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Explore the future

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Patrick CHAPON

Direct measurement of GDOES crater depth with built-in Differential Interferometer

May 2017

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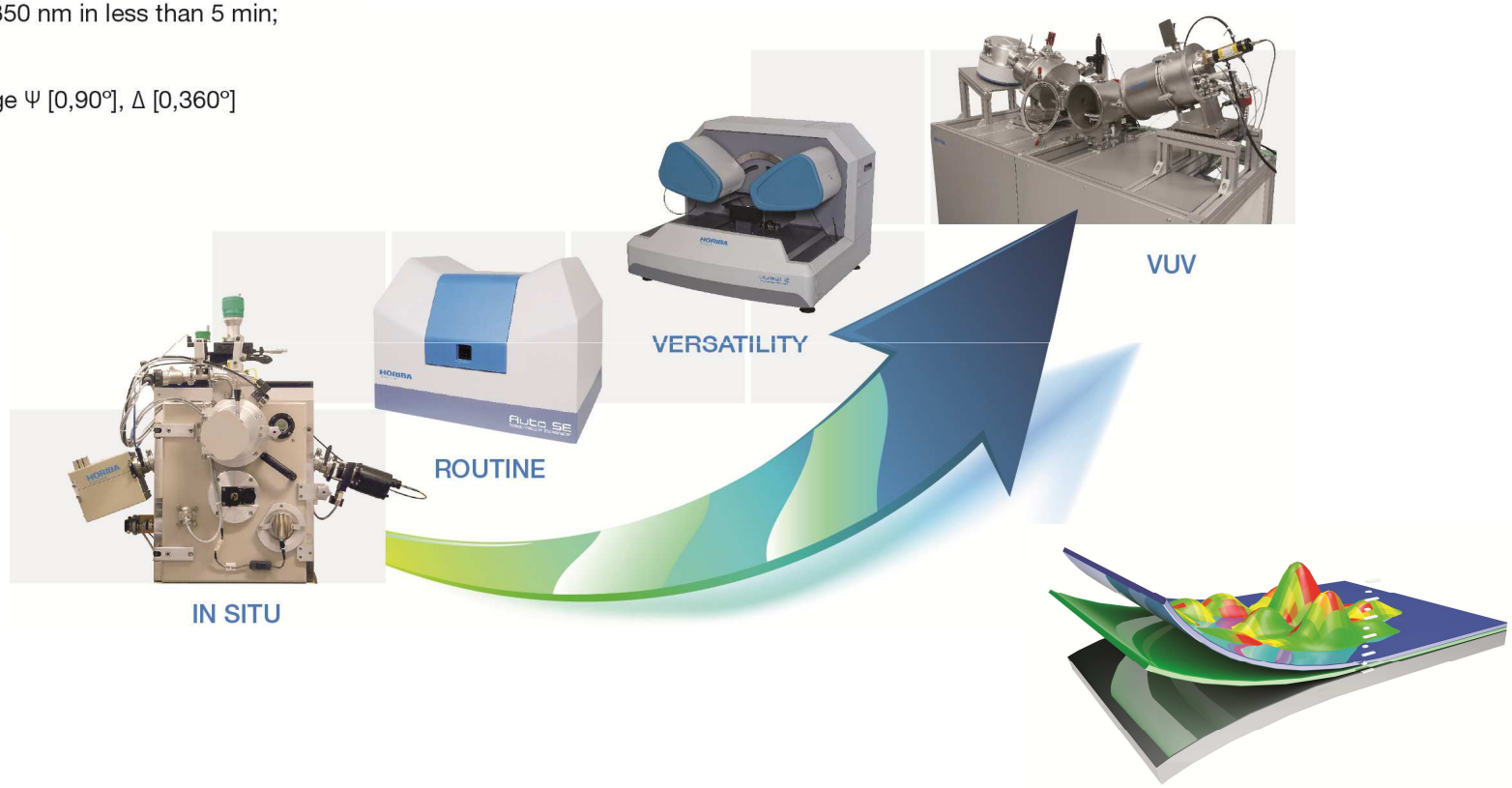
Come to visit !

