INTRODUCTION TO ELLIPSOMETRY

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PRESENTATION OVERVIEW

✓ **Theory**
  - What do we want to know ?
  - Why ellipsometry ?
  - Light and polarization
  - Ellipsometer configurations
  - Analysis of ellipsometric data

✓ **Company overview and products**
  - UVISEL ellipsometer systems

✓ **What can ellipsometry measure ?**
  - Ex situ applications

WHAT DO WE WANT TO KNOW ?

✓ Dimensional properties

- Accurate thin film measurement from a few angstroms to several microns
- For single layer or complex multilayer stacks (layer thickness, native thickness, roughness, interface)

✓ Optical properties

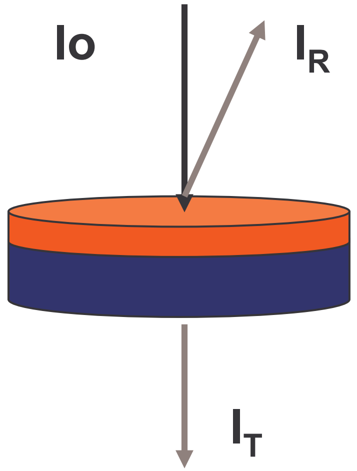
- Refractive index (n) and extinction coefficient (k) from the far-UV to near-IR for complex materials, graded and anisotropic layers

✓ Material properties

- Composition / crystallinity
- Microstructure
- Film uniformity by area and depth

WHY ELLIPSOMETRY ?
Specular techniques

✓ Transmission and reflection intensity measurements

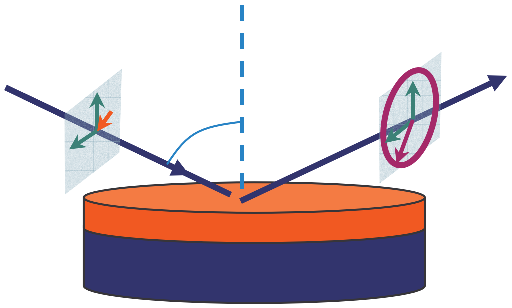


Transmission = I_T / Io

Reflection = I_R / Io

Fluctuations in lamp intensity or not collecting all of the beam can introduce error in the measurement

✓ Ellipsometry



$$\rho = \frac{r_p}{r_s} = \tan\psi e^{j\Delta}$$

Measurement :

Change in amplitude and phase shift of the Electromagnetic field

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ELECTROMAGNETIC PLANE WAVE

✓ The Maxwell equation solution is the plane wave described by :

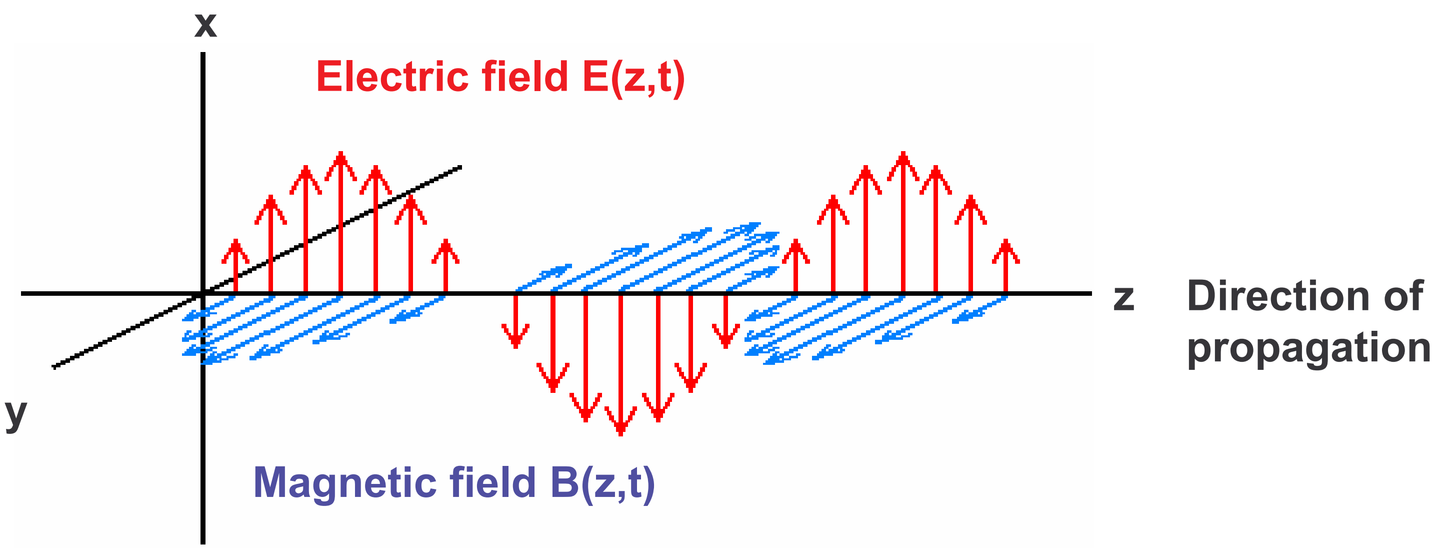
$$E = Re\left[E_0 \exp i(wt - k.r + \phi)\right]$$

