FOM Institute for Plasma Physics Rijnhuizen

Multilayer coatings for the 1st EUVL Process Development Tool

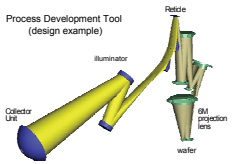
E. Louis, E. Zoethout, R. van de Kruijs, I. Nedelcu, S. Alonso van der Westen, T. Tsarfati, A. Yakshin, and F. Bijkerk

FOM Institute for Plasma Physics Rijnhuizen, the Netherlands

H. Enkisch, M. Lill, J. Lüdecke, F. Macco, G. Sipos, T. Westerwalbesloh, S. Müllender and P. Kürz

Carl Zeiss SMT AG, Oberkochen, Germany

EUV coatings for Alpha Demo Tool optics



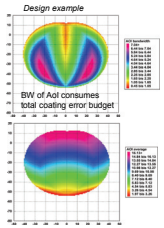
Alpha Tool
- NA 0.15 - 0.25, 50 nm resolution
- Aspheres, highly curved elements, gradient coatings, ...

Why Alpha Tool coatings are non-trivial

Globally valid specifications
Wavelength matching 0.1% d-spacing (7 pm)
Non-correctable added figure error 0.02% rms/100 pm
>63% R (capped, @ used AoI)
Residual substrate roughness ~ <0.3-0.4nm HSFR

Typical 'every day' accuracies

Substrate positioning in coater	sub-mm
Alignment accuracies substrates	~25 µm
ML-induced substrate stress	<100 MPa
Wavelength accuracy PTB	1 pm 'week-to-week'
Reflectometry accuracy PTB	+/- 0.1% abs rms



0.02% d-spacing requirement (non correctable):
➔ 1.5 pm layer thickness error
EUV coating task is 'PICOMETER TECHNOLOGY'

EUV facilities @ FOM

Used for Alpha Demo Tool coatings

- **UHV ML deposition set-up**
  - Substrates <200 mm coated area
  - 69.5% reflectivity
  - >67% including cap
  - >230 hrs lifetime at quasi CW source
  - Wavelength matching P/V 0.10%
  - Lateral uniformity of periodicity P/V 0.10%
- **Hard x-ray characterization** set-up
- **Thermal annealing** & low-power EUV set-ups
- 50 m² **clean room** space

EUV facilities @ Zeiss SMT

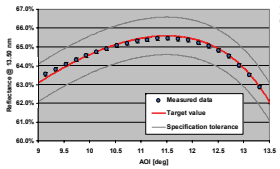
EUV application specific coating facility
- Based on 'FOM coating process'
- Allows deposition of >500 mm optical diameters
- UHV conditions (4x10⁻⁸ mbar)
- New ways of layer plasma treatment
- Improved layer thickness control (x-ray monitoring)
- Reflectance at 13.5 nm 67%
- Wavelength matching P/V 0.15%
- Lateral uniformity of periodicity P/V 0.12%

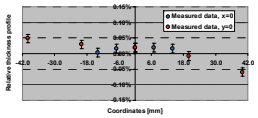
Van Loyen et al. SPIE Sta Clara (2003) ML5038-3

On-site EUV reflectometer
- Up to 500 mm dia, 30 kg samples
- Reproducibility reflectance 0.5%, wavelength 0.01%

Illuminator optics N1 Alpha Demo Tool

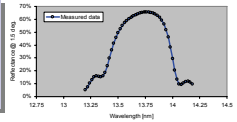
Highly convex illuminator element
Reqt. reflectivity @ used AOI +/-< 1% of target value
➔ 0.1% d-spacing budget





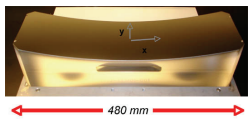
Results deposition
- d-spacing within +/- 0.05%
- Lateral reflectivity uniformity +/-<0.5% of target value @ used AOI
  - ✓ Factor 2 within specification
- NNI Reflectivity 65.5% @ 1.5°, HSFR 0.2 nm
- Co-deposited superpolished Si (HSFR 0.1 nm) 65.9%

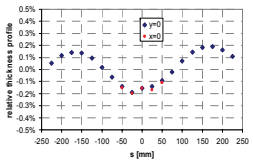
➔ ~0.4% reflectivity loss due to substrate roughness