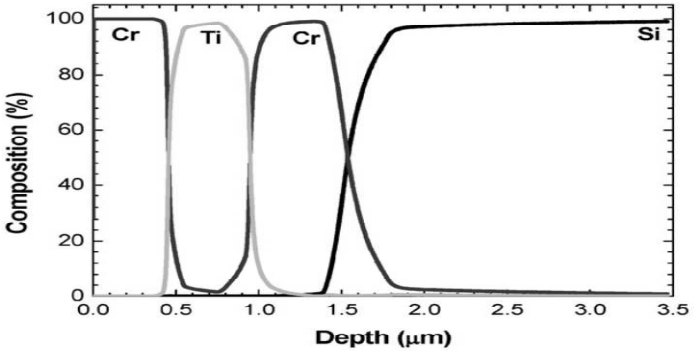
HORIBA Paris Saclay Site

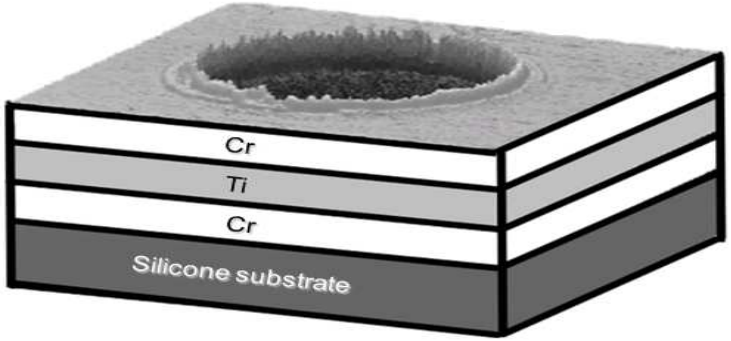
Thickness? Spectroscopic Ellipsometry

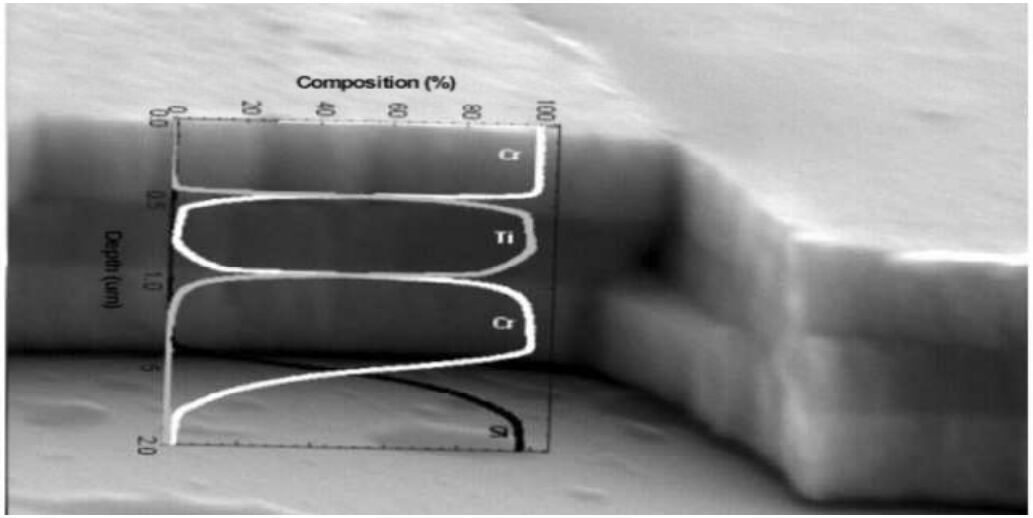
- From 145nm to 850 nm in less than 5 min; up to 2100 nm
- Measure full range Ψ [0,90°], Δ [0,360°]
- No moving parts



