



HAL
open science

Real-Time ellipsometric spectra without systematics errors

Laurent Broch, Nicolas Stein, Alexandre Zimmer, Yann Battie, Aotmane En Naciri

► **To cite this version:**

Laurent Broch, Nicolas Stein, Alexandre Zimmer, Yann Battie, Aotmane En Naciri. Real-Time ellipsometric spectra without systematics errors. ICSE-6, 2013, Kyoto, Japan. 2013. hal-02900842

HAL Id: hal-02900842

<https://hal.univ-lorraine.fr/hal-02900842>

Submitted on 16 Jul 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Real-Time ellipsometric spectra without systematics errors

L. BROCH¹, N. STEIN², A. ZIMMER³, Y. BATTIE¹, A. EN NACIRI¹

¹ Laboratoire de Chimie Physique-Approche Multi-échelle des milieux complexes (EA 4632), Université de Lorraine, 1 boulevard Dominique François Arago, CP 87811, F-57078 Metz cedex 3, France

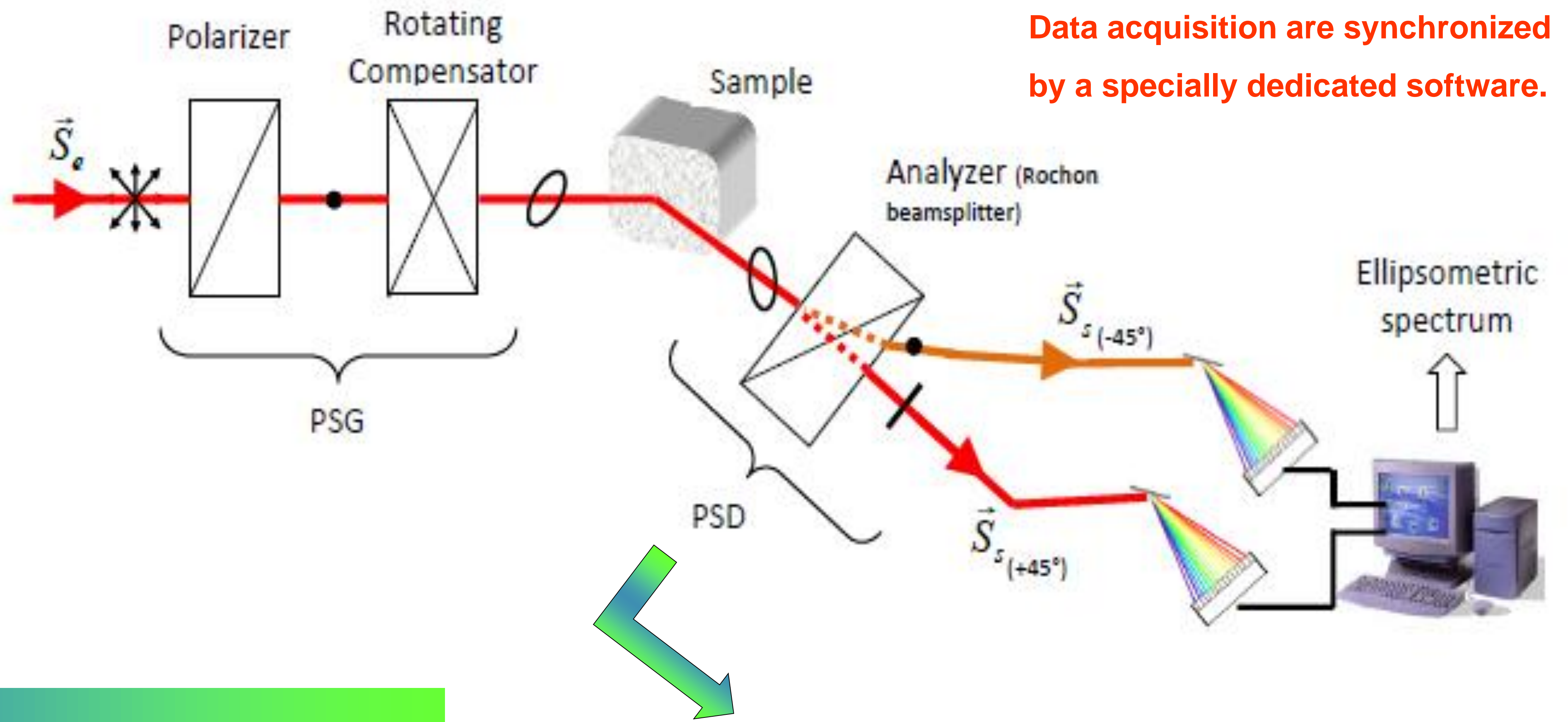
² Institut Jean Lamour, Université de Lorraine, CNRS 7198, 1 boulevard Dominique François Arago, CP 87811, F-57078 Metz cedex 3, France

