Enhanced failure analysis on open TSV interconnects

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Open TSV technology by ams

- Demonstrator for TSV - 3D interconnect technology for fast vertical signal transfer between image sensor and controller device
- Low T plasma enhanced Si/Si Dioxide direct bonding.
- Open TSV structure (BOSCH process)
- Ti/TiN /W/Al sidewall metallisation
**Purpose**

*Failure modes:*
1) TSV series resistance increase
   → Cracking or corrosion of conducting layer
2) TSV-surrounding substrate leakage
   → Defects/rupture of sidewall oxide isolation

*Reliability risks:*
- Compromised passivation
- Inadequate cleaning of TSV sidewall layers → adhesion
- Residual stresses in TSV sidewall layers
- Undetected (latent) manufacturing flaws in sidewall isolation oxide layer
Outline

- Challenges of open TSV failure analysis
- Defect localisation
  - Defect localisation using Photo Emission Microscopy (PEM)
  - Defect localisation using Lock-in Thermography (LIT)
  - Defect localisation using Electron Beam Absorbed Current (EBAC) in the SEM
- Defect preparation
- Case study
- Summary
Challenges of open TSV FA

**FA challenges:**
- Short at 63000 µm² area of inner TSV wall
- Access for further SEM/TEM physical analysis

**Adapted FA methods:**
- 3D localization by specimen tilt and stepwise defocusing (PEM, LIT)
- Precise short localisation within TSV by SEM/EBAC
- Large area pre cross-sectioning by mech. polishing or laser milling combined with plasma-FIB prep. and final FIB/SEM investigation
Defect localisation

3D TSV FA – using depth-resolved PEM

Focal series to localize the defect coordinates in 3 dimensions
Defect localisation

1 – Microscope chuck
2,3 – Mounting magnets
4,5 – Mounts
6 – Mirror adjustment screws
7 – Stub locking screw
8 – Mirror mount
9 – Polishing stub
10 – First surface
11 – 3D integrated device (with TSVs)
12 – Emission microscope objective lens
13 – Probe needles
Defect localisation using Lock-in Thermography (LIT)

- Electrical defects causing local temperature increase (shorts, increased interconnect resistance)
- Detection by microscopic thermal imaging
- Averaging over many lock-in periods improves signal-to-noise ratio (detection limit: few µW dissipation power, few µm spatial resolution)
Defect localisation

LIT Focus series

Surface

Defect position

Focus positions

-200 µm

-150 µm

-100 µm

Surface

Defect localisation

Amplitude [mK]

Position [px]

0 1 2 3 4

0 20 40 60 80 100

Distance to Surface [µm]

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Defect localisation using EBAC method

- SEM primary electrons reach the Poly-Si plate at suitable primary energy, the absorbed current is measured and amplified.
- Current divider is active at the GOX short, EBAC current flows partly through Silicon substrate.
  - Locally reduced EBAC current at defect site.
Defect localisation

using EBAC method

SEM Parameter:
- 15 keV acc. Voltage
- 4 nA PE current
- -0.4 V biasing of sidewall metallization
- Resulting current flowing through the defect 175 nA
- Inverted EBAC image (red) overlaid with SEM image
Defect preparation

Precise cross-sectioning for SEM/FIB defect access

- Precise mechanically polishing (Allied Multiprep Tool)
Defect preparation

Precise cross-sectioning for SEM/FIB defect access

- Alternative approach: short pulse laser milling
- 532 nm, 10 ps, averaged pulse power, 0.2 µJ at 200 kHz rep rate
- Problem: redeposition (debris)
Defect preparation

High throughput cross sectioning by Laser-FIB

- ZEISS AURIGA FIB/SEM platform
- ns DPSS laser 355 nm wavelength adapted to the load lock
- CAD Software for laser patterning
- Specimen holder for calibration of SEM and laser coordinates provides about 10 µm precision for site specific laser milling
Defect preparation

Precise cross-sectioning by Plasma FIB preparation

- Focused ion beam current >1 µA
- Xe ions with higher sputter yield
- More than 20x faster milling than for conventional Ga-FIB:
  - Xe: 25,000 µm³/min @1 µA (Si)
  - Ga: 1000 µm³/min @65 nA (Si)
- Beam currents 1.5 pA to > 1.3 µA
- Image resolution < 25 nm
FA of sidewall shorts

Case study: electrical shorted TSV

- Leakage current between metallization to substrate: several $\mu$A @10 V
- Electrical behavior like Diode characteristic
- 3D Localization by LIT defocus series and EBAC
- Short at sidewall in 200 $\mu$m depth (bottom edge)
FA of sidewall shorts

Case study: electrical shorted TSV
Mechanical pre-preparation

Precise pre cross-sectioning by mechanically grinding and polishing
FA of sidewall shorts

Case study: electrical shorted TSV investigated by FIB/SEM analysis

Specimen 45° tilted and rotated to get access for both SEM and FIB
FA of sidewall shorts

Case study: electrical shorted TSV investigated by FIB/SEM analysis

Cross-section 1

TSV sidewall metallization
FA of sidewall shorts

Case study: electrical shorted TSV investigated by FIB/SEM analysis

Electrical contact between Si-particle and W-layer

Si particle

Si sidewall level

Cross-section 2
Case study: electrical shorted TSV investigated by FIB/SEM analysis

- Position of Si – particle in CS 2
- Inhomogeneous Si-substrate connected to Si-particle
- Cross-section 3
- Si sidewall level

FA of sidewall shorts
FA of sidewall shorts

Case study: shorted TSV with nA leakage current

EBAC Localization:
- 15 keV acc. Voltage
- 6 nA PE current
- -0.25 V biasing of sidewall metallization
- Resulting current flowing through the defect 4.8 nA
- Inverted EBAC image (red) overlaid with SEM image
FA of sidewall shorts

Case study: shorted TSV with nA leakage current

- Rough Plasma FIB milling with 1.3 µA beam current, box dimensions of 700 µm x 300 µm and 500 µm depth (5 h)
- Local TSV opening and sidewall polishing with 70 nA (30 min)
FA of sidewall shorts

Case study: shorted TSV with nA leakage current

- Delamination and lifting of sidewall layers after PFIB opening -> low interface adhesion, residual stress
- EBAC signal identifies crack of sidewall layer
- Leakage probably caused by residues inside crack

Further TEM invest. planned to analyse interface problems
Summary

- LIT and EBAC imaging techniques have been successfully adapted for three dimensional and short localization within open TSV structures.

- Precise mechanically grinding and ps laser milling was demonstrated for precise cross-sectioning for further FIB/SEM physical analysis.

- Advanced as well as time efficient preparation techniques were presented for cross sectioning of TSV structures by Laser-FIB and/or Plasma FIB preparation.

- Feasibility of these techniques was demonstrated on devices with shorted open TSV structures and their particular root causes could be identified.