Output of a GD-OES analysis

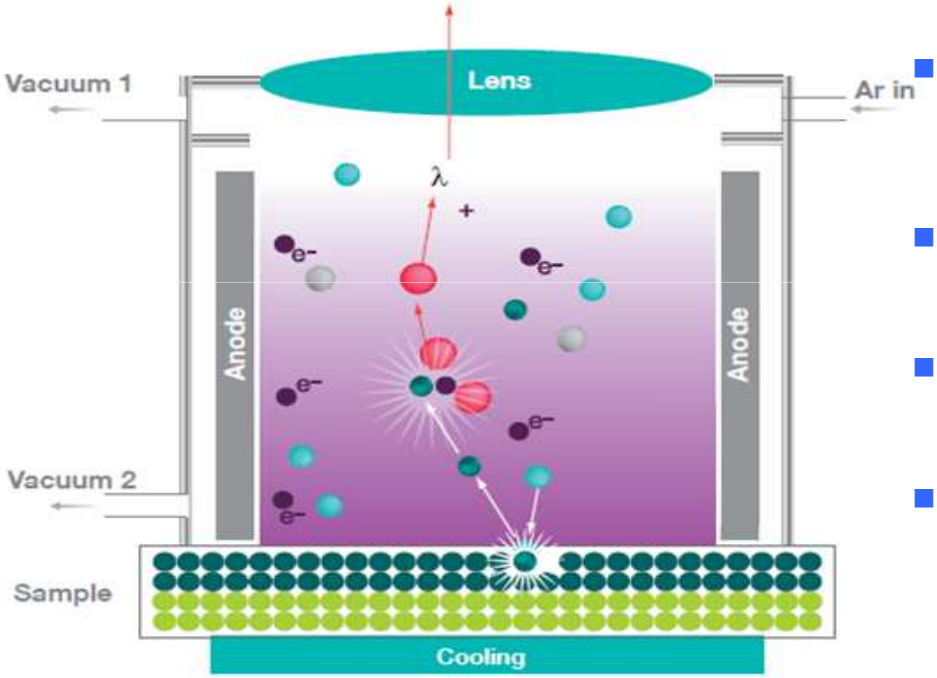






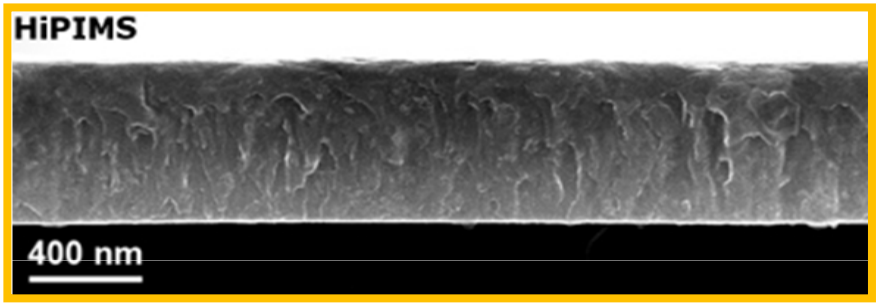
R. Escobar Galindo, E. Forniès and J. M. Albella (2005). *J. Anal. At. Spectrom.*, Vol 20, pp 1131-1138

