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Optimizing precision of rotating compensator ellipsometry

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Many authors proposed algorithms and methods for the calibration of the elements and for the reduction of the errors in measurements in order to increase the performance of ellipsometers [1-3]. In particular, an optimized tracking method which reduces random errors has been applied on rotating polarizer ellipsometry [4]. The aim of this work is to propose a method especially adapted to the RCE ellipsometers when measurements with a high degree of accuracy are required.

In the PCSA configuration (Polarizer, Compensator, Sample, Analyzer), the ellipsometric parameters of the sample, $\tan\Psi$ and $\tan\Delta$ are deduced from the Fourier coefficients of the detected light. The computed expressions of the variances $\sigma_{\tan\Psi}^2$ and $\sigma_{\tan\Delta}^2$ can be determined as a function of Ψ , Δ , the optical elements (A, P) and the variance of the average of the signal ($\sigma_{\sigma_0}^2$). Thus optimum precision conditions can always be achieved for any sample by an adjustment of the azimuths of the elements. An algorithm based on a minimization technique has been developed.

Standard measurement
(A=45° and P=0°)

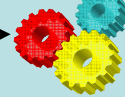
→ Ψ ; σ_Ψ
→ Δ ; σ_Δ

Is polarizer
Fixed ?

Yes

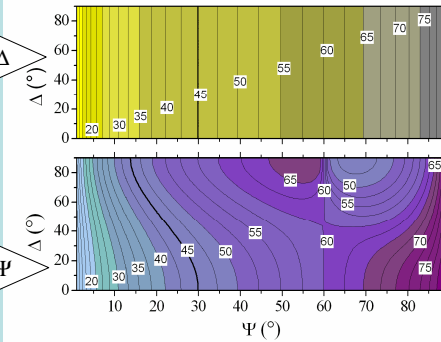
No

Tracking analyzer



Optimization for Tan Δ

New analyzer azimuth (ϑ^*)



* These graphs are valid for P=0°, for other values of the polarizer, new graphs are available.

measurement

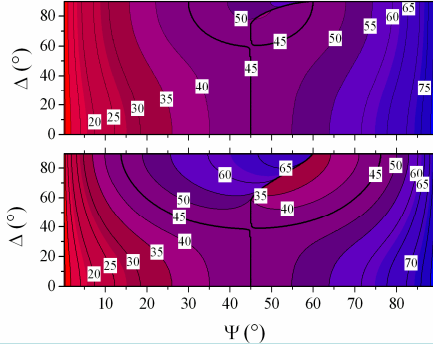
→ Δ ; σ_Δ
(σ_Δ)_{A;P=0°} < (σ_Δ)_{A=45°;P=0°}

measurement

→ Ψ ; σ_Ψ
(σ_Ψ)_{A;P=0°} < (σ_Ψ)_{A=45°;P=0°}

Tracking both analyzer and polarizer

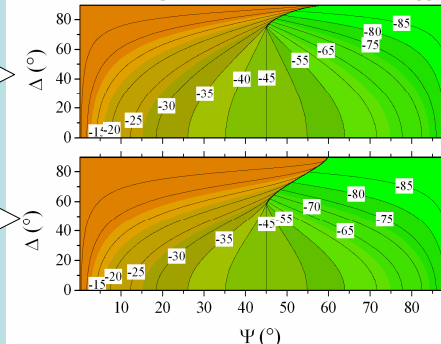
New analyzer azimuth (ϑ)



Optimization for Tan Δ

Optimization for Tan Ψ

New polarizer azimuth (ϑ)



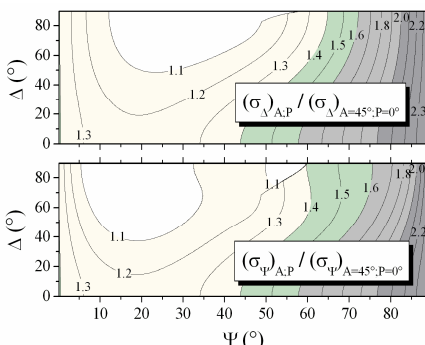
measurement

→ Δ ; σ_Δ
(σ_Δ)_{A;P} < (σ_Δ)_{A=45°;P=0°}

measurement

→ Ψ ; σ_Ψ
(σ_Ψ)_{A;P} < (σ_Ψ)_{A=45°;P=0°}

σ_Ψ and σ_Δ with tracking both analyzer and polarizer compared to σ_Ψ and σ_Δ obtained with A=45° and P=0°.



The positions of the optical elements determined by this method increase the signal-to-noise ratio. Consequently, the random errors decrease and the precision of the ellipsometric angles of the sample increase. The measurements validate and confirm the improvement of this method. The standard deviation of the Ψ and Δ angles measured by the tracking both analyzer and polarizer is always lower than the standard deviation obtained by the tracking analyzer alone. We note that better results are obtained with samples where Ψ is $\leq 10^\circ$ or $\geq 50^\circ$.

Measurements for a 125nm-SiO₂/Si sample
($\lambda=633\text{nm}$ and 70° of incidence)

| | Standard A=45°, P=0° | Tracking analyzer A=47.38°, P=0° A=62.14°, P=0° | | Tracking both analyzer and polarizer A=47.46°, P=-84.85° A=35.0°, P=-87.83° | |
|-----------------|-------------------------|---|--------|---|--|
| Ψ (°) | 63.982 | 63.967 | | 63.972 | |
| σ_Ψ | 0.012 | 0.011 | | 0.006 | |
| Δ (°) | 84.430 | | 84.448 | 84.435 | |
| σ_Δ | 0.033 | | 0.030 | 0.022 | |

References :

- [1] R. Klein, L. Kuntzler and A. El Ghemmaz, J. Opt. Soc. Am A 9, 11 (1994)
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- [3] R. W. Collins, in *Handbook of Ellipsometry*, edited by H. G. Tompkins and E. A. Irene William Andrew, New York/Springer-Verlag, Berlin, 2005, Chap. 7, pp. 481-556.
- [4] A. En Naciri, L. Broch, L. Johann and R. Klein, Thin Solid Films 406, 103-112 (2002)