³ Laboratoire Interdisciplinaire Carnot de Bourgogne, Université de Bourgogne, CNRS 6303, 9 avenue Alain Savary, BP 47870, F-21078 Dijon cedex, France

In real-time measurement, it is difficult to reduce systematic errors on spectra of ellipsometric angles Ψ and Δ by the mean of two measurements at two analyzer positions with the incidence plane $+45^\circ$ and -45° [1-2]. Generally, the analyzer is mounted on a motorized rotation stage. The rotation of the optical component from -45° to $+45^\circ$ requires few seconds, and this is incompatible with dynamic measurements.

Real-time Spectroscopic Rotating Compensator Ellipsometer (RTSRCE)

- Based on a rotating compensator technology [3] using two detectors in the visible domain (400-800nm).
- The analyzer is replaced by a fixed Rochon birefringent beamsplitter which splits the incidence light wave into two perpendicularly polarized waves, one oriented at $+45^\circ$ and the other one at -45° according to the plane of incidence.
- The two emergent optical signals are analyzed by two identical CCD detectors.
- The final spectrum is the result of the two averaged Ψ and Δ spectra acquired by both detectors.
- Ψ and Δ spectra are acquired without systematic errors on a spectral range fixed from 400 to 800nm. The acquisition time can be adjusted down to 25ms



The systematic errors

The detected light has the following form:

$$I = I_0 \left[a_0 + \sum_n (a_{2n} \cos 2nC + b_{2n} \sin 2nC) \right]$$

where $C = \omega t$ is the angle of the fast axis of the compensator at time t .

The ellipsometric parameters of the sample are deduced by:

$$\tan \Delta = \frac{\alpha_{2c} \sin 2P - \alpha_{2s} \cos 2P}{\alpha_{4c} \sin 2P - \alpha_{4s} \cos 2P} \left(\frac{1 - \cos \delta_c}{2 \sin \delta_c} \right)$$

$$\tan \Psi = \frac{K \cdot \text{sgn}A \cdot \sin 2A (1 \pm \sqrt{1 + 1/K^2})}{(1 + \cos 2A)}$$

where

$$\frac{1}{K} = \frac{\sqrt{(\alpha_{2c}^2 + \alpha_{2s}^2)(1 - \cos \delta_c)^2 / \sin^2 \delta_c + 4(\alpha_{4c} \cos 2P - \alpha_{4s} \sin 2P)^2}}{2(\alpha_{4c} \cos 2P + \alpha_{4s} \sin 2P)}$$

with $\text{sgn}A = 1$ for $A > 0$ and $\text{sgn}A = -1$ for $A < 0$.

All errors independent of their origins, propagate through the Fourier coefficients a_0, a_{2n} and b_{2n} . The systematic errors due to the positioning of the optical elements can be reduced by a suitable calibration procedure, but other errors due to the imperfection of the components affect the measurements. They are evaluated by calculating the Jacobian matrix relating $\delta \Delta$ and $\delta \Psi$ to the errors $\delta \alpha_0, \delta a_{2n}$ and δb_{2n} .