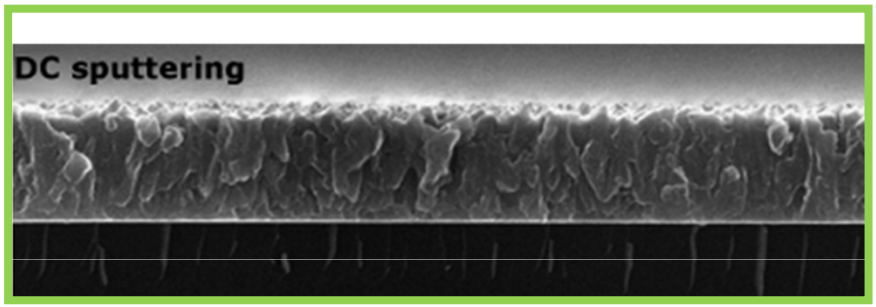
Principle of GD-OES



- In analytical GDs the sample is mounted outside the plasma chamber.
- The Ar plasma is confined inside a cylindrical anode and the sample is placed outside, acting as the cathode.
- Ar+ ions are accelerated towards the surface of the sample and they sputter it.
- The same plasma excites the sputtered species and light emission is observed.
- The real time measurement of the emitted light with an optical spectrometer therefore gives a depth resolved profile of the investigated material.

Until now depth = calculation





- Pure Ti layers deposited by two different sputtering techniques → different density – not easily taken in account by software.

The Analytical Scientist –May 2014

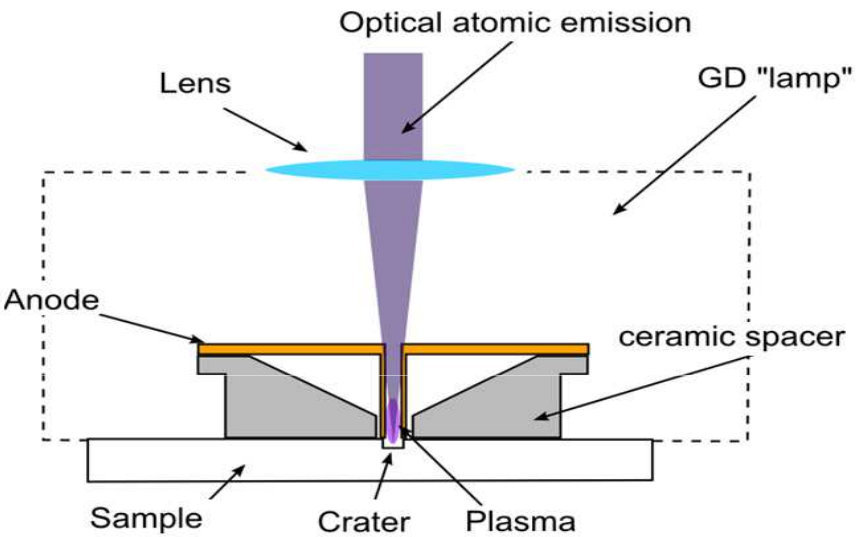
Gary Hieftje, Peter Griffiths, and Volker Deckert share their views on the past, present, and bright future of spectroscopy

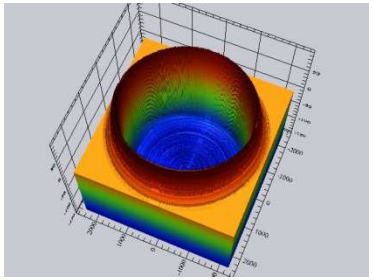
What are the opportunities and challenges?

GH: There are plenty of challenges (or opportunities, depending on your point of view):

- Low-noise, wide-bandwidth single-photon detectors
- Tunable lasers for the entire UV-Vis wavelength range
- Broad-scene imaging at nanometer spatial resolution
- Bright non-laser sources for IR
- Low noise, ultra-wide bandwidth analog amplifiers
- The need to develop a method for measuring sample erosion on the nanometer scale.

