Solving Zero-Sensitivity Points in Diffraction-Based Overlay Metrology

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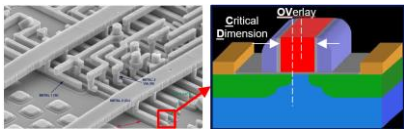
Introduction

- Semiconductor Chips = Multilayer Devices
- Critical dimension 7 nm
- Every layer should be aligned << 7 nm
- Pattern placement - Overlay metrology (OV) needs to be precise and robust << 1 nm

GOAL of this investigation:
Make OV metrology more robust against stack variations



CPU chip: stack thickness, OV and CD

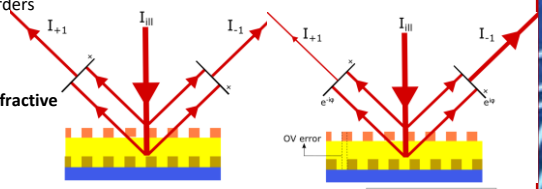
Principles of intensity-only Diffraction-Based Overlay (iDBO) Metrology

- Grating on grating
- Overlay: asymmetry in intensity of diffraction orders

$$I_{+1} - I_{-1} = K\,OV$$

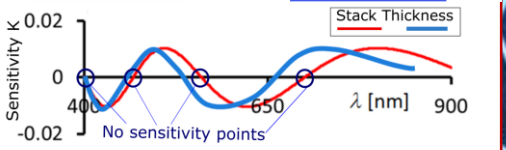
- **Sensitivity K depends on stack thickness and refractive index**
  - Solve for K with 2 biased grating pairs
  - Intensity measurements: **4**

$$\phi = \phi_{OV} + \phi_{stack}$$



Problem

- Sensitivity K can become zero if stack thickness changes. This can happen during semiconductor device manufacturing
- Zero Sensitivity points are 0 or π phase



K Sensitivity over wavelength for 2 stack thicknesses

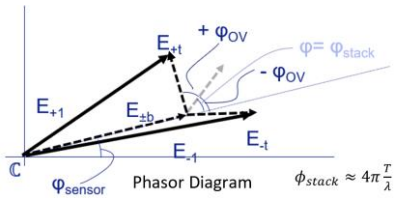
Solving zero-sensitivity points by Phase Resolved measurements (pDBO)

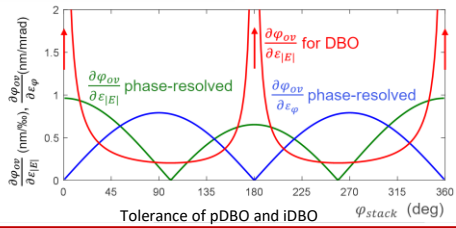
- Overlay information of both Intensity & Phase
- iDBO measure only length of vectors
- pDBO compares phases of each side
- Using phase removes the zero sensitivity points

$$OV = \frac{P}{2\pi}\frac{1}{2}arg\left(\frac{(E_- e^{-i\varphi\delta} - E_-\delta)(E_+ - E_+\delta)}{(E_+ e^{i\varphi\delta} - E_+\delta)(E_- - E_-\delta)}\right)$$

P = pitch size

ϕ_{OV}





Tolerance of pDBO and iDBO

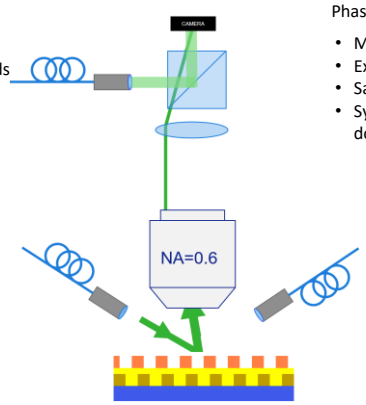
Dark-Field Holographic Microscopy

What is Holography?
- Mix Object beam with known Reference beam
- Separate DC terms from cross terms
  - Use Phase-shifting to determine complex fields

Why Holography?
- Amplifies our weak illumination signal
- Best known method of measuring the phase of complex light fields

Why Dark-Field?
- Discard specular reflection
- Reduce stray light from illumination

Our approach
- Off-axis illumination for measuring small pitches
- 2 strong coherent illumination beams that capture +1st and -1st diffraction order sequentially
- Fiber coupled delay line (not shown)

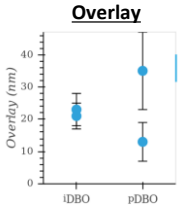


Dark-Field Holographic Setup, λ=520nm

Preliminary Results

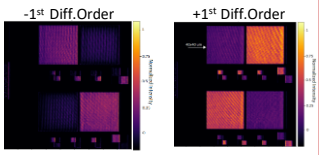
Phase resolved holograms from grating targets
- Measured on two locations
- Expected sign
- Same order of magnitude
- Systematic errors still dominated by calibration

Overlay

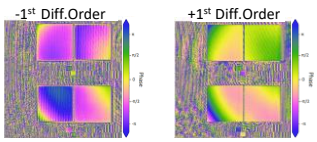


Overlay comparison of left and right illumination arms

Intensity



Phase



left vs right illumination arm

Preliminary Requirements of the Setup

Dark Field has an optical path length issue
- Derive the requirements for phase-shifting holography (Reference Angle = 0°)
- Light with sufficient coherence length:

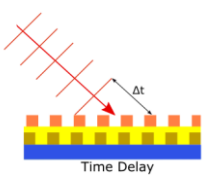
$$B < \frac{\lambda_c^2}{FOV/2}\frac{1}{\sin(\theta_{ill}) - M\sin(\theta_{ref})}$$

- Camera should resolve fringes

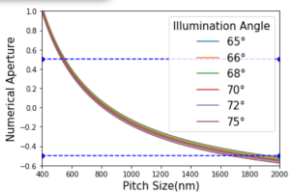
$$M > \frac{2\pi}{\Delta k}\left(\frac{1}{P} + \frac{\sin(\theta_{ill})}{\lambda}\right)$$

- Capture the 1st diffraction order

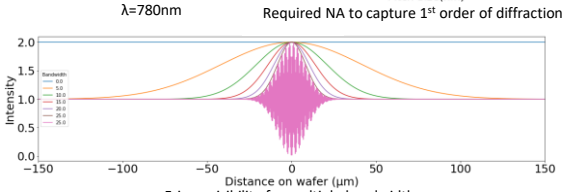
$$NA > \frac{\lambda}{P} - \sin(\theta_{ill})$$



Time Delay
λ=780nm



Required NA to capture 1st order of diffraction



Fringe visibility for multiple bandwidths

Conclusion & Outlook

Conclusion
- Phase resolved method for Overlay metrology robust for stack thickness variations
- Dark-Field Holographic Microscopy

Outlook
- Continue to improve calibration of Intensity and Phase profiles
- Demonstrate the removal of zero-sensitivity points
- Compare predicted analytical requirements with data obtained from the experimental setup

References:
1. A. J. den Boef,, Surf. Topogr.: Metrol. Prop. 4, 023001, 2016.
2. J. Benschop, et. al, Proc. SPIE 8683, Optical Microlithography XXVI, 86830P, 2013.

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