amplitude

frequency $2\pi f = \frac{2\pi\lambda}{c}$

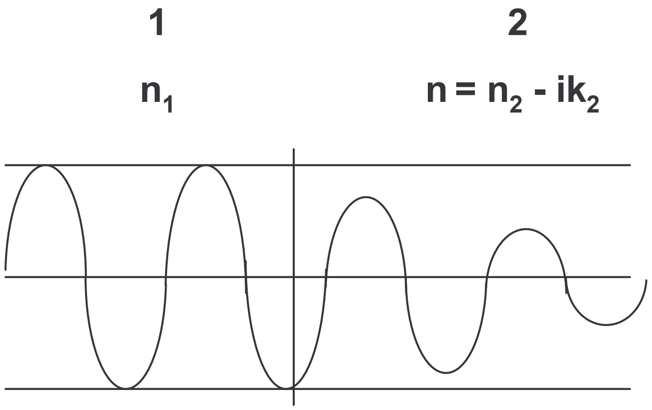
phase

propagation vector $\frac{2\pi}{\lambda} z$



ELECTROMAGNETIC PLANE WAVE

- ✓ $$\vec{E}(\vec{r},t) = \vec{E}_0 \exp\left(\frac{i2\pi\tilde{n}}{\lambda}\vec{q}.\vec{r}\right)\exp(-i\omega t)$$
  $$= \underbrace{\vec{E}_0 \exp\left(\frac{-2\pi kz}{\lambda}\right)}_{\textbf{Absorption part}} \underbrace{\exp i\left(\omega t - \frac{2\pi nz}{\lambda}\right)}_{\textbf{Propagation part}}$$

- ✓ 

The attenuation of the wave is described by Beer's law :

$$\mathbf{I = Io\ exp(-\alpha z)}$$

with : $\alpha = \dfrac{4\pi k}{\lambda}$ **= Absorption coefficient**

- ✓ Penetration depth : $D_p = \dfrac{\lambda}{2\pi k}$

LIGHT IN MATERIAL MEDIUM

✓ Light speed in material < Light speed in vacuum

- Refraction is the bending of light as it travels through the boundary of two mediums

- Refraction index is given by : $N = c/v$

- Refraction index = ratio between the light speed in vacuum and the light speed in matter

✓ Light beam intensity decreases as it gets into the material

- The extinction coefficient (k) represents the absorption of light in material

✓ Optical constants are commonly expressed as :

$$\left.\begin{array}{l}\text{- the complex index of refraction : } N = n + ik \\ \text{- the complex dielectric constant : } \varepsilon = \varepsilon_1 + i\varepsilon_2\end{array}\right\} \quad \varepsilon = N^2$$

MATERIAL PROPERTIES

✓ Matter properties is linked to :

- material chemical state (chemical composition, atoms, bonds)

- material state (liquid, solid, gas)

- organization (amorphous, crystalline, poly-crystalline material)

✓ Two property types :

- intrinsic properties : depend on material state (composition, organization)

- extrinsic properties : linked to how the material is build up (default, grain boundaries)