Constraints ☹ and Challenges ☺

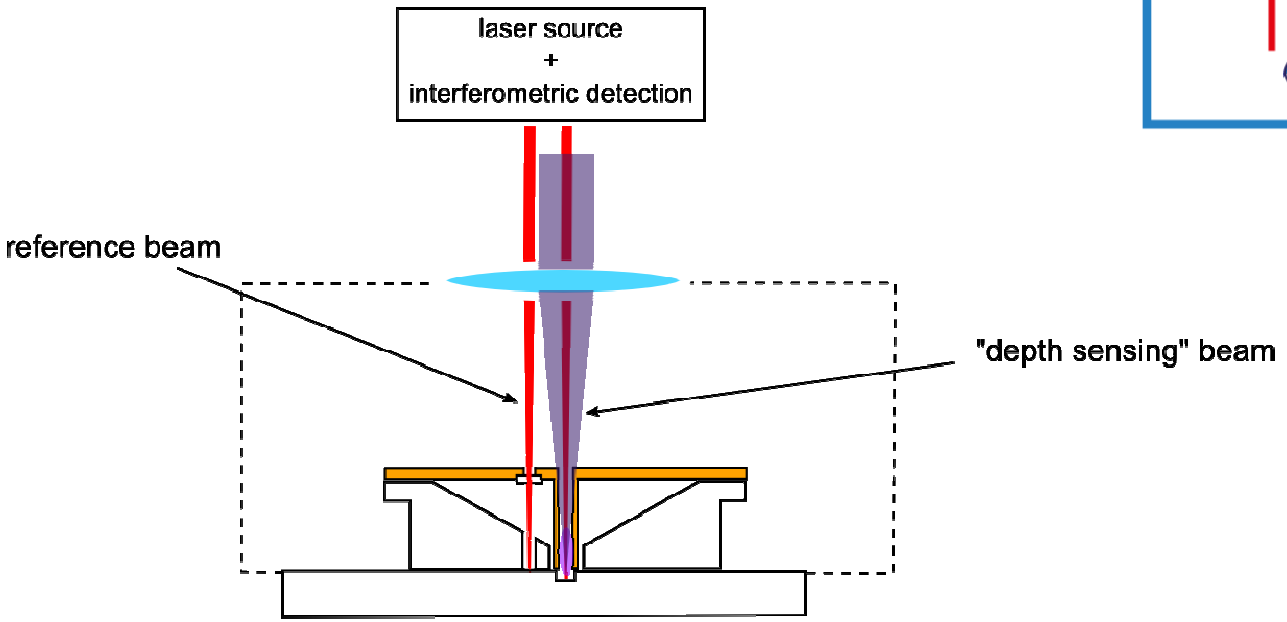




- ☹ Limited access to the crater: **necessity of a contactless measurement**.
- ☹ Necessity to **avoid any « light-loss »** during the spectroscopy analysis.
- ☺ Nanometric precision.
- ☺ Possibility to retrofit!

Technical solution: DIP

- Interferometric method.
- Relative measurement between the crater and the surface close to the crater.
- Red laser diode (~635 nm +/- 5 nm), no interesting spectroscopic line in this spectral region.



