An Advanced Method for Pad Stack Crack Assessment during Probe-Over-Active-Area

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Test for Infineon Segments

Connected Secure Systems

Automotive

Power & Sensor Systems

Industrial Power Control

POAA

Supplier

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In most advanced CMOS technologies, in order to optimize the area consumption, Probe Over Active Area (POAA) structures have been introduced. Active circuitry is therefore designed below the probing area with potential stress-induced problems.

- up to 20% area savings
- cost reduction

POAA Concept for CMOS Technology
Challenges during POAA

- Electrical failure
- Oxide crack
- Mechanical stress
- Electrical contact

Diagram showing: Vertical probe, Oxide cracks, Chip, Pad, SiOx, Cu, 100µm, 1 µm, 100 µm, 100 µm, 100 µm, 100 µm.
Stress in Layer Stack During Contacting

Principal Stress
Unit: MPa

Rigid semi-radius tip (10µm diameter)

Vertical Load: 0-300mN

Tensile stress in Si$_3$N$_3$ layer initiating cracks in upper oxide layer

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Stanford University
Classical POAA Qualification Process Flow

Disadvantages:
- At which contact stress do cracks initiate?
- Large sample size (up to 100k pads) needed to estimate crack risk at low ppm-level
- Optical inspection is time consuming and prone to human errors
- Critical probing parameters unknown
- Crack decoration method not applicable to certain pad stacks
- POAA qualification only possible at late phase of probing qualification

Find a faster, more efficient and more reliable crack detection method
Principle of Acoustic Emission Testing

Solid body

Acoustic waves

Crack

Force

AE sensor

Pre-Amplifier

AE-Controller

Filtering

A/D-Converter

Feature extraction

PC (Data processing and Visualisation)

AE result file

Event Monitoring

Condition Monitoring

Material Testing

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Test Bench PROFIT-2

- 2-axis tilting stage
- z-force sensor
- AE sensor holder
- Sensor-indenter system
- 3-axis motorized stage with 200mm vacuum chuck
- AE pre-amplifier & controller
- Force controller

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Resonating Sensor-Indenter System

Coupling of resonating sensor and indenter for high-sensitive acoustic signal detection

FEM-Simulations by PhD-student Florian Tremmel
Comparison Probe vs. Indenter Tip and Probe Marks

- **Probe**
  - Similar Tip Shape and Size
  - Similar Imprint Size and Depth
  - Imprint Size: 10.30 µm, 11.22 µm
  - Depth: 11.0 µm

- **Indenter**
  - Imprint Size: 10 µm
Step #1: Define probing-related contact parameters (tip shape, tip diameter, max. force).

Step #2: Repeat x-times contact cycle (sample size!) and record AE-data.

Step #3: AE data processing (feature extraction and scatter plot).

Step #4: Filter and cluster acoustic signal data for 1st cracks.

Step #5: Calculate and plot cumulative crack probability function.

Step #6: Extract characteristic Weibull parameters.

$F_0 = 233\text{mN} \quad m = 18.9$
Thin Layer Crack Detection by AE-Test Method

AE sensor

Indenter

Si₃N₄

SiO₂

Cu

SiO₂

Si-Wafer

View A - A

Oxide cracks

Time domain

Frequency domain

Peak Amp [dB]

201

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

Time [s]

Loadline

Unloading

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Experimental Settings:

- Indenter tip: 10µm flat punch
- Unstructured test chip
- Sample Size: 1000 contact cycles
- Max. load: 350mN
- Chuck speed: 2µm/s

Scatter Plot of Multiple Contact Cycles

Mathematical expression:

\[ E = \int_{0}^{t} U^2(t) \, dt \]
- \( E \): Burst signal energy
- \( U \): voltage
- \( t \): time

Diagram:

- Si₃N₄
- SiOₓ
- Cu
- SiOₓ
- Si-Wafer

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AE Data Filtering and Clustering

Experimental Settings:
- Indenter tip: 5µm flat punch
- 28nm CMOS technology
- Sample Size: 945 contact cycles
- Max. load: 250mN
- Chuck speed: 2µm/s

Optical crack correlation
Crack Probability Plots

Weibull distribution function model is suitable to predict the crack probability of semiconductor layer stacks.

Cumulative crack probability

\[ P_f(F) = 1 - e^{-\left(\frac{F}{F_0}\right)^m} \]

\( m \): Weibull modulus
\( F_0 \): Characteristic contact force

63%
Application of AE-method for POAA-Qualification

FP05: indenter with flat 5µm diameter diamond tip
FP10: indenter with flat 10µm diameter diamond tip

150x pads per option 3 and 4
15x contacted pads per chip
10 chips each per row

Pad Stack Option 3a

Pad Stack Option 4

Cu Pad

IMIDE
3A
3T

NO 3T
NO FA
POAA-Qualification: AE-Data Analysis

Sample type: Pad Option 4
Sample size: 150
Tip Diameter: Flat punch 5µm (FP05-A)
Max. Force: 250mN
Pre-Stress: no (0 TD)

Cluster #1:
Plastic deformation of Cu-pad

Cluster #2:
ILD cracks

Cluster #3:
Metal layer deformation

No ILD cracks  ILD cracks
POAA-Qualification: Crack Probability Plots

Sample Size: 150 pads

Weibull module $m = 24.67$
Charact. Force $F_{char} = 136.8$

Weibull distribution test at 5% significance level, $h = 0$

Weibull module $m = 11.48$
Charact. Force $F_{char} = 99.1$

Weibull distribution test at 5% significance level, $h = 0$
Crack Probability Pad Stack Opt3a vs. Opt4

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<th>Critical Force [mN]</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
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Conclusion:
Higher crack risk (approx. 35% lower critical force and higher variance) for pad stack option 3a compared to option 4 both for small and larger tip diameter.
Summary

• Development of an innovative acoustic emission test method for thin layer crack detection
• Patented sensor-indenter system with high acoustic signal sensitivity and wide SNR
• Fast, reliable and accurate determination of POAA crack probability demonstrated
• New POAA qualification method introduced at Infineon for CMOS technologies to characterize BEOL stack robustness
Follow-On Work

- AE-Data Clustering by Machine Learning
- Improved statistical model (3-parametric Weibull model)
- Consider more probing parameters (multi-TD, lateral scrub, dynamics) for crack robustness
- Extension of AE-test method to power technologies
- Test bench feature upgrades (AE-signal triggering, hot/cold chuck)
- Integration of AE-sensor element with probe needle
- Industry standardization for POAA crack
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