Characterization of multilayer mirrors with broadband extreme ultraviolet radiation

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PURPOSE OF THE METHOD

A new method for characterizing EUV multilayers with sub-nanometer precision is proposed. The method is based on the fitting of simulated broadband EUV reflectivities to measured data.

PROBLEM STATEMENT

The reflected spectrum of a multilayer (ML) can be calculated using the matrix method when the thicknesses of the layers and the materials are known [1]. The complex refractive index of the layers can be obtained from the Henke tables [2], and the density of the layers can be adapted accordingly. To address this, we propose a computational model based on the matrix method algorithm [1] and utilizing the refractive index from ref. [2].

SOLUTION APPROACH

To measure the thicknesses of multilayer systems with broadband EUV spectra, our approach utilizes as simulation of the spectrally resolved reflectivity for an estimated multilayer design. We vary the thickness (and potentially the design) in the simulation and minimize the error between the simulation and the measurement. We employ the least square method as a measure of the error.

1. Matrix Method Algorithm Implementation:

Develop a sophisticated computational model based on the matrix method algorithm to simulate the reflected spectrum of multilayer systems. Incorporate accurate complex refractive index data obtained from reputable sources such as the Henke tables. Adapt layer densities based on Henke tables to ensure realistic material properties in the simulation.

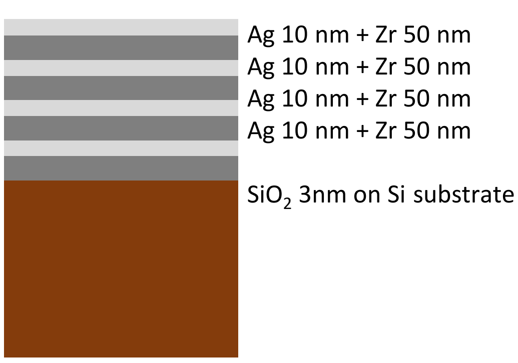

Fig.1 WAT sample

WAT sample:
Design ML (blue): Ag 10nm Zr 50nm Ag10nm Zr 50nm Ag10nm Zr 50nm Ag10nm Zr 50nm SiO2-3nm on Si substrate
ML with top Ag layer +0.5nm (orange)
ML with top Ag layer +0.1nm (yellow)

2. Steps in the simulation and parameter variation:

Utilize the computational model to generate simulated reflected spectra for a range of multilayer designs and thicknesses. Systematically vary the thicknesses and potentially the designs of the multilayer structures to explore a wide parameter space.

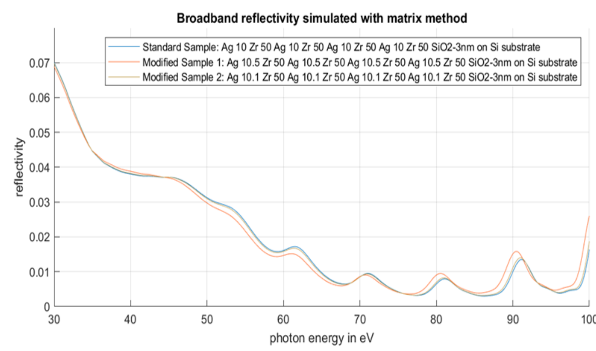

Fig.2 Simulated broadband reflectivity

Even though the differences between the blue and yellow curve look small (0.1 nm difference in one layer!), the positions of the maxima are separated by ~0.1 eV, which can be measured by a high-resolution spectrometer.

This example shows that the method is extremely sensitive to layer thicknesses. It is much more sensitive than XCT [3] and we may get to a resolution in the order of 0.1 nm, which is required for high-performance EUV multilayer mirrors.

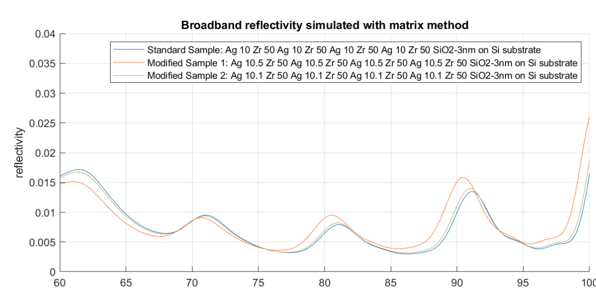

Fig.3 Change in resolution of reflectivity

3. Error Minimization using Least Square Method:

1. Compare the simulated reflected spectra with experimental measurements obtained from real-world samples.
2. Employ the least square method to quantify the discrepancy between the simulated and measured spectra.
3. Iteratively adjust the multilayer thicknesses to minimize the least square error and improve the agreement between simulation and experiment.

Molybdenum (Mo) and Lanthanum (La) layers buried under a silicon layer were investigated as a sample for proof-of-principle studies in the silicon transmission window [3].
Residuals are then calculated by comparing the experimental reflectivity data with each known reflectivity curve. The least square method is utilized to quantify the discrepancy between the experimental and simulated reflectivity data for each known thickness. This step provides a measure of the fitting accuracy and serves as the basis for identifying the closest match in thickness between the unknown sample and the known dataset.

Based on the calculated residuals, the thickness corresponding to the reflectivity curve with the smallest residual is identified as the closest match to the unknown sample. This determination enables the characterization of the unknown sample's thickness with respect to the known dataset.

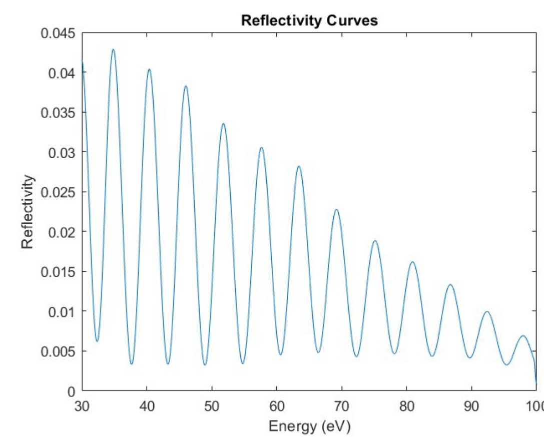

Fig.4 Reflectivity data obtained

For visualization and interpretation, the reflectivity curve corresponding to the closest thickness and the experimental reflectivity curve of the unknown sample are plotted together. This visual comparison facilitates an intuitive understanding of the degree of similarity between the unknown sample and the closest match in the known dataset.

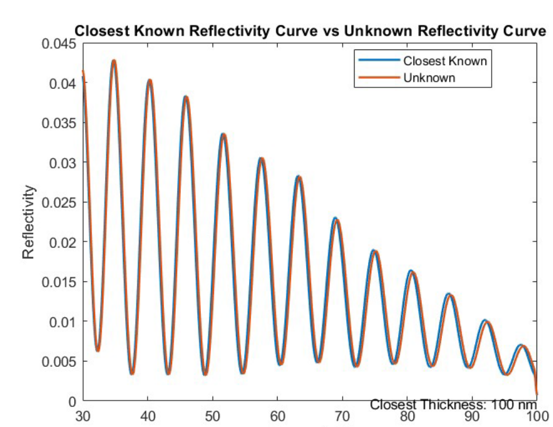

Fig.5 Simulation of reflectivity of the unknown curve

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