EUV Dark-Field Microscopy for Actinic Defect Inspection

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Introduction to EUV mask blank inspection

- Laboratory scale defect detection tools for mask blank inspection at 13.5 nm are highly demanded and crucial to the successful implementation of next generation EUV lithography;
- Substrate roughness and remaining particles of size 20 – 150 nm are critical for print circuit quality during wafer manufacturing;
- Aerial scanning tools (Zeiss ALM5 at 157 nm) and phase measurement tools (Lasertec MPM at 157 nm) are available, but not for EUV;
- Amplitude defects as e.g. particles on top of multilayer mirror (ML) and phase defects inside of ML have to be detected and localized at the ML-defined wavelength (actinic), i.e. at λ = 13.5 nm.

Theory of defect detection

- (amplitude/phase) defects can be detected efficiently in dark field mode
- detection sensitivity is limited by different kinds of noise:
  - signal noise = \( \frac{n_f}{P \cdot QE \cdot P \cdot M} \)
  - noise readout noise (crucial if fast readout is needed)
  - amplification: gain M, noise factor F (additional noise)
  - dark (thermal) noise (temperature and time dependent)
  - spurious noise (clock induced charge (CIC), small)
  - photon induced noise (noise from signal itself)
  - \( N_{\text{ph}} = h\nu(3.7eV - 25eV) / 13.5 nm \)
  - A reasonably high level of confidence of signal detection requires photon induced noise be higher than others:
  - The Rose criterion: Signal/Noise ≥ 2 needed for 100% certainty in distinguishing image features
  - estimation of source requirements:
    - Required irradiation dose (determined by detector sensitivity, magnification, transmission and defect scattering efficiency into objective solid angle) = 1 - 100 mJ/cm²;
    - Illumination slightly divergent;
    - Typical magnification = 20; Large object field = 500 – 1000 mm²;
    - Scan speed 4 mm/s @ 10 fps & 650 mm²;
  - Source requirements:
    - Used etendue = 10⁻¹⁰ m²·sr; Collection efficiency \( \eta_{\text{coll}} = 0.7 \times 2 \times 5 \times 10^{-6} \);  
    - Average radiancy = 0.3 – 30 W/(cm²·sr) = 1 W/(cm²·sr) (DPP, 1:1 imaging)

Experimental setup

The experimental dark field reflection microscope based demonstrator for defect inspection has been successfully realized.

- central wavelength: 13.5 nm
- 3k-electronic source, 0.5 mA, 1% BW, 50 Hz
- diameter: 500 – 800 µm
- grazing incidence ellipsoidal collector
- NA_{cic} > 0.03, NA_{ellip} ≥ 0.04
- NA_{cic} > 0.14, NA_{ellip} ≥ 0.16
- iris aperture, Zr filter; deflection ML mirror 45°
- central stop => dark field operation
- mask blank holder and positioning (25 mm)
  - FOV=650 µm, RES=800 nm limited by CCD (1024² pixel of size 13 µm, 1.1 fps, 10-e-7pin)
- Schwarzschild objective
  - 21x, focal length 27 mm
  - NA_{ellip} = 0.11, NA_{cic} = 0.21
  - specified resolution 70 – 100 nm

Experimental results

- structured pits on a multilayer mirror:
- structured bumps on a multilayer mirror:
- natural defects on a multilayer mirror:

Conclusions and outlook

- With limited resources and restriction to available components, we have accomplished first steps for a defect inspection concept.
- Programmed structures (pits and bumps) and natural defects on multilayer mirrors have been measured. Defect detection limits with a large field of view and moderate magnification were investigated in terms of required source photon flux and detection camera performance.
- We are confident that an economic solution for sub-30 nm sensitivity and acceptable throughput can be achieved in the next steps.