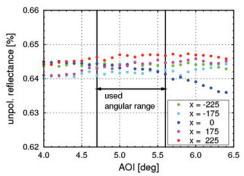


Illuminator optics N2 Alpha Demo Tool

largest optical element
Reqt. reflectivity @ used AOI +/-< 1% of target value
➔ 0.3% d-spacing budget







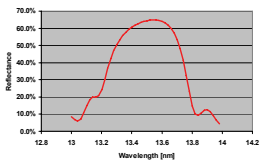
Largest EUV ML optic to date successfully coated
- First real EUV optic from new large area EUV coating facility @ SMT
- Several new coating technologies successfully incorporated

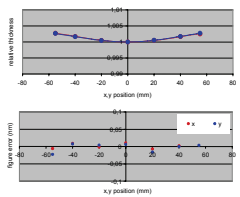
Results deposition
- Lateral uniformity < 0.2%: within spec (0.3%)
  - ➔ results in reflectance uniformity +/- 0.25%
- Reflectivity 64.5% (EUVR characterized)

Projection optics Alpha Demo Tool

Requirements deposition
- Non-correctable added figure error <100 pm
- Reflectance uniformity < +/- 1%
- Stress 0 +/- 100 MPa

Alpha Tool
NA 0.15 - 0.25, 50 nm resolution
aspheres, highly curved elements, gradient coatings

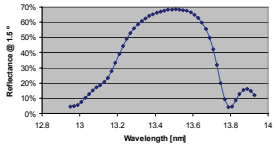




Results 1st PO box optics depositions
- ~65% reflectivity including capping layer and 0.3 nm substrate roughness
- Stress mitigated down to -30 MPa
- Total coating stack non correctable thickness error down to 15 pm rms.
- Reflectance uniformity < +/- 1%

<15 pm added figure error: 'Sub-atomic lateral coating accuracy'

Recent capping layer development

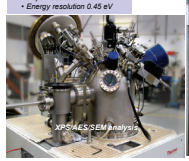


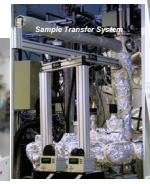
New capping layer:
➔ reflectance 68.5%
comparable to uncapped

New dedicated coating facility @ FOM

Now reproducibly delivering 68.7% (auto deposition, uncapped)
UHV connection with ex-situ XPS, AES, SEM accelerates development
All equipment installed & operational
Cap layer research and interface engineering in progress

XPS
- In-vacuum analysis
- Angular resolved
- Lateral resolution 15 µm
- Depth resolution - 1nm
- Energy resolution 0.45 eV





Summary status coating programme: All Alpha Demo Optics coated

FOM
- Major effort in scaling coating technology towards true prototype
  1st Alpha Demo depositions completed.
  - Three illuminator elements coated, all within spec
    - Profile within ± 0.05%
  - Three PO Box elements coated, all within spec
    - 15 pm added figure error
- Advanced development coater constructed
  - Reference quality (68.7% reflectance) achieved
  - Research aiming at Production tool targets
- Knowledge base and processes being transferred to Zeiss
- Design of new Zeiss ML coater + assistance in commissioning
  - Based on FOM process
  - Numerous technological extensions implemented

Zeiss
- New, dedicated EUV coating facility fully operational
  - 67% reflectivity achieved so far
- 1st Alpha Demo depositions completed
  - One large 480 mm illuminator element coated within spec
  - Three PO Box elements coated within spec.
  - Large 50 cm diameter optic coated within spec
- Lab-scale EUV reflectometer (EUVR) employed in parallel to PTB

Acknowledgments

Carl Zeiss (Oberkochen)
http://www. zeiss.de/
BMBF Projekt 'Grundlagen der EUV-Lithographie 13N8088 and' MEDEA Project EXTATIC

Foundation for Fundamental Research on Matter (Utrecht)
http://www. fom.nl/ and www.rijnh.nl

ASM Lithography (Veldhoven, The Netherlands)

Philips Research (Eindhoven, The Netherlands)

Physikalisch -Technische Bundesanstalt (Berlin)

TPD/TNO (Delft, The Netherlands)

SCIENTEC Engineering (Putten, The Netherlands)

More Moore, IST–1-507754-IP