Determining Optical Constants in the VUV Range: Combining Ellipsometry and Angle-Resolved Reflectometry

Alexander Gottwald[1], Hendrik Kaser[1], Johannes Falkenburg[2], Norbert Esser[2,3]

[1]Physikalisch-Technische Bundesanstalt, Berlin, Germany
[2]Leibniz Institut für Analytische Wissenschaften e.V. (ISAS), Berlin, Germany
[3]Technische Universität Berlin, Berlin, Germany
Corresponding e-mail address: alexander.gottwald@ptb.de

The measurement of optical constants of thin films in the vacuum ultraviolet spectral range can be regarded to be challenging. Not only the experimental determination is difficult, but also the dependence of the results on the sample preparation. Thus, available data are scarce and mostly without reliable uncertainties. We present an approach for a sound measurement of *n* and *k* by combining two independent methods.

INTRODUCTION

Results from measurements of optical constants (i.e. the refractive index *n* and the extinction coefficient *k*) in the vacuum-ultraviolet spectral range (VUV) between 10 nm and 200 nm) can be found in literature, using different methods like e.g. transmission measurements and Kramers-Kronig analysis. Most of these reported values do not come with reliable (i.e.: traceable in the sense of metrology) uncertainties. Moreover, different methods seem to produce deviating results, or the values significantly depend on the individual sample preparation which makes it difficult or even impossible to systematically compare the results. The complexity in creating experimental data arise from the combination of high demanding surface preparation and measurement conditions from ultra-clean vacuum surrounding to the need for a tuneable VUV radiation source what usually requires the use of monochromatized synchrotron radiation.

METHOD

Basically, reflectometry and ellipsometry are both based on the measurement of the radiation reflected from the surface under investigation. They are complementary in the sense that reflectometry measures the change of the amplitude whereas ellipsometry measures the phase shift of the radiation when reflected at a surface. For both methods, the resulting quantities (*n*, *k*) must be determined numerically from the measured information.

Our measurements were conducted at PTB's Metrology Light Source. For the reflectometry measurements a goniometer-based vacuum set-up is available [1]. It allows the angle of incidence and reflectance to be independently selected and also to rotate the plane of reflection to account for the polarization. We used the VUV ellipsometer from the Leibniz Institute for Analytical Sciences (ISAS) by which amplitude and phase of the reflected radiation can be determined [2]. From the measured data the results for *n* and *k* were obtained pointwise by the Transfer-Matrix-Method and application of the Particle Swam Optimization to find the best fit. The uncertainty was analyzed by help of a Markov Chain Monte Carlo method.

RESULTS

We developed the method on the example of a TiO2 thin film (on a Si surface) for which optical constants in the wavelength range from 130 nm to 230 nm were determined [3] Our focus lay on the comparison of the methods, and validation of the results. We found that the resulting values strongly depend on model parameters like e.g. film thickness. This indicated that a multi-method approach will help to improve the results by independently determining system parameters. Although currently ellipsometry tends to have large uncertainties than reflectometry, it is extremely useful in regions where the values for the reflected amplitudes get very small.

REFERENCES

1. A. Gottwald et al., Determination of B_4C optical constants by angle-dependent reflectance measurement for 40 nm to 80 nm wavelength, Appl. Opt. **56**, 5768, 2017
2. M. D. Neumann et al., A synchrotron-radiation-based variable angle ellipsometer for the visible to vacuum ultraviolet spectral range, Rev. Sci. Instrum. 85, 055117 , 2014
3. A. Gottwald et al., Validation of thin film TiO2 optical constants by reflectometry and ellipsometry in the VUV spectral range, Meas. Sci. Technol. 30, 2019