SPECTROSCOPIC EUV REFLECTOMETRY FOR CHARACTERIZATION OF THIN FILMS AND LAYERED STRUCTURES

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INTRODUCTION

Modern nanotechnology is continuously raising demands on quality and purity of thin films and interlayer interfaces. As thicknesses of employed layers decrease to single nanometers, traditional characterization tools struggle to satisfy simultaneously thoroughness, precision and non-destructibility requirements. Spectroscopic reflectometry with extreme ultraviolet radiation (EUV, 3–40 nm wavelength) offers a possibility of non-destructive study of surfaces. To this end, EUV spectroscopic reflectometry has been employed as a non-destructive metrology tool, which also allows controlling in-depth structure of the produced materials. We report on a series of reflectivity measurements on the samples of interest, e.g. different high-k thick films, that has been performed using a newly developed tabletop Polychromatic Angle-resolving Non-destructive Tool for High-speed Extreme ultraviolet Reflectometry (PANTHER). For the purposes of detailed structural characterization, information about chemical bonds structure and local-site symmetry is obtained through analysis of near-edge reflectivity data. Collection of spectral “fingerprints” and analysis of near-edge reflectivity of samples have been done additionally at the ELETTRA synchrotron facility, Trieste. The experimental and analytical results along with the outlook on the development of the method are presented and discussed. In addition to that, a suitability of the tool to the industrially relevant applications such as analysis of surface contamination, are illustrated by results of experiments with test samples exposed to real EUV source operation environment.

EXTREME ULTRAVIOLET RADIATION

For the EUV radiation of given wavelength \( \lambda \), the estimated penetration depth \( d_{pen} \) into the interface depends on the grazing incidence angle \( \beta \), and can be found as follows:

\[
d_{pen} = \frac{\lambda}{4 \sin(\beta/2) \sqrt{1 - (\sin(\beta/2))^2}}
\]

where \( a = 1 - 5 \) is the complex refractive index of the material.

In the case of conventionally defined free decay \( k \) is equal to \( 1 \), which corresponds to a decay to approximately 3% of the incoming intensity. With \( k_{\text{ex}} \), only 3% of the initial radiation will remain at the calculated depth. Latter is beneficial for estimating the in-depth sensitivity of the reflectivity measurements and it makes potentially possible in-depth scans of the studied structures.

NEAR-EDGE EUV REFLECTOMETRY

Presence of an absorption edge in reflectivity spectra allows for direct elemental sensitivity. With multi-angle approach, in case of more complex layered systems, it allows decoupling the fitting parameters (thickness, density and roughness of each layer) by modulating the reflective index of the stack around the absorption edge differently, depending on the incidence angle. Therefore, reflectivity measurements in near-edge regions make structural analysis more precise.

Near-edge fine structure in reflectivity spectra, which is at Al\(_2\)O\(_3\), Al\(_2\)O\(_3\)–Cu, CuO, SiO\(_2\) as potential contaminants, the following layer models provide the best fit of reflectometry data:

- Position 0.1 mm (0.8 mm) C (0.3 mm) CuO (0.2 mm) SiO\(_2\) Si
- Position 0.1 mm (0.8 mm) C (0.3 mm) CuO (0.2 mm) SiO\(_2\) Si
- Position 0.1 mm (0.8 mm) C (0.3 mm) CuO (0.2 mm) SiO\(_2\) Si

Photoemission electron microscope image of the contaminated Si sample recorded at h\(v=5.2 \) eV photon energy (He lamp). Field of view: 2\(\mu\)m x 2\(\mu\)m. Insert: photoelectron kinetic energy spectrum between 30 eV and 40 eV recorded at h\(v=113.7 \) eV photon energy (Xe DPP). The presence of copper and copper oxide is evident.

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LLO FILMS OF DIFFERENT CRYSTALLINITY

Different crystalline modifications of LaLuO\(_3\) (LLO) have been characterized by EUV reflectometry. Measurements were performed at ELETTRA synchrotron facility (BEAR beamline).

SUMMARY

- EUV spectroscopic reflectometry is a powerful tool for structural investigation of thin films.
- Multi-angle reflectivity measurements near elemental absorption edges increase precision of complex layered systems characterization.
- Near-edge fine structure analysis is an element-specific method for probing bonds, local symmetry and oxidation states of materials.