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Profile and material characterization of sine-like surface relief Ni gratings by spectroscopic ellipsometry

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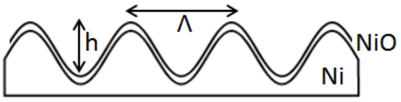
A. Motivation

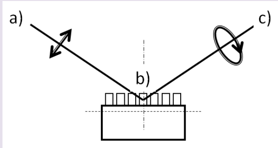
Spectroscopic ellipsometry (SE) performed in a wide spectral range is capable of monitoring various profile and material properties of periodically patterned nanostructures with high sensitivity, such as the period, width, depth and shape of patterned elements, native oxide overlayers, or the edge roughness of the patterned grooves [1]. We apply it to investigate the geometric properties of sinusoidally modulated surface-relief gratings, which are of high interest for many optical devices but has received almost no attention by SE. By comparing SE spectra with simulations with varied geometrical parameters, we can determine both the relief shape and the native oxide overlayer developed on the grating surface.



B. Spectroscopic ellipsometry

Spectroscopic ellipsometry

Principle



a) Initial polarization state
b) Interaction with a sample
c) Change of the polarization

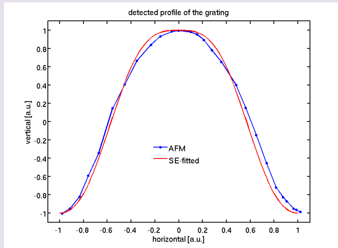
$$\frac{r_p}{r_s} = tan(\Psi)e^{i\Delta}$$

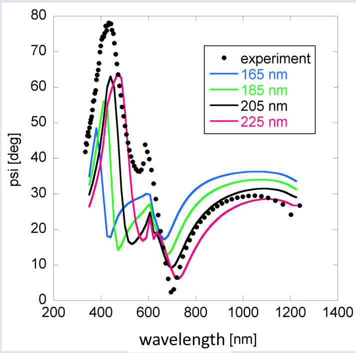
Theory

To analyse the spectro-ellipsometric experimental data, we apply **rigorous coupled wave analysis** (RCWA) using the correct Fourier factorization rules, which enables fast convergence. We analyze a sine-like Ni grating sample made by holographic lithography, covered by a NiO overlayer. Due to non-ideal fabrication process of both patterning and material deposition, the Ni surface relief is not perfectly sinusoidal. Therefore, for its determination we need not only the period and depth of the grooves, but also additional parameters describing their sharpness. Moreover, we also need to determine the thickness of the NiO surface overlayer.

Experimental

WVASE spectroscopic ellipsometer (Woollam, Ltd.). We have performed measurement of SE with three angles of incidence, 20, 30, and 40° in the spectral range from 300 to 1200 nm.





Results

Comparing experimental SE spectra with simulations based on various depths and profile shapes, we have found:

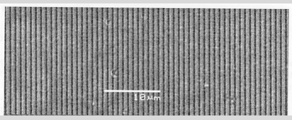
(1) grating period Λ = **917 nm**,
(2) profile depth ***h*** **= 205 nm**, and
(3) the profile shape non-ideality approximated by the formula z = (h/2){1 − cos[*P*(*y*)]}, where P(y) = (2p/L)[Ay + (2/L)(1–A)y2] with shape profile parameter **A = 0.52** (A = 0 corresponds to the ideal sinusoidal case).

Thickness of the NiO overlayer was fixed on 3.5 nm as determined by SE on non patterned part of the sample.

C. SEM, AFM, Optical microscopy

SEM

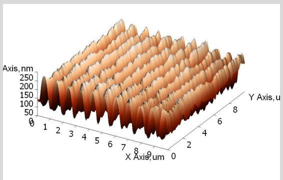
Λ_{SE}=916.7 nm



JEOL, normal incident, U_a=10kV, mag. 2500x

AFM

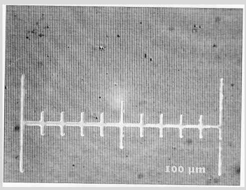
Λ_{AFM}=917.2 nm
h_{AFM}=170 nm



Solver NEXT (NT-MDT), tips-NSG10,10μx10μm scans

Optical microscopy

Λ_{OM}=918.6 nm



Leitz, Ergolutx, mag. 1000x

D. Results summary

Method	SEM	AFM	Optical microscopy	Spectroscopic ellipsometry
Grating period [nm]	916.7	917.2	918.6	917.0
Profile depth [nm]	x	170	x	205
Advanteges/ disadvanteges	Fast and flexible, high resolution/ limited access to surface profile, surface metallization is required	Real surface topography/ Small surface area scan, tip deconvolition artefacts	Fast and flexible inspection / low resolution, no access to depth profile	Sensitive on NiO overlayer and surface profile non-ideality, non-invasive/ difficult and time expensive calculations

E. References

[1] M. Veis and R. Antos, J. Nanomater **2013** (2013) 621531.
[2] D. C. O'Shea, T. J. Suleski, A. D. Kathman, D. W. Prather, *Diffractive optics : design, fabrication, and test,* SPIE—The International Society for Optical Engineering, Bellingham, Washington (2004).

F. Conclusions

Spectroscopic ellipsometry routinely used as a characterization technique of bulk, single layers and multitayers has been proven to be also highly efficient for non-invasive characterization of laterally periodically patterned nanostructures as for example sinusoidal gratings. In this special case SE is sensitive on grating geometrical parameters (period, depth and profile shape non-ideality), material optical properties and also on presence of a surface overlayer. We have presented potentiality of SE on case study of an oxidized sinusoidal Ni grating and compared results obtained by SE with those determined by standard characterization techniques as SEM, AFM, and optical microscopy.