Outputs from the interferometer

$$\Delta\varphi^{depth} = \frac{4\pi}{\lambda} \times d$$

Only depth related

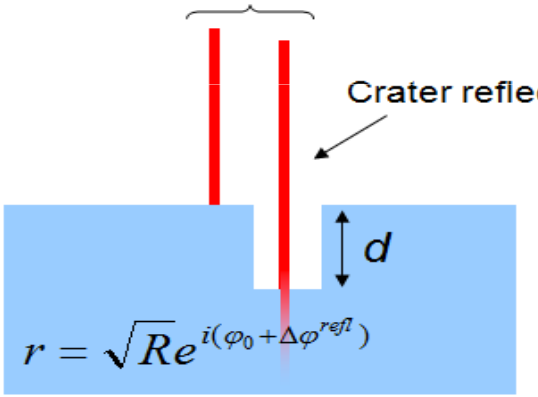
Relative dephasing

$$\Delta\varphi(t) = \Delta\varphi^{depth} + \Delta\varphi^{refl}$$

Crater reflectivity

$$R(t)/R(0)$$

Sample structure and depth related



Experimental setup

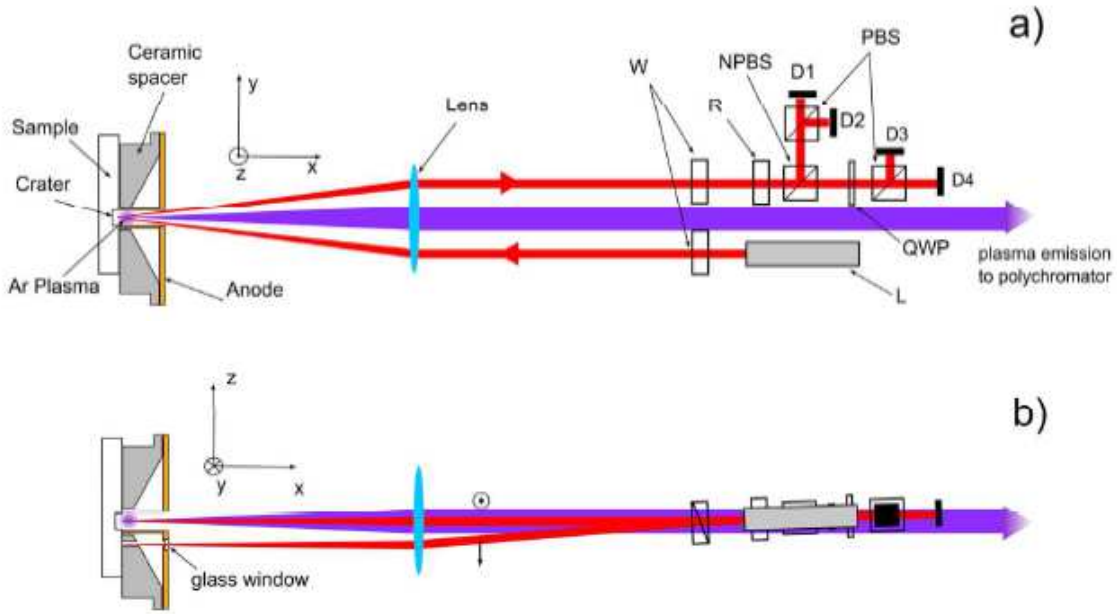


Figure 3. Schematic representation of the optical path for the DiP setup, viewed from the top (a), and the side (b). L: laser source, W: Wollaston polarization beam splitter, R: 45° polarization rotator, (N)PBS : (non) polarizing beamsplitters, QWP : quarter waveplate, D1 to D4 : Silicon photodiodes.

The detection scheme shown in Figure 3 is that of a homodyne polarization interferometer [12]. After the reflection onto the sample, the two laser beams are recombined. The different polarizations (linear and circular) are then separated and measured by using four photodiodes (D1 to D4, in Figure 3), giving signals S1 to S4 of the form

$$S_1 = A_1 + B_1 cos\Phi$$
$$S_2 = A_2 - B_2 cos\Phi$$
$$S_3 = A_3 + B_3 sin\Phi$$
$$S_4 = A_4 - B_4 sin\Phi$$

where the parameters A_i and B_i may be slowly varying functions of time.

For non transparent samples, the crater depth D is linked to the phase φ according to

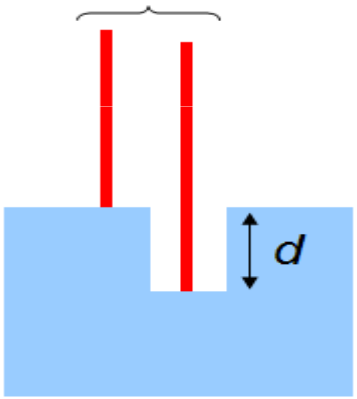
$$D = \frac{\lambda}{4\pi}\Phi \qquad \text{Eq.(1)}$$