    - elastic, metallic, magnetic, optical, electric

MATERIAL PROPERTIES

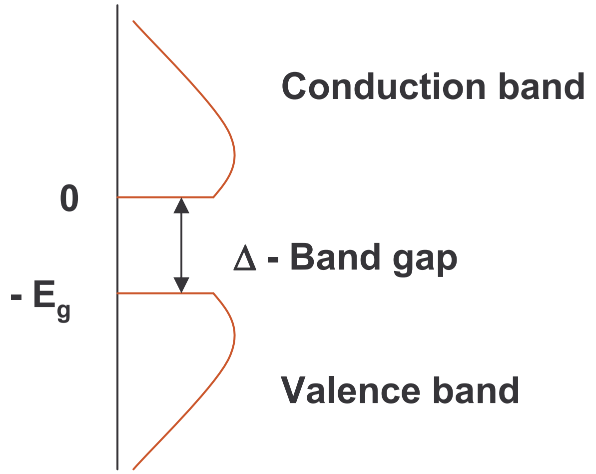
✓ Material classification

- Band structure

→ dielectrics

→ semi-conductor

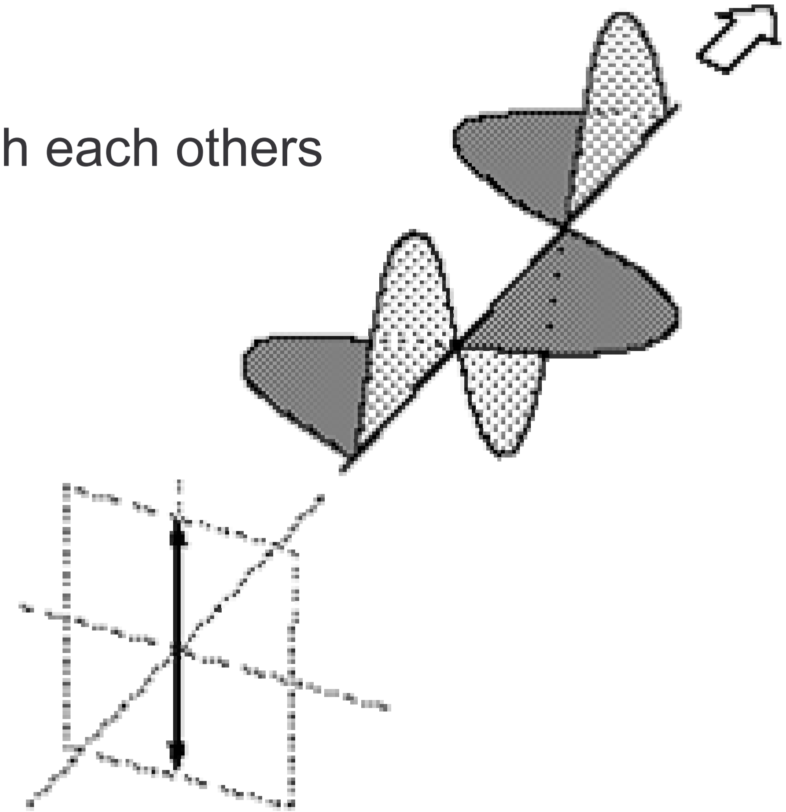
→ metals



classes	resistivity	carrier	Conc/cm^3	Effect on resistivity
metal	$10^{-6}\ \Omega$ cm	free e^-	10^{22} to 10^{23}	none
SC	$10^{-3}\ \Omega$ cm to $10^{+4}\ \Omega$ cm	N type → e^- P type → hole	10^{13} to 10^{19}	Strong (doping)
dielectric	$10^{+8}\ \Omega$ cm	/	/	none

