EUV optics cleanliness qualification using spectroscopic ellipsometry

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Background & Motivation

x-rays: λ = 0.1-30 nm

Mo, Si, d, θ

H, C, R, R', Adsorption, Diffusion, EUV radiation, Optic, e^-, Secondary electrons

Jeromy Hollenshead, J. Vac. Sci. Technol. 2006

- Multilayer mirror for EUV optics
- Physical mechanism of carbon contamination on EUV optics under EUV radiation

Goal: predict EUV reflectance loss due to carbon deposition using visible-light ellipsometry

Juequan Chen et al., Detection and characterization of carbon contamination on EUV multilayer mirrors, Optics Express, 17 (2009) 16969-16979

Juequan Chen et al., Characterization of EUV induced carbon films using laser-generated surface acoustic waves, Diamond and Related Materials, 18 (2009) 768-771

Methodology

- Principle of Ellipsometry

$$\rho = \frac{R_p}{R_s} = \tan(\psi) e^{i\Delta}$$

E, p plane, s plane, Linearly polarized light, Normal, Elliptically polarized light, Sample

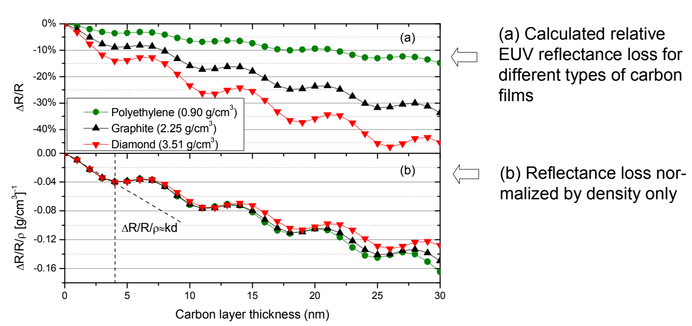
Change in polarization after reflection supplies thickness and optical constants of contamination layer

- Wavelength range used:
  - 0.7-5.1 eV (245.3-1689.4 nm)
- *In situ* & *ex situ*

- 3 types of carbon contamination examined:
  - EUV induced carbon
  - Physical vapor deposition (PVD) by e-beam evaporation
  - Evaporation from a graphite filament (hot filament C)
- EUV reflectometry and grazing incidence X-ray reflectivity (GIXR) used as reference

Experimental results

1. Principle of EUV reflectance loss



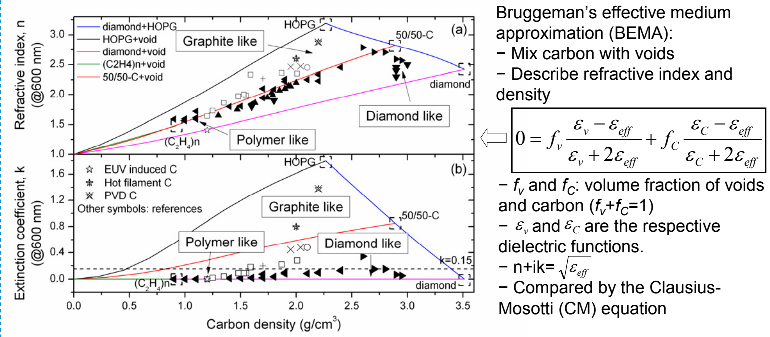
(a) Calculated relative EUV reflectance loss for different types of carbon films

(b) Reflectance loss normalized by density only

⇨ Reflectance attenuation scales with density and thickness only

⇨ In typical EUV optics contamination (< 5 nm) type of carbon is irrelevant for reflectance loss determination

2. Estimating the carbon density from the optical constants



Bruggeman's effective medium approximation (BEMA):
- Mix carbon with voids
- Describe refractive index and density

$$0 = f_v \frac{\varepsilon_v - \varepsilon_{eff}}{\varepsilon_v + 2\varepsilon_{eff}} + f_C \frac{\varepsilon_C - \varepsilon_{eff}}{\varepsilon_C + 2\varepsilon_{eff}}$$

- f_v and f_C: volume fraction of voids and carbon ($f_v+f_C=1$)
- ε_v and ε_C are the respective dielectric functions.
- n+ik= $\sqrt{\varepsilon_{eff}}$
- Compared by the Clausius-Mosotti (CM) equation

⇨ Refractive indices for various types of carbon are all in the triangle (black-purple-blue line): limits density range for a measured n

⇨ Range of density reduced further by k:
- diamond-like (or polymer-like) if k < 0.15
- graphite-like if k > 0.15

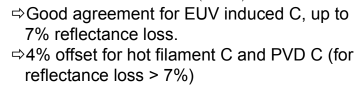
⇨ Reduced range of density → EUV loss accurately predicted by ellipsometry data

3. Estimation of EUV reflectance loss

Estimation of carbon density

Carbon type	n @600 nm	Density Max (g/cm³)	Density Min (g/cm³)	e1 @0 eV	Density Max (g/cm³)	Density Min (g/cm³)	Density (g/cm³)
Method	ellipsometry	BEMA	BEMA	extrapolated	CM	CM	GIXR
EUV C	1.41	1.17	0.79	1.95	1.40	0.63	1.2±0.2
Hot C	2.60	2.53	1.68	9.44	2.266[1]	1.99	2.0±0.1
PVD C	2.88	2.54[2]	1.95	10.63	2.266[1]	2.06	2.2±0.2

[1] The density of HOPG is applied as the upper limit of graphite like carbon.
[2] This limit is based on *k* because it is smaller than that based on *n*



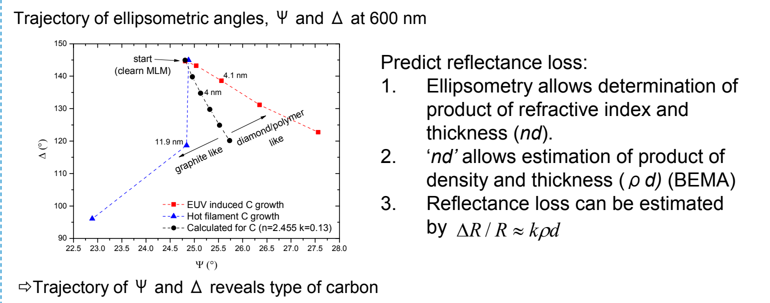
⇨ Good agreement obtained between densities measured by GIXR and estimated values using the BEMA and CM model.

⇨ Good agreement for EUV induced C, up to 7% reflectance loss.

⇨ 4% offset for hot filament C and PVD C (for reflectance loss > 7%)

4. Application for ultrathin carbon films

Trajectory of ellipsometric angles, Ψ and Δ at 600 nm



Predict reflectance loss:
1. Ellipsometry allows determination of product of refractive index and thickness (*nd*).
2. '*nd*' allows estimation of product of density and thickness (ρd) (BEMA)
3. Reflectance loss can be estimated by $\Delta R/R \approx k\rho d$

⇨ Trajectory of Ψ and Δ reveals type of carbon

Conclusions

1. EUV reflectance loss due to carbon deposition is mainly determined by the carbon layer thickness and density and not by it's composition.
2. All published experimental carbon densities and refractive indices are well described by Bruggeman's effective medium approximation (BEMA).
3. For EUV induced carbon, the predicted reflectance loss based on the BEMA agrees well with the experimental data with an accuracy of ~ 1%, thus enabling qualification of the cleanliness of EUV optics.

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