SCATTEROMETRY AND AFM MEASUREMENT COMBINATION FOR AREA SELECTIVE DEPOSITION PROCESS CHARACTERIZATION

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OUTLINE

- Motivation
- Scatterometry and AFM metrology introduction
- Experimental validation
  - Scatterometry results
  - AFM results
  - Hybrid metrology
- Conclusions and perspectives
MOTIVATION

- Area-Selective Deposition (ASD) is an advanced technique for layer deposition with atomic level control.
- Formation of structures with self-assembly of atoms in the desired areas:

![Material to deposit](image)

Growth area

Non-growth area

**Experimental observations**

- Good selectivity
- Loss in selectivity (island growth)
- Bad selectivity
Metrology for the study of ASD samples:

- Combination of 2 complementary measurement techniques, Scatterometry and Atomic Force Microscopy (AFM)

<table>
<thead>
<tr>
<th>Scatterometry</th>
<th>AFM</th>
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<tbody>
<tr>
<td>- Thickness of the deposited layer</td>
<td>✔️</td>
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<tr>
<td>- Lateral overgrowth</td>
<td>✔️</td>
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<tr>
<td>- Quantification of the loss in selectivity</td>
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SCATTEROMETRY METROLOGY

- The diffracted light on periodic structures allows to reconstruct the geometry profile of measured patterns.

- Nova’s modeling toolbox
  - Standard optical model
  - Machine Learning model

- Advantages:
  - Fast metrology
  - Sensitive to geometry & materials characteristics

- Disadvantage:
  - Indirect measurement method
AFM MICROSCOPY

- Probe oscillation at resonance frequency
- Mode: True non contact
- XY scanner: 100x100 µm²
- Apex, Radius of Curvature: 2nm
- Z scan travel: 15 µm

- Advantages:
  - Direct measurement approach
  - Atomic resolution

- Disadvantages:
  - Very slow metrology
  - Not sensitive to material characteristics

The probe is following the topography by oscillating above it.
SIGNAL DECOMPOSITION

- Power Spectral Density (PSD): The PSD for a signal is a measure of its power distribution per frequency unit.

Signal

PSD function

PSD curve

Signal B = Signal A + High Frequency

Signal A
NUCLEATED ATOMS QUANTIFICATION ALGORITHM

- Change in topography compared to the reference reveals nucleation of atoms on the studied surface
- The surface under the normalized PSD is proportional to the total number of nucleated atoms on the studied area
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ASD EXPERIMENTAL SAMPLES

- Experimental patterns: Line-Space grating (SiO2/W) where the ZrO2 is selectively deposited on SiO2

- Design of Experiments (DOE):
  - ZrO2 deposition conditions: 30, 40, 50, 60, 70 and 80. All DOE deposition conditions have same ASD target
  - Reference wafer without ZrO2 deposition
SCATTEROMETRY RESULTS: STANDARD OPTICAL MODEL

**Growth area**

- **Thickness 1**
  - **ZrO₂**
  - **SiO₂**

**Non-growth area**

- **Thickness 2**
  - **ZrO₂**
  - **SiO₂**
  - **W**

Except the wafer edge effects, the layer thickness 2 varies in the range $[4.0, 7.8]$ (nm).

**Deposition condition 80**

- **ZrO₂ thickness not optimal**
- **Target thickness**
- **Bad process selectivity**

**Deposition condition**

- **Target thickness**
The lateral overgrowth occurs at center of wafers for the deposition conditions 60, 70 and 80.

Lateral overgrowth is independent of the ZrO2 thickness (above growth area) as seen in the wafer maps.
AFM MEASUREMENTS

Experimental setup:
- Scanned size: 4µm x 4µm
- Measured wafers: Reference, Dep. cond. 50, 60, 70 and 80
- 13 dies measured by wafer
**ASD SELECTIVITY LOSS**

**Total number of nucleated atoms on W (average per wafer):**
- The wafer dep. cond. 60 has the smallest ZrO2 nucleation signature, while the dep. cond. 80 has the biggest one
- The ZrO2 fingerprint on dep. cond. 50 is slightly higher than 60

The surface under the normalized PSD is proportional to the total number of nucleated atoms on the studied area.
SUMMARY OF SCATTEROMETRY AND AFM RESULTS

Typical stack by wafer:

- **Deposition condition 30**
  - SiO₂
  - ZrO₂
  - Low ZrO₂ growth

- **Deposition condition 40**
  - SiO₂
  - ZrO₂
  - Good selectivity

- **Deposition condition 50**
  - SiO₂
  - ZrO₂
  - Good selectivity

- **Deposition condition 60**
  - SiO₂
  - ZrO₂
  - Good selectivity

- **Deposition condition 70**
  - SiO₂
  - ZrO₂
  - Bad selectivity

- **Deposition condition 80**
  - SiO₂
  - ZrO₂
  - Very bad selectivity

According to AFM
SCATTEROMETRY RESULTS VALIDATION BY TEM

TEM results have confirmed:

- **Lateral overgrowth** evolution according to the deposition condition
- **ZrO2 layer thickness** on both growth and non-growth area
- **Serious selectivity loss** for deposition condition 80
NOVA’S MACHINE LEARNING (ML) MODEL

Machine learning concept:

1. Cross combination of the spectra with PSD data by using a set of machine learning algorithms to generate mathematical estimator

2. The estimator predicts the quantity of ZrO2 nucleated atoms from scatterometry spectra
Nova’s Machine Learning (ML) model

ZrO\textsubscript{2} nucleated atoms rate

Comparison on training data

ML model predictions

uncertainty = 0.023

Standard optical model

Thickness 1

Thickness 2

LATERAL OVERGROWTH

Deposition condition

PSD (a.u.)

ZrO\textsubscript{2} nucleated atoms rate (a.u.)

Ref. 50 60 70 80
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CONCLUSIONS AND PERSPECTIVE

- Combination of the Scatterometry and AFM techniques allows to accurately characterize the ASD process
- The combined metrology revealed until down to very small changes in the process selectivity
- Hybrid model has been successfully built by exploiting the standard and machine learning models

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- Future work: XPS measurements
THANK YOU
FOR YOUR ATTENTION