Ref: article submitted in JAAS

Case 1: Bulk sample

- The simplest case: Only one reflecting surface

Relative dephasing $\Delta\varphi(t) = \Delta\varphi^{depth}$



$$\Delta\varphi^{depth} = \frac{4\pi}{\lambda} \times d$$

Only depth related

$$\Rightarrow d = \frac{\Delta\varphi}{4\pi} \times \lambda$$

$\Rightarrow$ conversion factor : 50.5 nm/rad

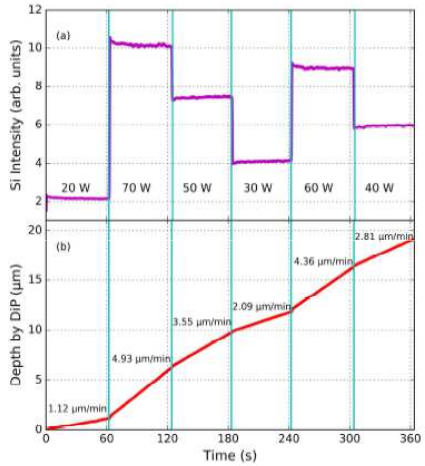


Figure 7. GD-OES analysis of a Si wafer. The Ar gas pressure was kept constant and the power was randomly varied from 20 W to 70 W. (a) Evolution of the Si signal as a function of the sputtering time. It shows the rapid response and the variation of the light intensity when the RF power is varied. (b) The evolution of the depth as a function of the sputtering time. For each variation of the applied power, a variation in the depth slope is observed. Erosion rates are reported in the figure.

Case 2: Multilayered sample

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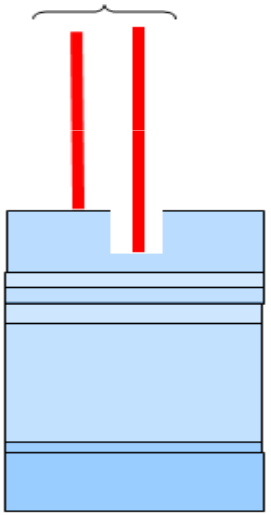
- Only one reflecting surface at a time

Relative dephasing

$$\Delta\varphi(t) = \Delta\varphi^{depth}$$



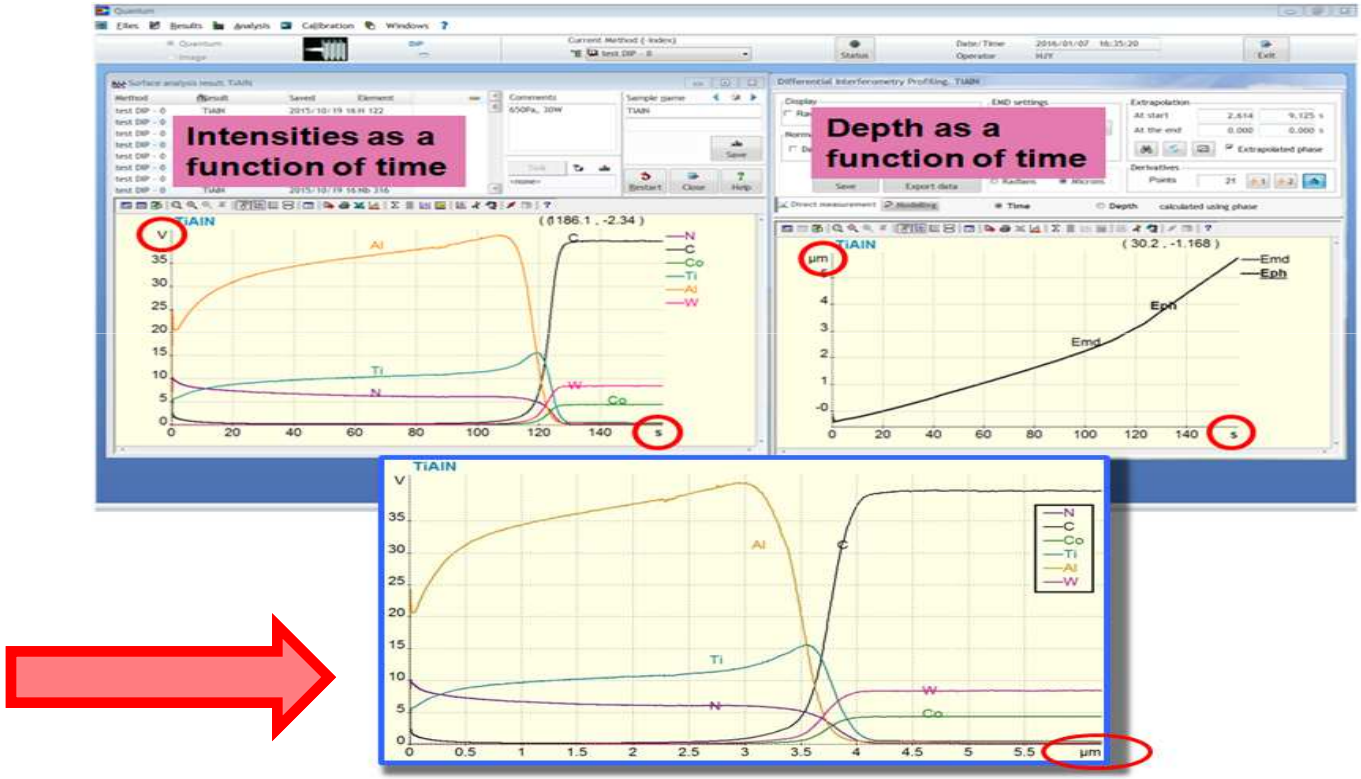
$$\Delta\varphi^{depth} = \frac{4\pi}{\lambda} \times d$$

