Novel Method for TSV Profile Metrology Using Spectral Reflectometry

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- **TSV Middle:** TSV fabricated after FEOL processing, before wafer thinning
  - Introduction at contact level or later metal level

Inline Test Points for TSV Monitoring

- Long mean time to detect process variability
- Electrical characterization of TSVs limited prior to backside processing
The Role of TSV Etch Control

- Via etch is a critical step in 3D integration impacting TSV insulation and metallization operations and wafer thinning
- Key parameters for nondestructive monitoring
  - TSV CD
  - TSV depth (also feed forward to wafer thinning)
  - TSV profile
**TSV Profile Impact on TSV Performance**

- Stringent control over TSV profile (e.g. side wall angle) is required to ensure:
  - Robust coverage of liner, barrier, and Cu seed
  - Eventual filling of the via is without voids or defects

- TSV electrical and reliability performance are dependent on etch profile
TSV Features Studied

- TSVs integrated in BEOL (3-9 wiring levels below TSV)*
- Annular and circular structures
- TSV top diameter: 5 to 20 um
- TSV depth: 15 to 75 um
- Sidewall angle: 88 to 90 degrees
- Etch process:
  - TCP source
  - Rapid switching between deposition and etch processing

* M. Farooq et al., IEDM 2011
TSV Measurement Method Used

- Single system that provides reliable metrology of all TSV dimensions
  - Top CD: using a high magnification microscope
  - Depth: using spectral reflectometry
  - Profile: using dark-field reflectometry (model-based interpretation)
Full TSV Dimensional Characterization

- Wafer map results
- Throughput confirmed: > 20 WPH (21 sites)
Depth Measurement

- Based on spectral reflectometry
- Depth extracted from high-frequency spectral oscillations

\[ D = 64.92 \, \mu m \]
Top CD and Depth

- Depth $3\sigma$ verified spec: < 60 nm
- Top CD $3\sigma$ verified spec: < 20 nm

High Precision Allows Effective Control of Etch Rate and Uniformity
New Optical Mode Optimized for Dark-Field Reflectometry

- A broadband spectrum is collected in dark-field optical configuration:
  - Light reflected from the top is blocked
  - Light from within the via is collected

- Higher NA enhances side-wall interaction
Profile Analysis Using Optical CD Concepts

- Sensitivity to all sidewall features
- Pre-built library of DF spectra calculated for different parameters
- Real-time comparison of measured spectra to library to determine profile parameters
Novel Modeling Approach to Calculate the DF Spectrum

- TSVs are typically large and practically isolated
  - RCWA (OCD standard model) is inapplicable
- A new hybrid ray-tracing / physical optics model was developed
- Due to high spectral sensitivity, moderate profile fit is sufficient
Model-Based Sensitivity Analysis

- Validated model allows predictive analysis of spectral sensitivity
- The Dark-field spectrum is highly sensitive to variation in: SWA, BCD, Bottom Curvature

**SWA of Annular Via**

**SWA of Circular Via**
Sensitivity Analysis on Measured Profile

- Sensitivity confirmed: SWA changes < 0.02° can be detected
  - Full-range of SWA across the measured wafer is < ±0.1°
- Within-wafer variation in profile parameters is reliably mapped

![Diagram showing Dark-Field Spectrum and SWA distribution](image-url)
Correlation to X-SEM

- High SWA (and Bottom CD) correlation to SEM measurements

![Graph showing correlation between DF Reflectometer SWA and X-section Measured SWA with an R^2 value of 0.9406]
Future work

- New applications
  - Film coverage inside of via
  - Systematic defects
  - Via sidewall roughness

- Extended modeling
  - Small-CD vias
    - Additional parameters (multi-slope, etc.)

- Correlation of via profiles to electrical parameters
Summary

- Etch metrology is critical for TSV Middle integration
  - Long mean time to detect process variations with typical inline test
  - Key parameters: TSV CD, depth, and profile
    - Depth control and feed forward to wafer thinning
    - Profile control to ensure reliable insulation and metallization of TSV

- Spectral reflectometry was used for high precision TSV depth measurement

- Dark-field reflectometry was used for TSV profile metrology
  - “OCD for TSV”, a novel approach
  - Provides for the first time full TSV dimensional measurement
  - Sensitivity and performance confirmed on a range of via types and sizes
Thank you!

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