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EUV/X-ray Multilayer Optics: Meeting the Challenges of Next-Generation Applications

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Abstract: This paper summarizes recent advances in the development of EUV/x-ray multilayer optics for photolithography, free-electron and tabletop lasers, and solar physics. Driven by the needs of their respective applications, the optics meet a variety of extraordinary specifications including coating thickness control in the picometer (rms) range, low coating stress, resistance to atmospheric corrosion, while at the same time maintaining high reflective performance.
OCIS codes: (340.0340) X-ray optics; (310.0310) Thin Films;

1. Introduction

The emergence of novel extreme ultraviolet (EUV)/x-ray sources and related applications [1,2,3] is posing extremely stringent requirements on the performance of multilayer optics, which are nowadays required to perform increasingly precise and complex functions and to meet tight and often conflicting specifications. Such challenges include the need for thickness control in the sub-nanometer range and low thin film stress for wavefront preservation. Also needed is stability against radiation damage, elevated temperatures, contamination and atmospheric corrosion effects, while achieving the highest possible reflectance in the relevant wavelength region.

This paper presents recent advances in the development of (i) multilayer optics for the first micro-exposure tools (METs) with numerical aperture (NA) =0.5 for EUV photolithography (ii) corrosion-resistant, low-stress and high reflectivity multilayer mirrors for EUV/x-ray laser sources and solar physics. All multilayer coatings discussed in this paper were deposited by DC-magnetron sputtering at Lawrence Livermore National Laboratory.

2. Results and discussion

METs are small field (30 µm × 200 µm) tools aiming to provide early learning towards the extendibility of EUV lithography using 13.5 nm wavelength of illumination, especially in the areas of photoresist and mask development. METs with NA = 0.3 have been operational for over 10 years, using laboratory (e.g: laser plasma) or synchrotron EUV sources. Next-generation METs with NA=0.5 (MET5) have been recently developed to demonstrate EUV patterning of features with resolution as small as 8 nm (half-pitch) [4]. The MET5 multilayer projection optics consist of a 2-mirror, modified Schwarzschild design and are subject to extremely stringent wavefront error and wavelength matching tolerances [5]. To minimize the wavefront error contributions of the multilayer optics in the MET5 system, the MET5 multilayer coatings were especially optimized to achieve simultaneously the highest reflectivity, lowest stress and lowest figure error. The resulting multilayer coating stress values are on the order of -100 MPa (compressive) with peak reflectance around 60%. The multilayer coating profile in the lateral direction was designed for both M1 and M2 mirrors to produce a reflectance vs. wavelength curve with a phase and a centroid wavelength that remain constant at all locations within the mirror clear aperture, at the angles of incidence of the MET5 system. Multilayer thickness control across the curved surface of each mirror was achieved using a velocity modulation technique during deposition. The multilayer coatings for MET5 achieved non-compensable, multilayer-added figure errors below 0.08 nm (80 picometers) rms, and an area-weighted centroid wavelength of 13.5 ± 0.05 nm, which was the specification for each MET5 mirror [6].

Mg/SiC is the best-performing multilayer coating in the 25-80 nm wavelength region, as it possesses a unique combination of consistently high reflectivity, good spectral selectivity, thermal stability to 350 degrees C and near-zero stress. However, Mg/SiC suffers from Mg-induced atmospheric corrosion which leads to degradation of the multilayer film (Fig. 1 (a), (b)). This problem has prevented Mg/SiC coatings from being used in applications that require long lifetime stability. To address this problem, we studied and elucidated the mechanisms of corrosion propagation in Mg/SiC multilayers and we developed corrosion barrier layers consisting of Al-Mg [7]. The Al and Mg are deposited as two separate layers and they spontaneously intermix to form a partially amorphous Al-Mg layer which provides efficient corrosion resistance while maintaining the favorable reflective properties of the original, unprotected Mg/SiC multilayer. (Fig. 1(c)). The efficacy of this corrosion resistance concept was verified experimentally on Mg/SiC films aged for 3 years. The phenomenon of spontaneous intermixing and amorphization of sputtered Al and Mg layers with nanometer-scale thickness was observed and investigated for the first time during this work [8, 9].

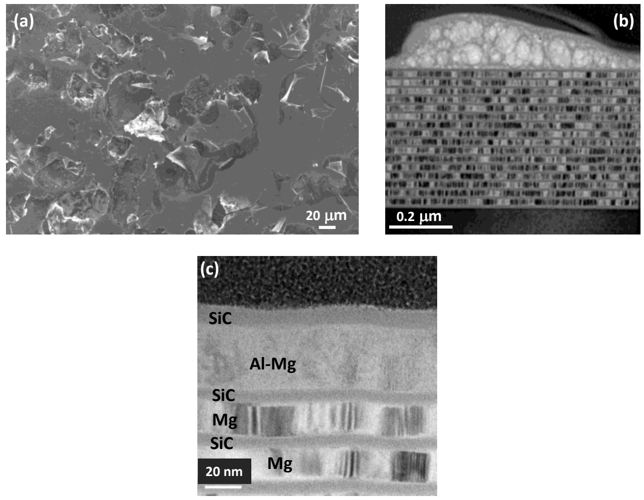

Fig. 1: (a) Scanning Electron Microscopy image of the top surface of severely corroded Mg/SiC multilayer film. Material is partially or entirely delaminated from the top surface. (b) Cross-sectional TEM image of corroded region within Mg/SiC multilayer. Corrosion has consumed the 4 top Mg/SiC bilayers and has formed Mg corrosion products, shown as the area with "cellular" appearance [9]. (c) Cross-sectional Transmission Electron Microscopy image of the top layers of a corrosion-resistant Mg/SiC multilayer designed for operation at wavelengths around 46 nm at normal incidence. The spontaneously intermixed Al-Mg corrosion barrier is shown underneath the top SiC layer [7].

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