For example, the contribution to Δ resulting from $\delta \alpha_2$ is derived from equation of $\tan \Delta$ by first differentiation with respect to α_2 :

$$\delta \Delta_{\alpha_2} = \frac{1 - \cos \delta_c \cos^2 \Delta \sin 2P}{2 \sin \delta_c \alpha_4 \sin 2P - \beta_4 \cos 2P} \delta \alpha_2$$

Taking into account that α_2 and $\delta \alpha_2$ are proportional to a_2 and δa_2 [i.e. $\alpha_n = G a_n$ and $\beta_n = G b_n$, G may be considered as the overall gain and is assumed to be real and frequency independent] we obtain:

$$\delta \Delta_{a_2} = -\text{sgn}A \frac{\sin 2P \cos \Delta}{\sin \delta_c \sin 2P} \delta a_2$$

δa_2 is evaluated using a Taylor expansion of S . At the first order, the Stokes vector of the detected light is:

$$S_f = S_f^0 + \sum_k \frac{\partial S_f}{\partial \lambda_k} \delta \lambda_k = S_f^0 + \sum_k (\delta S_f)_k$$

where S_f^0 is the Stokes vector for the ellipsometer without any imperfect elements. For a given perturbation λ , the second element of the second term allows to obtain the corresponding Fourier coefficients $\delta a_0, \delta a_{2n}$ and δb_{2n} . The perturbation of the Stokes vector caused by an error is given by replacing the ideal matrix by the corresponding error matrix δM .

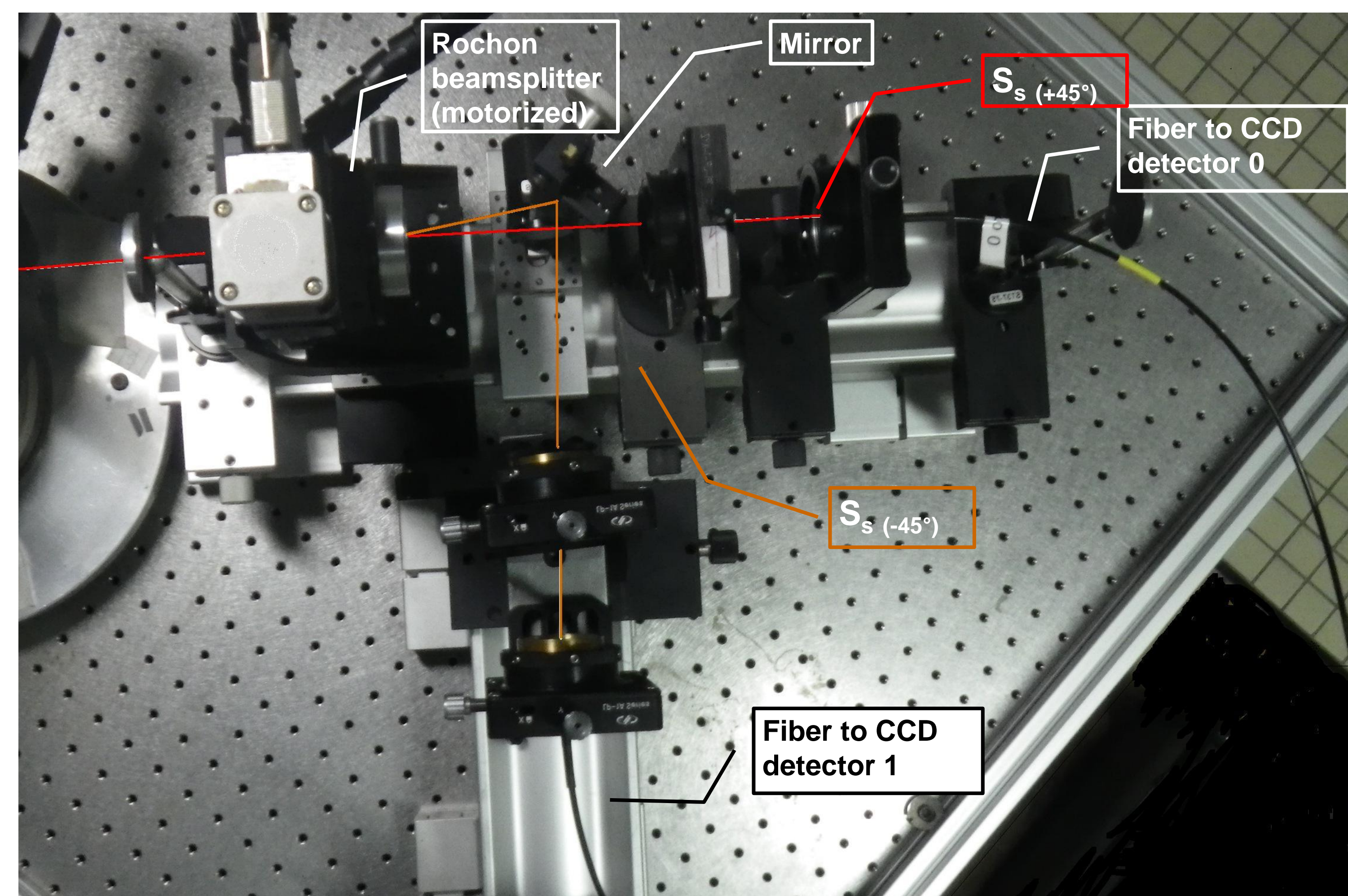
Azimuthal errors: $\delta A, \delta P, \delta C$
Element imperfections: $\gamma A, \gamma P, \gamma C$

