

Multilayer collector optics for operation in EUVL source environments with alternative fuels

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Introduction

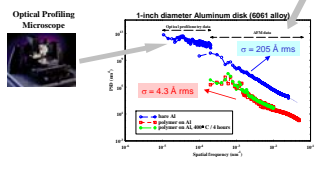
One of the main challenges regarding condenser mirrors for EUVL is lifetime, since these optics are subject to increased heating and contamination. One approach would be to manufacture inexpensive substrates and multilayer-coat with the appropriate material pair, that would meet all required specifications and would allow replacement at no substantial cost.

We are developing polymer-smoothing processes for diamond-turned* (such as Al) and ground/polished (SiC, Si-SiC) substrates to reduce mid- and high-spatial frequency roughness, and novel multilayer coatings for normal incidence operation at EUV wavelengths. Both components (smoothed substrate, multilayer coating) need to satisfy a unique set of properties such as high thermal stability ($T \geq 400^\circ\text{C}$), to be compatible with operation under EUVL source environments using alternative fuels.

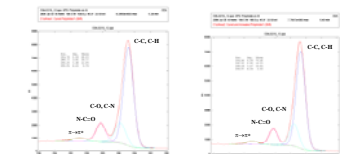
*R. Soufli, E. Spiller, M. A. Schmidt, J. C. Robinson, S. L. Baker, S. Ratti, M. A. Johnson and E. M. Gullikson, "Smoothing of diamond-turned substrates for extreme-ultraviolet illuminators", to be published in the Dec. 2004 issue of Optical Engineering

Polymer-smoothing process dramatically improves aluminum roughness and maintains surface quality after 4 hrs/400°C annealing

$$\sigma^2 = \int_0^f 2\pi f S(f) df \quad \text{where } S(f) = \text{PSD (nm}^2), f = 10^{-3} \text{ nm}^{-1}, f_0 = 5 \times 10^3 \text{ nm}^{-1}$$

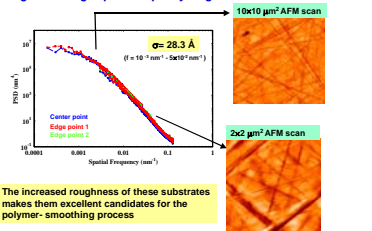


XPS analysis of the smoothing polymer before and after annealing for 4 hrs / 400 °C shows significant chemical changes



	Carbon Chemical States in %		
	C-C, C-H	C-O, C-N	N-C=O
Cured	71.3	15.8	12.9
Cured + Annealed	72.9	16.2	10.8

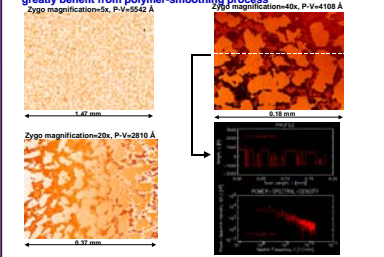
AFM analysis on two-phase Si-SiC substrates demonstrate significant high-spatial frequency roughness



The increased roughness of these substrates makes them excellent candidates for the polymer-smoothing process

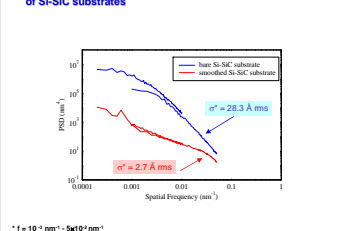
Acknowledgment: Substrates courtesy of Trintek-SSG

Mid-spatial frequency morphology of Si-SiC substrates could greatly benefit from polymer-smoothing process



Acknowledgment: TOPO software used in this analysis, written by D.L. Windt

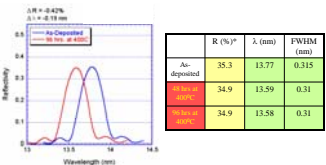
Smoothing improves high- and mid-spatial frequency roughness of Si-SiC substrates



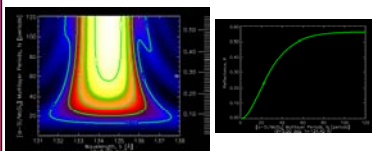
* $f = 10^{-3} \text{ nm}^{-1} = 5 \times 10^3 \text{ nm}^{-1}$

The reflectance and wavelength stability of MoSi₂/Si multilayers after 96 hours at 400°C is excellent

Experimental results from N=50 bilayers of MoSi₂/Si

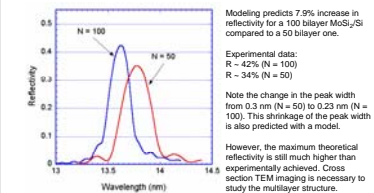


Modeling* indicates that the optimum number of bilayers for MoSi₂/Si is ~100



*Using values from the CXRO tables for Mo, Si optical constants.

8% increase in reflectivity was achieved experimentally due to increase in the number of bilayers

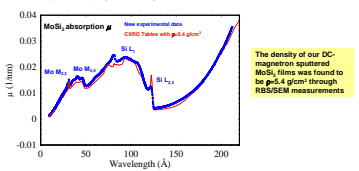


Large discrepancies exist in optical constants literature for MoSi₂ - new transmission measurements are underway

CXRO tables combine Mo and Si optical constants data and a bulk MoSi₂ density of 6.3 g/cm³ and predict 44% reflectance at 13.45 nm for MoSi₂/Si. Using other experimental optical constant sets for MoSi₂ (D. L. Windt, personal communication), the predicted reflectivity is 22%.

We measured transmission T and MoSi₂ film thicknesses x to determine the wavelength-dependent refractive index $n(\lambda) = \frac{1}{2} \sqrt{\frac{1}{T} - 1}$ of MoSi₂, through:

$T = T_{exp} \frac{\mu_0}{\mu}$, where $\mu = n^2 \mu_0$, to obtain n . Kramers-Kronig transformation will be used to obtain k .



Conclusions / Follow-on work

- Demonstrated smoothing of high-spatial frequency roughness on flat Al (from 205 Å to 4.3 Å) and Si-SiC (from 28.3 Å to 2.7 Å) substrates. Smoothed substrates showed excellent thermal stability after 4hrs / 400 °C annealing. Further smoothing and thermal tests on a variety of substrates are currently underway.
- Developed MoSi₂/Si multilayers with excellent wavelength / reflectance stability under 96 hrs / 400 °C annealing conditions. Further optimizations and testing of high-temperature multilayers are currently underway.
- Performed new measurements of the density and the refractive index of DC-magnetron sputtered MoSi₂ films, which are essential parameters in the modeling of MoSi₂/Si multilayer performance
- Ultimately plan to combine the optimum substrate and multilayer solutions on curved illumination optics for commercial EUVL systems