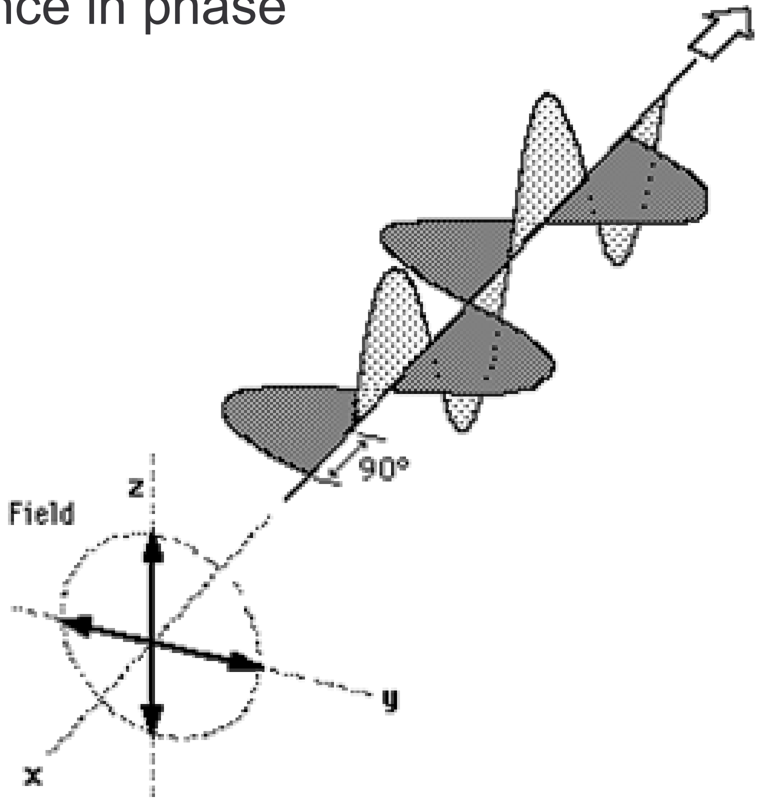
LINEARLY POLARIZED LIGHT

- The transverse electric field and the magnetic field are propagating in same direction
  - fields are orthogonal
  - waves are in phase with each others



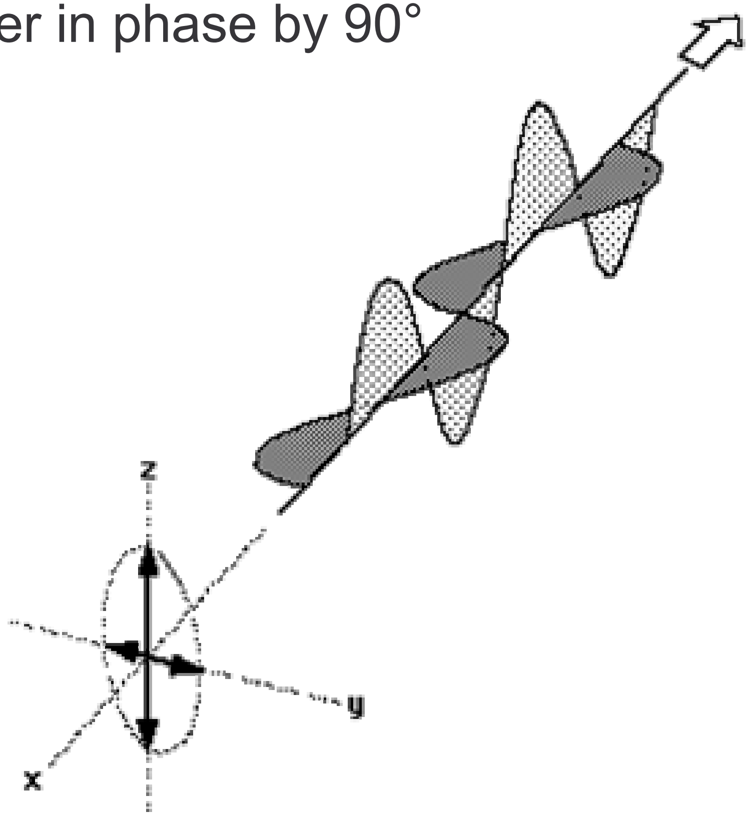
CIRCULARLY POLARIZED LIGHT

- Two perpendicular electromagnetic plane waves of :
  - equal amplitude
  - 90° difference in phase