Systematic errors in RCE without Rochon beamsplitter with $A = 45^\circ$ or $A = -45^\circ$.

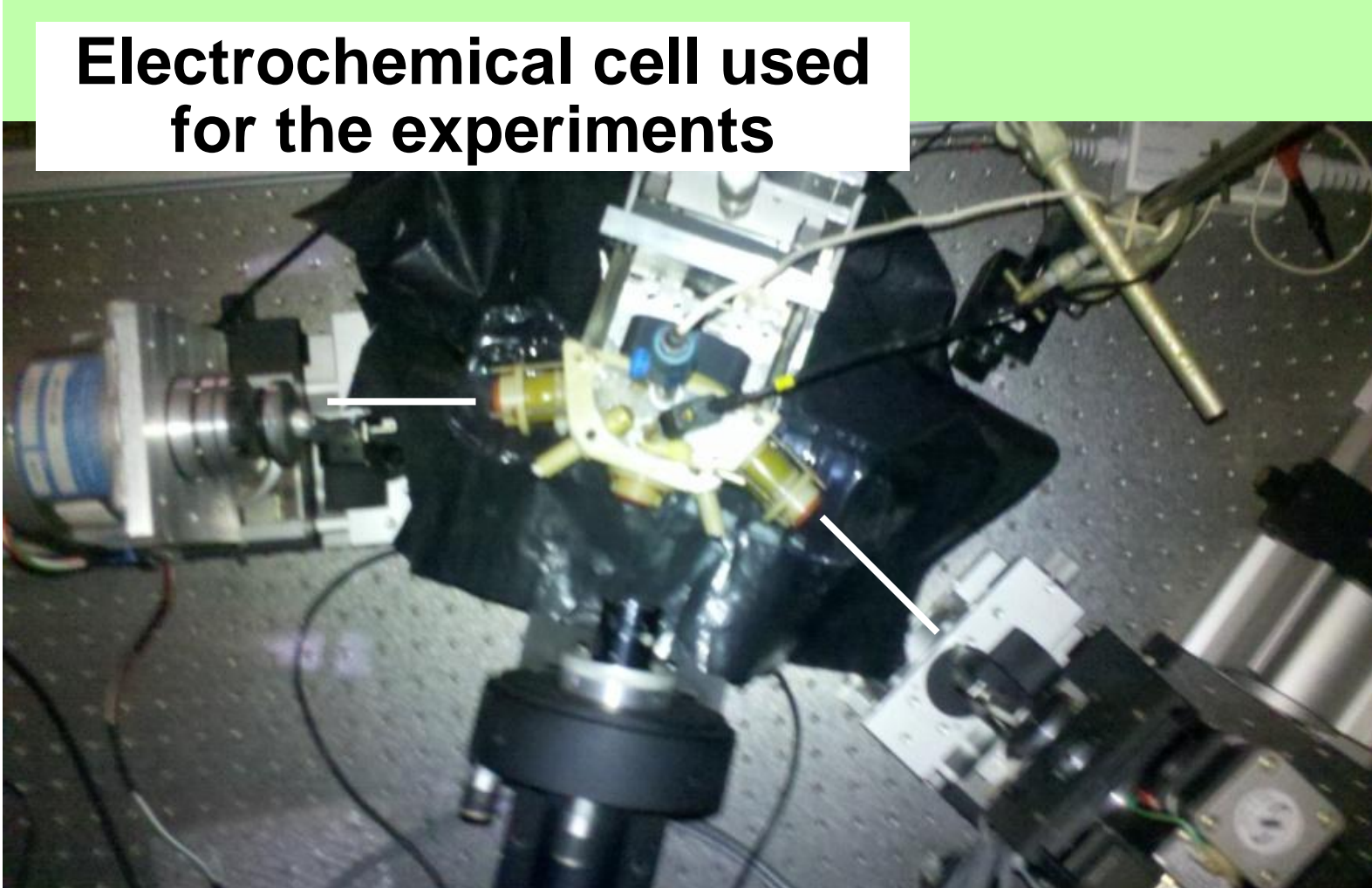
Origin	$\delta \Psi$	$\delta \Delta$	Origin	$\delta \Psi$	$\delta \Delta$
δA	$-\text{sgn}A \sin 2\Psi$	0	γA	0	$-\text{sgn}A \sin 2\Psi$
δP	$-\text{sgn}A \cos \Delta$	$2 \text{sgn}A \sin \Delta \cos 2\Psi$	γP	$\text{sgn}A \cos 2P \sin \Delta \cos^2 2\Psi - \sin 2P \cos \Delta \cos 2\Psi \sin 2\Psi$	$2(-\sin 2P \cos^2 \Delta + \text{sgn}A \cos 2P \cos \Delta \cot \Psi)$
δC	$2 \text{sgn}A \cos \Delta$	$-2 \text{sgn}A \sin \Delta \cot 2\Psi$	γC	0	0

