

High-temperature MoSi₂/Si and Mo/C/Si/C multilayer mirrors

Sergiy Yulin, Nicolas Benoit, Torsten Feigl*, Norbert Kaiser

Fraunhofer-Institut für Angewandte Optik und Feinmechanik, Albert-Einstein-Str. 7, D - 07745 Jena, Germany

*feigl@iof.fhg.de

Introduction

The application of multilayer mirrors in EUVL requires not only the highest possible normal-incidence reflectivity but also a long-term and thermal stability at the operating temperatures. This requirement is most important in the case of the first mirror of the illumination system close to the EUV source (C1) where a short-time decrease of reflectivity is most likely.

A serious problem of Mo/Si multilayers is the instability of reflectivity and peak wavelength under high heat and radiation loads. The instability of Mo/Si multilayers becomes especially critical at elevated temperatures of more than 200°C, thus limiting the application possibilities of Mo/Si multilayers for coating of the condenser optics for EUVL.

Investigations on high temperature multilayers were focused on two alternative Si-based systems: MoSi₂/Si and Mo/C/Si/C multilayer mirrors. The multilayer designs as well as the deposition parameters of the two systems were optimized in terms of high peak reflectivity at a wavelength near 13.5 nm. Annealing in vacuum was carried out at elevated temperatures up to 500°C for up to 100 hours.

Multilayer deposition



Specifications

Technology	DC magnetron sputtering
Conception	inline, sputter down
Substrate size	up to 300 mm diameter
Magnetrons	3 sources, 360 x 120 mm ²
Base pressure	1*10 ⁻⁷ mbar
Working pressure	1*10 ⁻³ mbar
Process time	1 hour to 1.5 hours

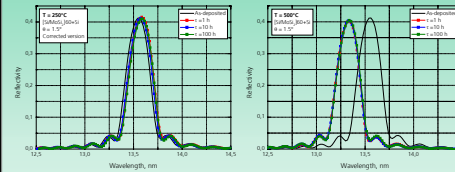
Multilayer annealing



Specifications

Technology	electrical annealing
Conception	high vacuum oven
Temperature range	50 to 900 °C
Heating rate	2 to 20 K/min
Homogeneity	+/- 5 K
Base pressure	1*10 ⁻⁵ mbar
Annealing times	1, 10, 100 h

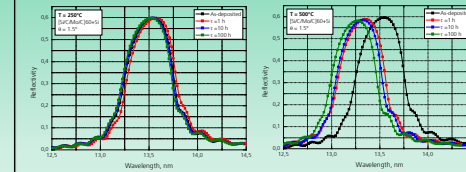
MoSi₂/Si – isothermal annealing



Measured MoSi₂/Si reflectivity, annealing at 250 °C for 1, 10 and 100 h

Measured MoSi₂/Si reflectivity, annealing at 500 °C for 1, 10 and 100 h

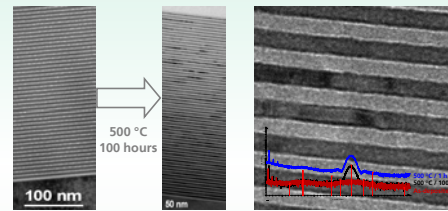
Mo/C/Si/Ci – isothermal annealing



Measured Mo/C/Si/C reflectivity, annealing at 250 °C for 1, 10 and 100 h

Measured Mo/C/Si/C reflectivity, annealing at 500 °C for 1, 10 and 100 h

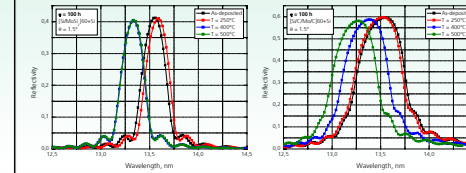
Structure of MoSi₂/Si



TEM of MoSi₂/Si, as-deposited

TEM and HR TEM of MoSi₂/Si after 500 °C / 100 h annealing. XRD analysis of structure: crystallization of MoSi₂ at 500 °C

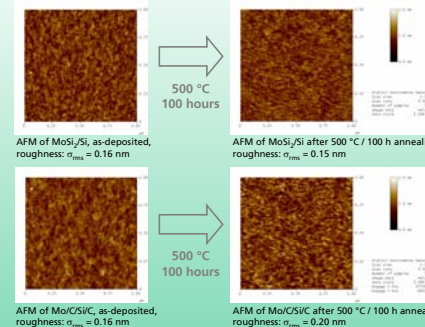
100 hours annealing of MoSi₂/Si and Mo/C/Si/C



Measured MoSi₂/Si reflectivity, annealing at 250 °C, 400 °C and 500 °C

Measured Mo/C/Si/C reflectivity, annealing at 250 °C, 400 °C and 500 °C

Microtopography of MoSi₂/Si and Mo/C/Si/C



AFM of MoSi₂/Si, as-deposited, roughness: $\sigma_{rms} = 0.16$ nm

AFM of MoSi₂/Si after 500 °C / 100 h annealing, roughness: $\sigma_{rms} = 0.15$ nm

AFM of Mo/C/Si/C, as-deposited, roughness: $\sigma_{rms} = 0.16$ nm

AFM of Mo/C/Si/C after 500 °C / 100 h annealing, roughness: $\sigma_{rms} = 0.20$ nm

Summary

Thermally induced small changes of the MoSi₂/Si multilayer properties were found but they were independent of the annealing time at all temperatures examined. The optical properties of Mo/C/Si/C did not change in the temperature range below 250 °C during 100 hours annealing. Slow degradation of the optical properties with time occurred at higher temperatures. The combination of high thermal stability and good optical properties of MoSi₂/Si and Mo/C/Si/C multilayer mirrors underlines their potential for their use in coating of EUVL collector optics.

Acknowledgement

The authors gratefully acknowledge the financial support for this work from Cymer, Inc. In particular, we would like to thank Norbert Böwering, Alex Ershov, Kent Bruzzone, and Igor Fomenkov for their assistance and many discussions. We would also like to thank Frank Scholze, Christian Laubis and Heike Wagner (PTB Berlin) for reflectivity measurements and Ute Kaiser and her team (University of Ulm) for TEM investigations.



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