Process Control of Lithography and CMP by Innovative Optical Methods

2008 International Workshop on EUV Lithography
June 10-12, 2008, Wailea Beach Marriott, Maui, Hawaii, USA

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Process Control of Litho and CMP by Innovative Optical Methods

Content

• Introduction and Motivation
• Advanced Resist Thickness Control
• Control of Critical Dimensions
• Surface Characterization Using Wave Front Sensing
• Determination of Flatness
• Summary and Conclusions
Introduction

Flatness on Patterned Wafers

- surface flatness requirements = critical dimension of technology generation (ITRS); currently 65-45 nm(!)

Chemical Mechanical Planarization

- maintain the initial surface flatness
- patterned wafer (materials- metals, dielectric) → challenge for metrology
- > 10 CMP steps during MPU or Logic manufacturing

Lithography

- EUV requires extreme flat surfaces
- Depth of focus ~ CD
Motivation

Optical Components of the EUV Litho Tool

mirror:
- low frequency deviations from specified form produce wave aberrations
- high frequency deviations from specified form produce flare

mask requirements
- global flatness: consequences for focus control
- high frequency components introduce flare

exposed wafer surface
- global flatness: consequences for focus control
Simulated Impact of Aberrations on the Imaging of Contact Hole Arrays

- Example – array of contact holes
- Display of different imaging failures

Motivation

Simulations were done with Dr.LiTHO:
www.drlitho.com
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• Summary and Conclusions
Process and Measurement Steps in the Litho-Etch Sequence

**Advanced litho process control based on proven concepts**

Coating ➔ Development ➔ Etch

Layer thickness ➔ CD & Overlay

- In situ resist thickness measurement
- Endpoint detection during resist development (CD<45 nm)
- Advanced integrated CD, profile, and LER measurement

Stand-alone measurement ➔ Integrated measurement

> 2010 ➔ time

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Control of Layer Properties and Patterns

Application of ellipsometer and reflectometer systems with adapted algorithms

Layer parameters
- Thickness, n,k
- Thickness, n,k
- Thickness, n,k

Layer system
- Isotropic layer 1
- Isotropic layer 2
- Isotropic layer 3
- Substrate

Optical model
- Grating 1
- Grating 2
- Isotropic layer 1
- Substrate

Structural parameters
- Thickness, CD, n,k
- Thickness, CD, n,k
- Thickness, n,k

Ellipsometry, reflectometry
- Ellipsometer for measurement on blank and patterned wafers
- Alternative: Reflectometer system

Modelling
- Regression

CD, layer thickness, optical properties
- Scatterometry
Control of Coating and Develop by Spectroscopic Reflectometry

**In situ spectroscopic reflectometer for fast resist thickness measurements**

**Motivation**
For sub-micron lithography, resist processing emerged as critical process step
Optical in situ metrology for resist thickness measurements and endpoint detection was required

**Key problem**
Availability of a robust measurement system

**Solution**
Development of a novel in situ spectroscopic reflectometer system for integration into production track systems

With the in situ spectroscopic reflectometer superior evaluation capabilities versus e.g., single-wavelength measurements were obtained (avoidance of diffraction effects)
Control of Coating and Develop by Spectroscopic Reflectometry

Control of resist thickness and endpoint detection during resist development

**Resist thickness control**
- Viscous resist flow (planarization)
- Spinning speed
  - 3500 rpm
  - 6500 rpm
  - 9500 rpm
- Drying of solvent

**Development endpoint detection**
- Endpoint threshold

Compensation of process deviations by adjusting the spin speed using an empirical process model

Endpoint detection during resist development of contact hole structures
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Motivation
In sub-100nm lithography, fast non-destructive information and control on structural parameters of resist features is required.

Key problems
Availability of fast scatterometry techniques for measurement on production wafers and regularly shaped structures.