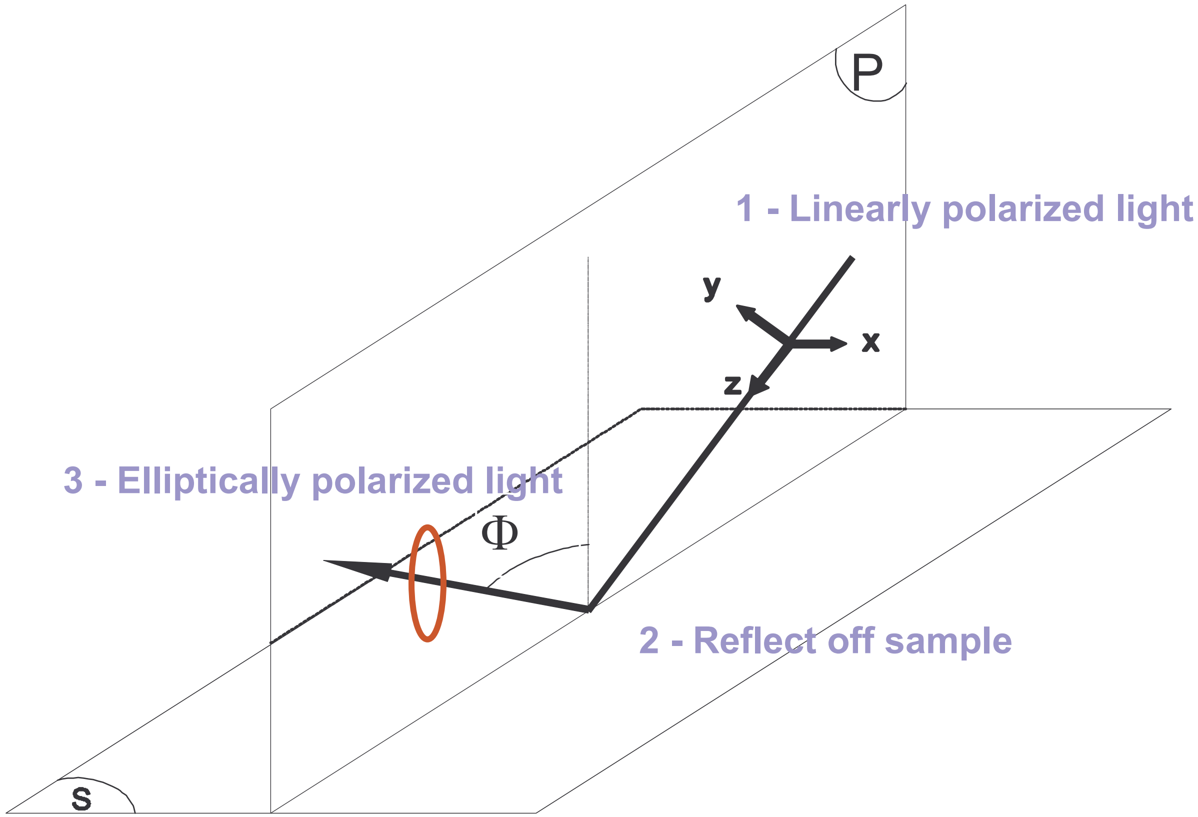
ELLIPTICALLY POLARIZED LIGHT

- Two perpendicular electromagnetic plane waves of :
  - unequal amplitude
  - which differ in phase by 90°



ELLIPSOMETRY OVERVIEW

✓ ***Measurement of the changes in the polarization light by reflection from a surface***



Fresnel coefficients :

$$r_{01}^{p} = \frac{n_1\cos\Phi_0 - n_0\cos\Phi_1}{n_1\cos\Phi_0 + n_0\cos\Phi_1} = |r_p|e^{j\delta_p}$$

$$r_{01}^{s} = \frac{n_0\cos\Phi_0 - n_1\cos\Phi_1}{n_0\cos\Phi_0 + n_1\cos\Phi_1} = |r_s|e^{j\delta_s}$$

BASIC ELLIPSOMETRY EQUATION

$$\rho = \frac{r_p}{r_s} = \tan\psi e^{j\Delta}$$

- Ψ and Δ	Ellipsometric angles - measured data
- $\tan\psi = \frac{\lvert r_p \rvert}{\lvert r_s \rvert}$	Ratio amplitude
- $\Delta = \delta_p - \delta_s$	Phase difference introduced by reflection from sample

- Angle definition range

$$\psi \in [0,90] \quad \text{and} \quad \Delta \in [0,360]$$

ELLIPSOMETRY ADVANTAGES

✓ **Measures ratio of two values**

- highly accurate & reproducible
- no reference necessary

✓ **Measures a « phase » Δ**

- very sensitive, especially to ultrathin films (< 10 nm)

✓ **Spectroscopic Ellipsometry (SE)**

- increased sensitivity to multiple film parameters
- eliminates period problem for thick films
- measures data at wavelength of interest

⇒ **A NON DESTRUCTIVE TECHNIQUE**

Optical elements used in ellipsometry :
LIGHT SOURCE

✓ **Ideal case**

- very stable
- covers a wide spectral range from the FUV (190 nm) to the NIR (2.1 µm)

→ Xe arc lamp

✓ **Drawbacks**

- low intensity in the FUV (below ≈ 220 nm)
- strong atomic emission lines from ≈ 800 - ≈ 1000 nm

Optical elements used in ellipsometry :
OPTICAL FIBERS

✓ **To couple the light beam from the output of the light source to the input polarizer & from the output of the analyzer to the input monochromator**