Systematic errors in RCE with Rochon beamsplitter at $A = 45^\circ$.

Origin	$\delta \Psi$	$\delta \Delta$	Origin	$\delta \Psi$	$\delta \Delta$
δA	0	0	γA	0	0
δP	0	0	γP	$-\sin 2P \cos \Delta \cos 2\Psi \sin 2\Psi$	$-2 \sin 2P \cos^2 \Delta$
δC	0	0	γC	0	0



In situ ellipsometric monitoring of electrocrystallization of Bismuth telluride films

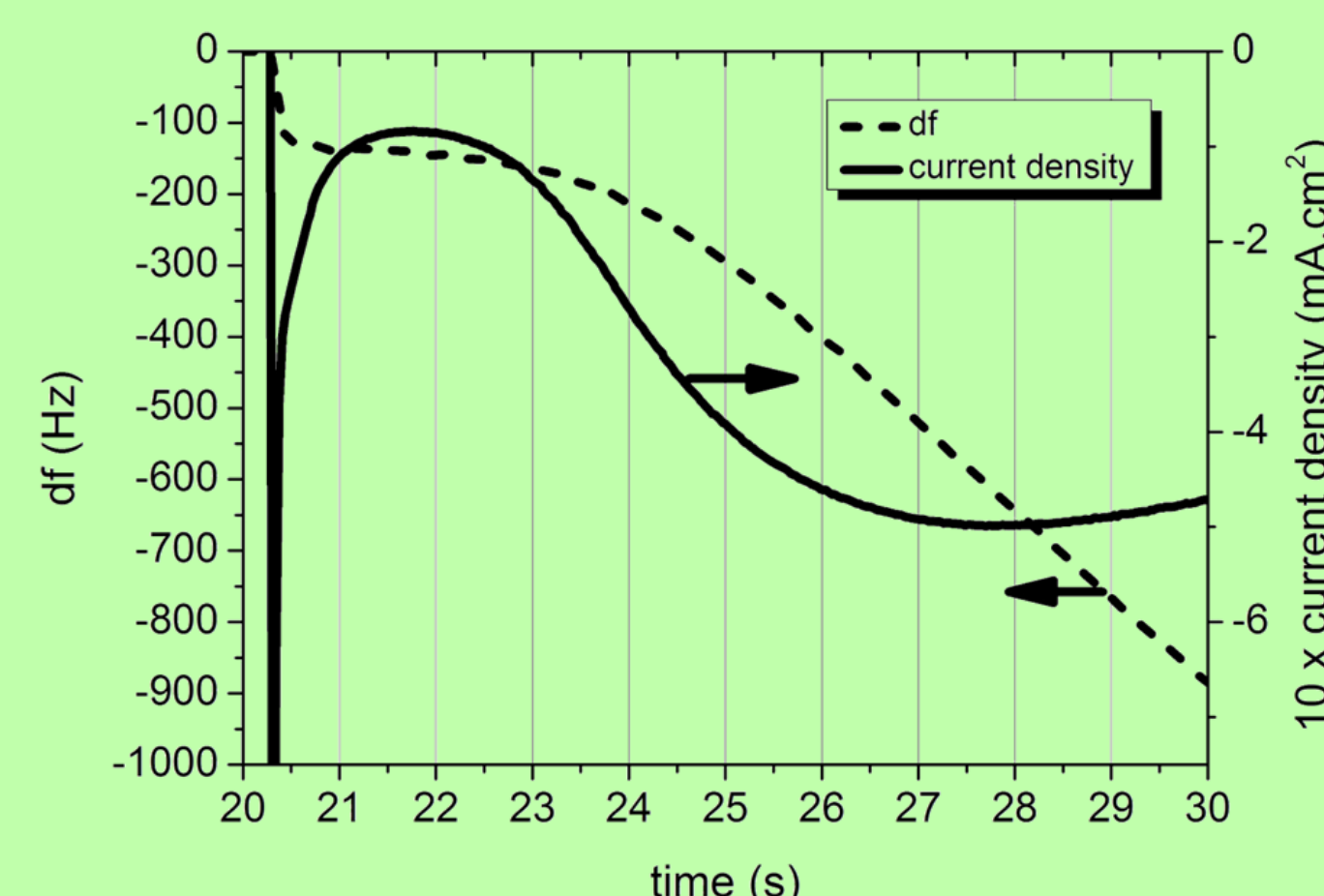
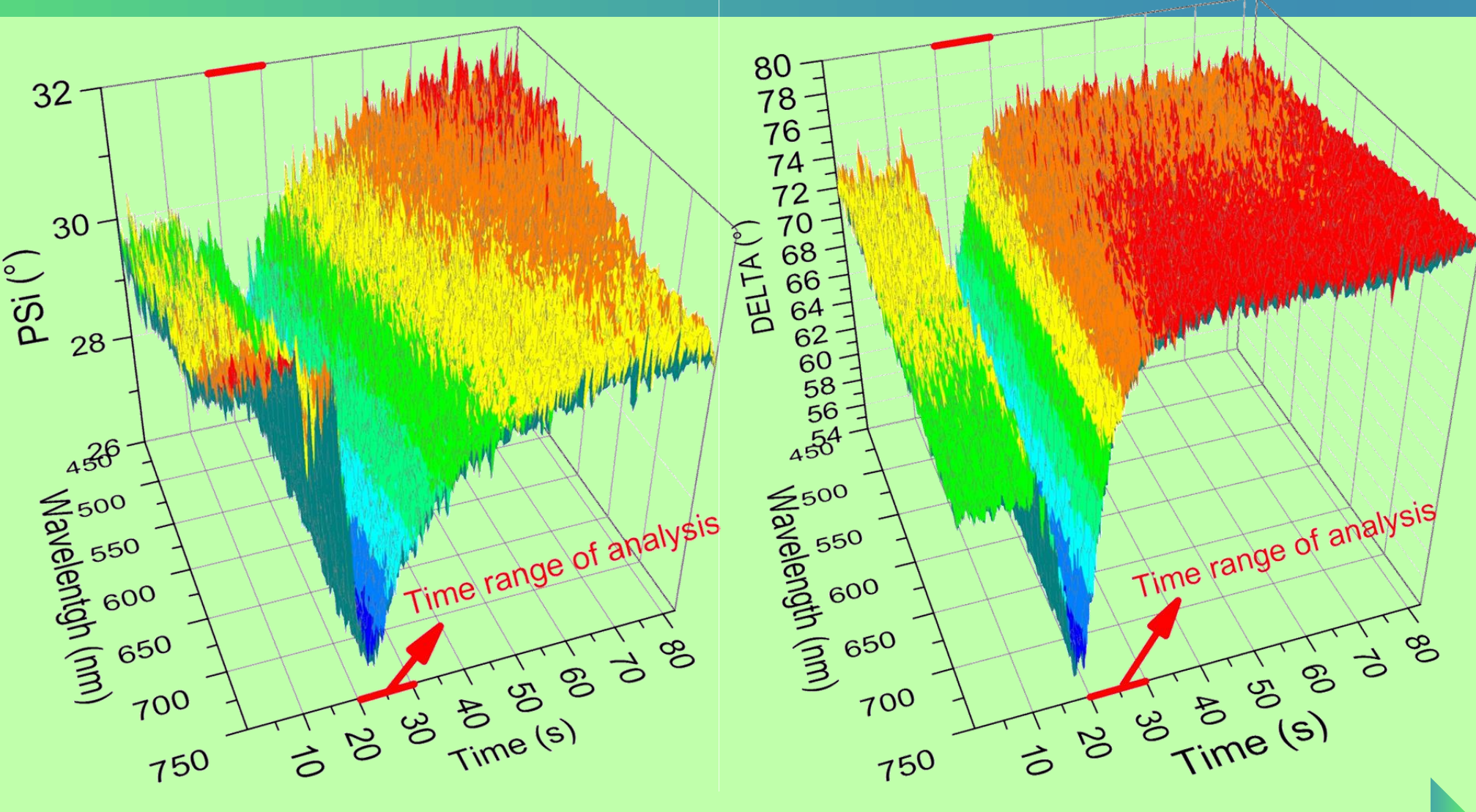


