Phase Profilometry

WISE 2000

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Outline

- Motivation of Phase Profilometry
- Electromagnetic simulation of ellipsometric response of periodical structures
- A library-based profile extraction method
- Sensitivity study and comparison with 2-θ scatterometry
- Recent experimental results
- Conclusion
Illustration of Spectroscopic Ellipsometry
Thin Film Characterization

\[ \rho = \frac{r_p}{r_s} = \tan(\Psi).e^{j\Delta} \]

Measured Parameters

\( \tan\Psi \) and \( \cos\Delta \)
Film Stack Analysis

Measurement = Model Simulation?

Physical Model
- Film Stack and structure
- Material n, k, dispersion
- Composition Fraction

Experimental Measurement
CosΔ

TanΨ

Ti, ni, ki
Concept of Optical Profile Metrology

- Scattering (diffraction) of light from features produces strong spectral structure in reflected optical field
- Analyze structure to obtain topography information
- Periodic structures (gratings) can be numerically modeled “exactly”

Incident Laser Beam
Incident Polarized White Light

0th order
0th order

2-θ Scatterometry (BioRad)
Specular Spectroscopic Profilometry
Electromagnetic Simulator

- Fourier expansion of the grating profile
- Eigensystem formulation
- Linear system solution of E&M field
- In theory, this approach is “rigorous”
CD-AFM Profile Segmentation

UV5:
100 layers
739.75nm

ARC:
1 layer
162.9nm
Simulator Convergence (TE)

Even though we only measure the 0th order, many more orders must be considered during the simulation.

Transverse Electric: # of retained order = 31
Simulator Convergence (TM)

Transverse Magnetic

# of retained order = 41
Comparison of Measured and Simulated Signal

blue – measured
red – simulated
GTK online Interface at the SFR Website

http://radon.eecs.berkeley.edu/~tduncan/gtk2.html
A Library Based Methodology for Profile Extraction

1. Profiles
2. gtk
3. Compiled Library

Pre-computed, off-line library build
Real-time, in-line measurement

Measured
Extracted
FEM Experiment for 1D Grating

- **focus**
- **dose**
- center: 13.5mJ/cm²
- dose step: 0.5mJ/cm²
- focus step: 0.1 µm
- area: 200µm x 200µm
- KLA-Tencor UV-1280 SE

UV5
BARC
SI

0.28µm 0.28µm
TanΨ of the Entire FEM

Focus

Dose

BCAM

5/30/00
Matching on $\tan \psi$ and $\cos \Delta$
Example of Profile Extraction

Blue is actual.

Red is extracted.
Profile Extraction over the Entire FEM

Red is actual.

Blue is extracted.

BCAM
The Effect of Material Index Variation (UV5)

- $n$
- $k$
- $\tan \Psi$
- $\cos \Delta$
Sensitivity Analysis – Phase Profilometry

1.5nm Sensitivity

1nm Sensitivity

BCAM
Sensitivity Analysis -- 2θ Scatterometry

1.5 nm Sensitivity

1 nm Sensitivity
Comparison between Phase Profilometry and 2θ Scatterometry

<table>
<thead>
<tr>
<th>Phase Profilometry</th>
<th>2θ Scatterometry</th>
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<tbody>
<tr>
<td>Multi wavelength, fixed angle</td>
<td>Multi angle, single wavelength</td>
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<tr>
<td>Uses existing Spectroscopic Ellipsometer</td>
<td>Requires specialized hardware</td>
</tr>
<tr>
<td>Both magnitude and phase info</td>
<td>Magnitude reflectivity only</td>
</tr>
<tr>
<td>More sensitive to profile variation</td>
<td>Less sensitive to profile variation</td>
</tr>
<tr>
<td>Utilizes full spectrum material property, less prone to uniqueness problem</td>
<td>Uses material property at single wavelength, unable to distinguish films with similar optical properties at measurement wavelength</td>
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Gate Stack with 193 nm Lithography

3900 Å Resist → 820 Å ARC
2500 Å Poly → 65 Å SiO₂
Si

120/120 Line/Space
Focus-Exposure Matrix
Measurement Area: 120 µm * 80 µm

BCAM
Extracted Profile

Focus (in µm):
-0.5
-0.2
+0.1
+0.4

Exposure (in mJ/cm²):
18.0
16.5
15.0
13.5
CD Contour Map

Exposure

Focus (in \(\mu m\))
Comparison with AFM and CD-SEM

Phase profilometry in Red    AFM in Blue

Correlation = 0.98
Proposed Application for Damascene Process In-line Metrology

- Damascene Processes bring a new, difficult challenge to critical dimension measurement.
- Metal line metrology and endpoint detection is important for process control.
- Both film thickness and metal line profile can be measured and used for process control.
Advantages of Phase Profilometry

- Accurate and full profile information
- Uses software plus cheaper hardware (compare to CD SEM) already existing in fabs
- Throughput comparable to CD-SEM
- Scalable for future technologies
- Non-destructive
- Inline/in-situ capable
- Does not require “golden” wafer to calibrate
- Capable to measure both profile and film stacks
Conclusion

- Phase profilometry shows high sensitivity to profiles of gratings.
- Profiles of FEMs have been extracted for resist, poly and metal features.
- Good correlation with CD-SEM and AFM was achieved.
- Phase profilometry is a promising in-line CD and profile metrology for the sub 180nm pattern transfer process.
- The rich information obtained from phase profilometry can be further used for process optimization and control.