxide.
Fritting – Theory

- The vertical Probe tip touches the contact pad.
- Depending on the contact pressure the oxide film is broken partly and electrical bridges arise.
- The number and size of the bridges is equivalent to the $C_{RES}$ quality.
Fritting – Theory

- What happens, if bridges are only few and small?

Small bridge through oxide film. Before high current flow.
Fritting – Theory

- Current must flow through small bridge.
- Bridge and neighbourhood are heated up
- Contact Pad material migrates to the bridge.

High current flow situation:
Black → Lines of current flow.
White → Lines of equipotential surface.
Fritting – Theory

- Bridge is widened $\Rightarrow C_{RES}$ decreased
- Contact pad material migrated to the bridge and tip surface

Wide bridge through oxide film.
After high current flow.
Tip surface is contaminated.
Fritting – What’s that?

- Fritting is a kind of electrical breakdown at the contact surface between the probe tip and the contact pad of the IC.
- It improves the electrical contact by building or stabilizing bridges through the oxide film, if the film was not mechanically broken completely.
- After Fritting the probe tip is welded with the contact pad. After removing the contact residuals of the welding remain at the probe tip and will oxidize.
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Contact Resistance and Fritting Theory

Experimental Data
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Experimental Data / Parameters

• Input Parameters:
  – Overtravel (OT, µm)
  – Probe Material
  – Contact Material (Rhodium, Rh, Aluminum 600nm, Al)
  – Electrical Conditions (Current and direction, mA)
  – Number of Touchdowns (TDs)

• Output Measures:
  – Contact Resistance (Cres, Ohm)
  – Contact Force (CF, cN)
  – Visual Inspection (Video Camera System)
  – Scanning Electron Microscope (SEM)
What is a “Bathtub” Curve?

- A symmetric “bathtub” curve at full overtravel is preferable.

If fritting occurs, will be observed in this region.

A shift is indicative of material accumulation on contact area.

OT increase | OT decrease

Intrinsic CRES
Bathtub Experiments

• Test Sequence
  – CRES vs Overtravel performance tests up to 100μm overtravel (OT)
  – CRES measurement Pin-to-Pin with 3mil diameter

• Test Execution for total 30 TDs each
  – Performed on Rh-Plate and Al-Wafer
  – Performed with existing and new beam material
  – Performed at 1mA and 100mA
Bathtub Comparison I

- Contact Resistance Cres [Ohm]
- OT [μm]
- 600nm Al @ 1mA/exist. Mat
- Rhodium @ 1mA/exist. Mat

Film Resistance

Metallic Contact
Bathtub Comparison II

Comparison of Contact Resistance (CRES) between Existing Mat and New Mat at 1mA and 600nm Al.

- **Existing Mat @ 1mA/600nm Al**
- **New Mat @ 1mA/600nm Al**

**Difference in CRES**
New Mat -550 mOhm
Bathtub Comparison III

Contact Resistance [Ohm] vs. OT [µm]

- 1mA @ 600nm Al/exist. Mat
- 100mA @ 600nm Al/exist. Mat

Fritting
CRES vs. Current

• Test Sequence
  – 30 TDs at 38µm Overtravel (no intermetallic contact on Al-Wafer)
  – CRES measurement Pin-to-Pin with 3mil beam diameter

• Test Execution for total 30 TDs each
  – Performed for a set of currents (1mA-1A)
  – Performed on Rh-Plate and on Al-Wafer
  – Performed with existing and new beam material
CRES vs. Current

CRES decrease Because of Fritting

Difference in CRES
New Mat -550 mOhm
Visualization of Test

- Pin-to-Pin CRES across substrates
  - **NO FRITTING** observed on Rhodium plate
  - **FRITTING** observed 600nm Aluminum wafer

ViProbe 3.0-mil Beam
100-um Overtravel
Pin-to-Pin on Rhodium Plate

ITS - Test Analysis Center
CRES Longterm tests

- **Test Sequence**
  - 200 TDs on a 600nm Aluminum Wafer at 38µm Overtravel
  - CRES vs Overtravel performance tests up to 100µm overtravel on a Rh-Plate

- **Test Execution for total of 20K TDs on wafer**
  - Al-wafer with 1mA and Rh-Plate at 1mA
  - Al-wafer with 300mA and Rh-Plate at 300mA
  - Performed with existing and new beam material
  - Performed Pin-To-Pin
  - No Cleaning at all
CRES Longterm Tests

More Cur. = More CRES (Film resistance)

Fritting

Contact Resistance Cres [Ohm]

OT [µm]

Start of Longtermtest 1mA (Exist Mat)
Start of Longtermtest 300mA (Exist Mat)
End of Longtermtest 1mA (Exist Mat)
End of Longtermtest 300mA (Exist Mat)
CRES Longterm Tests

Contact Resistance Cres [Ohm]

OT [µm]

Exist. Mat: Start of longterm test @ 300mA
New Mat: Start of longterm test @ 300mA
Exist. Mat: End of longterm test @ 300mA
New Mat: End of longterm test @ 300mA

Fritting
Expected Offset
Exist vs new Mat
SEM Images after 20K TD Longterm Test @ 1 and 300mA without any Cleaning

Existing Material - Initial

New Material - Initial

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Martens, Allgaier, Broz

IEEE SW Test Workshop
CRES Longterm Tests
Pin High / Low

• Test Sequence
  – 200 TDs on a 600nm Aluminum Wafer at 25µm Overtravel
  – CRES vs Overtravel performance tests up to 100µm overtravel on a Rh-Plate

• Test Execution for total of 20K TDs on wafer
  – Pin with 300mA (High) and Rh-Plate (Low)
  – Pin with 300mA (Low) and Rh-Plate (High)
  – Performed with existing and new probe material
  – Performed without cleaning
CRES Longterm Tests
CRES Histogram after 15K TDs @ 300mA without Cleaning

Number of Contacts

Contact Resistance [Ohm]
CRES Longterm tests
CRES Cum. Probability after 15K TDs @ 300mA without Cleaning

Metallic Contact
- Exist Mat
- New Mat

90% Film Resistance
90% Film Res.

Less Film resistance for pos. Volt. at new Mat

Cumulative Probability

Contact Resistance [Ohm]
SEM Images after 20K TD Longterm Test @ 300mA without any Cleaning

Pin low

Exist Mat

New Mat

Pin High

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Production CRES Measurement

• Smartcard application 32x parallel
• One Probecard with 16 sites existing Material (red) 16 sites new Material (green) with symmetric pattern
• CRES Monitor on digital channel put into std. Production Test Program
Production Data

CRES Difference 550 mOhm

Overall Path Resistance [Ohm]

Number of Contacts

Exist Material
New Material

Production Data
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Results & Future Work
Results & Future Work I

• New beam material was evaluated in lab and production environments
  – Decrease of resistivity proven: -550 mOhm compared to existing material
  – New Beam material shows better film contact resistance and fritting performance

• Amplitude and directionality of applied current/voltage highly influenced the accumulation of debris as well as the increase of film resistance
  – Higher currents lead to higher CRES
  – Positive voltages higher affected than negative voltages

• Off-line testing under controlled conditions with “standardized” methods can provide key insights for understanding CRES behavior that can help a probe engineer develop wafer sort processes and define cleaning practices.
Results & Future Work II
(many interesting studies !)

• Evaluate fab processed materials
  – Shorted wafers and test die
• Define an “Online Cleaning Rules Set”
• Investigating the effects and repercussions of the Fritting mechanisms
• Temperature influence on film resistance
  – Range similar to production
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Men At Work
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Questions?