Simultaneous and synchronous records of :

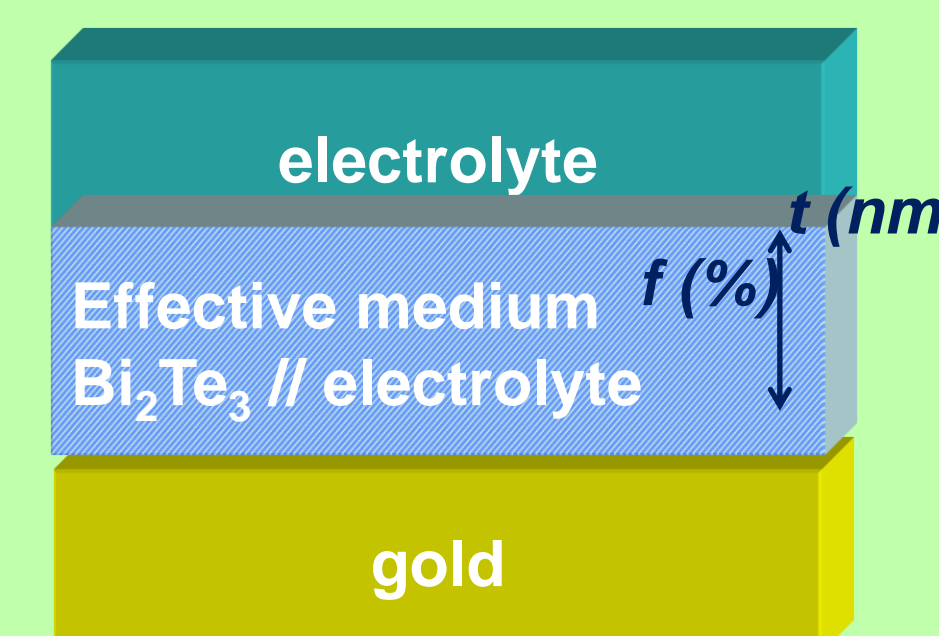
- Optical data: Ψ and Δ spectra
- Gravimetric data: Electrochemical Quartz Crystal Microbalance
- Coulometric data: Potentiostat

Acquisition times :