Only depth related

$$\Rightarrow d = \frac{\Delta\varphi}{4\pi} \times \lambda$$

$\Rightarrow$ conversion factor : 50.5 nm/rad

Example : PVD coating



Accuracy

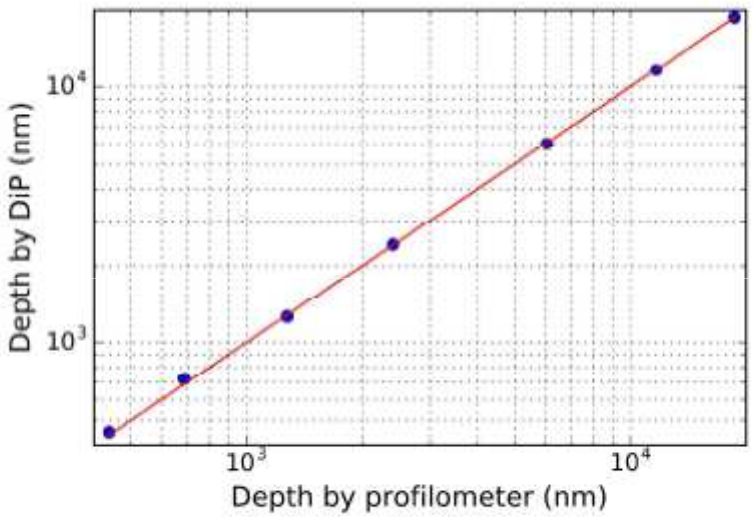


Figure 6. Depth measured by DiP as a function of the depth measured by the mechanical profilometer. Solid line is a linear fit of equation y=1.003x-2.2.

Comparison with Ellipsometry

- GD + DIP

- Sputtering
- Fast Elemental Depth Profile
- Depth by Interferometry
- One laser wavelength
- Needs reflective surface/interfaces

- Best nm !

- Ellipsometry

- Change of polarization state
- Very sensitive and ideal for complex materials (anisotropy, gradients etc) ; importance of modelling.
- Multi wavelengths
- Needs transparent/semi transparent layers
- Non destructive, possible in situ
- Best Å !

DIP Summary

- Optical technique coupled to standard GD
- Differential Interferometry

- Ideal for reflective samples

- A new tool for thickness determination

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Thank you very much for your attention