

Mo/Si multilayers with arbitrary period thickness distributions

Stefan Braun*, Thomas Böttger, Thomas Foltyn, Matthew Moss, Ludwig van Loyen and Andreas Leson

IWS Dresden, Fraunhofer-Institute Material and Beam Technology, Winterbergstrasse 28, D-01277 Dresden, Germany

* e-mail: stefan.braun@iws.fraunhofer.de, Phone: 0351/2583432, Fax: 0351/2583314

Introduction

Problem

State-of-the-art:

Deposition of uniform or 1-dimensional graded layers using deposition geometries with

- linearly accelerated substrate motions (\Rightarrow linear gradients),
- rotating substrates (\Rightarrow gradients with rotational symmetry).

Potential requirements for EUVL:

Thickness profiles with

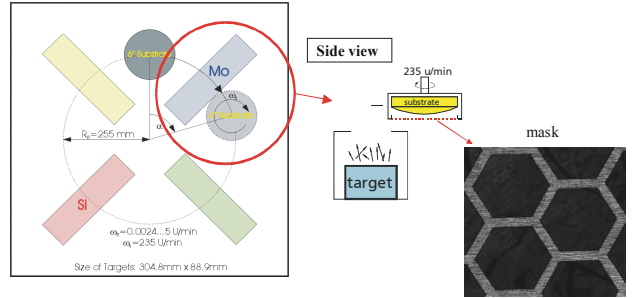
- arbitrary period thickness distributions,
- steep gradients

on flat and/or curved substrates.

\Rightarrow The introduction of mask-deposition techniques is necessary!

Solution of the problem

Introduction of a fixed mask with laterally varying transmission between target and substrate.



Theoretical and experimental results

Theory

Every hole, i , acts as a partial particle source and produces a thickness contribution d_i on the wafer.

Question: What does the total thickness distribution on the wafer look like?

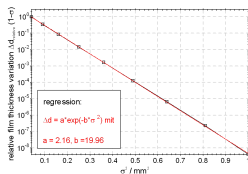
Assumptions:

- Sources are arranged on a square grid with lattice parameter $a = 1$ mm
- Gaussian sources, i.e. d_i on the substrate position (x, y) is given by

$$d_i(x, y) = \frac{A_i}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-x_i)^2 - (y-y_i)^2}{2\sigma^2}\right)$$

- A_i ... area of the hole
- σ ... parameter describing the width of the Gaussian curve
- x_i, y_i ... position of the center of Gaussian source i
- x, y ... substrate position

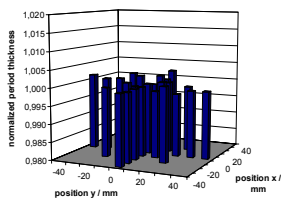
Result:



Relative film thickness variation decreases exponentially with σ^2 .
 \Rightarrow Since σ is related to the distance, d , between mask and substrate, d must be optimized in order to get smooth layers.

Experiments

Layer thickness uniformity



Period thickness measurements (Cu-K α reflectometry) on different lateral mirror positions using a uniform mask profile:

$$\sigma_{d, \text{relative}} = 0.11\%$$

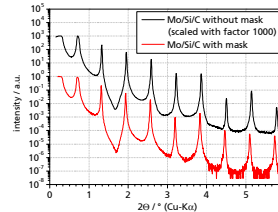
$$\frac{d_{\text{max}} - d_{\text{min}}}{d_{\text{mean}}} = 0.44\%$$

Reflectometry

Cu-K α reflectometry:

- no peak broadening
- no roughness increase

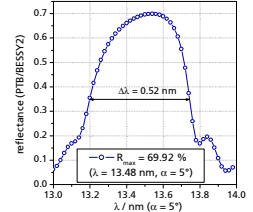
compared to multilayers deposited without mask.



EUV reflectometry:

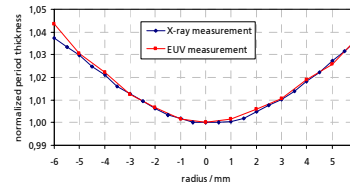
- high reflectance: 69.9 %
- unchanged bandwidth

compared to multilayers deposited without mask.



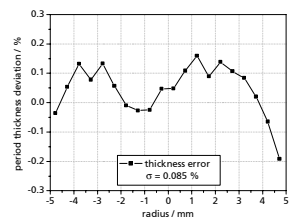
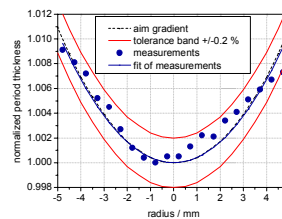
Lateral gradients

Comparison of X-ray and EUV reflectometry on flat wafers.



No differences within the measurement uncertainties. Both – EUV and X-ray reflectometry – can be used to determine thickness profiles.

Gradients on curved substrates ($R_{\text{curvature}} = 35$ mm)



Also on substrates with strong curvatures, period thickness gradients can be deposited with a deviation < 0.1 % from the aim profile.