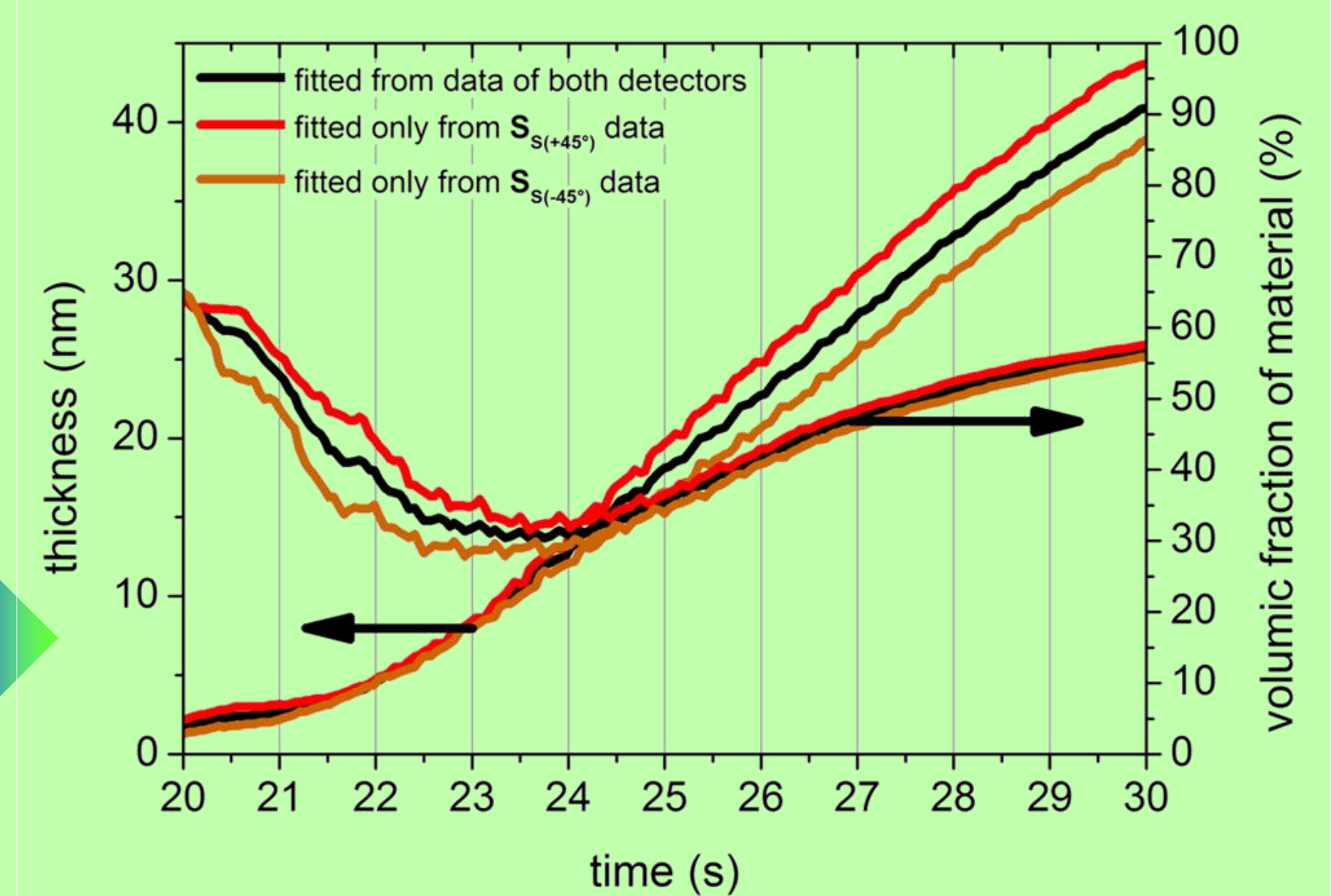
SE : 50 ms/EQCM : 160 ms/ potentiostat : 100 ms



Optical model



Fitted parameters
Material volumic fraction f (%)
thickness t (nm)



	Time	Thickness (nm)	Volumic fraction (%)
Fitted only from $S_{s(+45^\circ)}$ data		4.9	43.4
Fitted only from $S_{s(-45^\circ)}$ data	22s	4.8	33.5
Fitted from data of both detectors		4.7	38.6
Fitted only from $S_{s(+45^\circ)}$ data		35.8	52.5
Fitted only from $S_{s(-45^\circ)}$ data	28s	30.6	50.3
Fitted from data of both detectors		32.9	50.5

- References
- [1] R. Kleim, L. Kuntzler and A El Ghemaz, J. Opt. S. Am. A 11:2550-2558 (1994).
 - [2] J. Lee, P. Rovira, I. An and R. Collins, Review of Scientific Instrument 72:1742-1754 (1998).
 - [3] L. Broch, L. Johann, N. Stein, A. Zimmer and R. Beck, Review of Scientific Instrument 78:064101 (2007).