Solutions
Development of the Phi-Scatterometry technique.
Development of the arbitrary angle effective medium approximation (AAEM).
Advanced Techniques for Pattern Control

Control of patterning processes in a 300 mm DRAM production line

- Initial off-line scatterometry and SEM measurements for basic neural network training
- Adaptive neural network model of diffraction effects
- On-line scatterometry measurement of current sample
- Process fault detection by scatterometry measurement
- Optional fault classification by SEM measurements

Well resolved and misprocessed resist patterns of a DRAM cell array structure

Evaluation algorithm for integrated line width control on production wafers applied in Phi-Scatterometry

Phi-Scatterometry signature detecting misprocessed wafers

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Motivation
For pattern control, fast scatterometry algorithms are required

Solution
Development of a scatterometry algorithm based on the Arbitrary Angle Effective Medium approximation (AAEM)

AAEM algorithm
• Approximation of structure as uniaxial crystal using standard algorithms for anisotropic materials
• Algebraic formulas for effective indices are valid for any angle of incidence
• Easy implementation and adaptation of regression methods
• Much faster than RCWA (40x)

Principle of the arbitrary angle effective medium approximation (AAEM)
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Surface Characterization Using Wave Front Sensing

Principles of wave front sensing
Wavefront = normal surface to light rays

- Optical system characterization
- Reflective surface characterization
Surface Characterization Using Wave Front Sensing

Detection of wave front aberrations

- analysis of patterned wafers possible
- Shack Hartmann - detection of focus shift

*collimated beam*

*aberrated wavefront*

Wave front = normal surface to light rays
Surface Characterization Using Wave Front Sensing

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**Collimated beam**

- Microlens array
- CCD

**Aberrated wavefront**

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Definitions for wafer geometry

- **Local wafer geometry** → integrated metrology
- **Spot measurement** for in-line control and filtering of data
- **Global wafer geometry** → stand alone tools for inspection

**Spatial Wave Length [mm]**

- Roughness: [0-50 nm]
- Nano topography: [0-100 nm]
- Flatness: [0-3 µm]
- TIR: [0-40 µm]
- Sori/warp: [-35 to 35 µm]
- Bow: [0-100 nm]

**Amplitude [µm]**

- AFM
- Capacitive distance measurement
- Interferometry on bare wafer
- Wave front sensing on pattern wafer

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Determination of Flatness

Methods for calculation of flatness

Cross Section Analysis
polynomial description of global wafer geometry
First orders: tilt, bow, warp…

\[ y = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 \cdot x^3 + a_4 \cdot x^4 + \ldots \]

Higher orders: TIR Flatness

Double Gaussian Filtering
(2D High-pass filter)

\[ F(t_x, t_y) = 2 \cdot \exp \left( -\pi \left( \frac{t_x^2 + t_y^2}{\alpha \cdot \lambda_c} \right)^2 \right) - \exp \left( -2 \cdot \pi \left( \frac{t_x^2 + t_y^2}{\alpha \cdot \lambda_c} \right)^2 \right) \]

\( \lambda_c \): cut off

Sharp cut off

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  \[ \lambda_c: \text{cut off} \]
Results and Discussion

Measurements on patterned wafers: e-Xplore™

Bare Wafer

STI Patterned Wafer

Interconnect Patterned Wafer

Non-destructive real-time measurement
Results and Discussion

Nanotopography

• Local data correction for the missing data in the measurement of the interconnect (local 5*5 average matrix operation)

• Spatial Filtering of Data using double Gaussian filter with a cut-off of 18 mm

• Differences in the substrates

• Height resolution < 15 nm
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- Improvements in resist thickness control by \textit{in situ} metrology

- Development of the Phi-Scatterometry technique

- Development of the Arbitrary Angle Effective Medium approximation (AAEM)

- Demonstration of feasibility of wave front sensing on patterned wafer surfaces

- Further developments:
  - Scatterometry for 32nm and 22nm/EUV lithography
  - Integratable flatness and nanotopography control
Acknowledgement

- European Commission for funding within NanoCMOS contract No. 0507587, PULLNANO contract No. IST-026 828 and SEA-NET contract No. IST-027982.
- Thanks to all contributing partners within NanoCMOS project, PULLNANO project, ANNA project and SEA-NET project
- Thanks to the co-authors A. Nutsch, G. Roeder, A. Erdmann, all from Fraunhofer-IISB, Erlangen

Links

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