✓ **Core diameter :** 1 mm

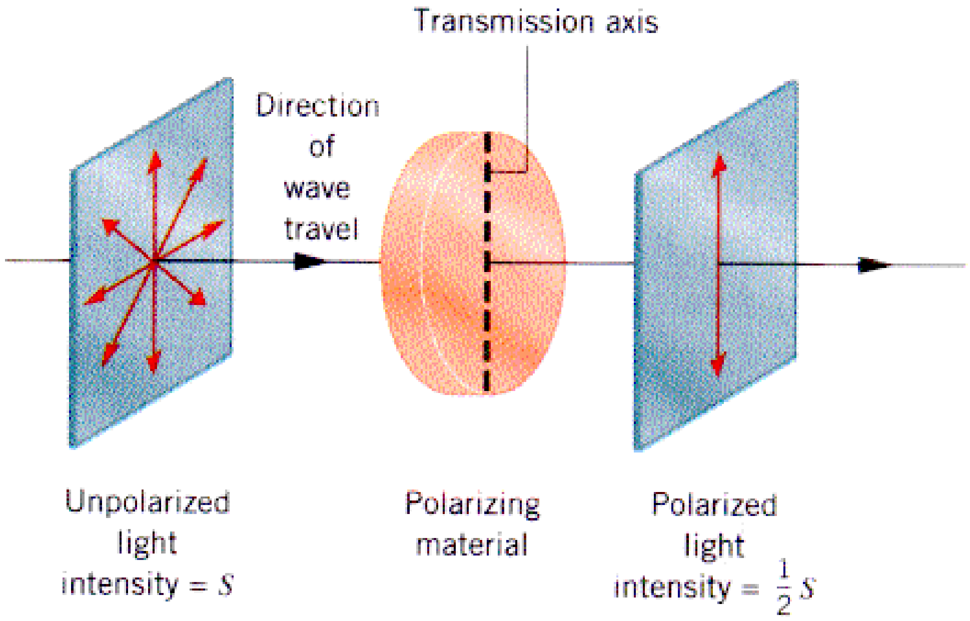
✓ **2 types :**

- UV fiber : 190 - 880 nm
- NIR fiber : 260 - 2 µm

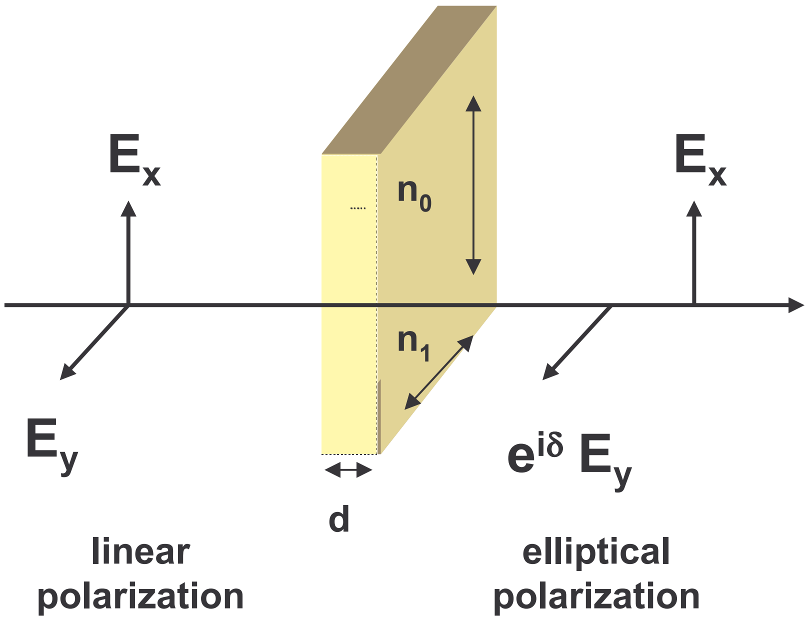
Optical elements used in ellipsometry :
POLARIZERS

✓ **Pass linearly polarized light**

- Optical axis determines direction of polarization allowed to pass
- Extinction ratio measures ratio of light that passes parallel and perpendicular to polarizer : typically = 10^{-5}



Optical elements used in ellipsometry :
THE PHOTOELASTIC MODULATOR (PEM)



- **PEM definition**

→ fused silica bar sandwiched between piezo oscillating at the frequency w=***50 kHz***

- **Stress effect**

→ creation of an optical anisotropy in the silica bar

- **Strain modulation**

→ optical anisotropy modulated

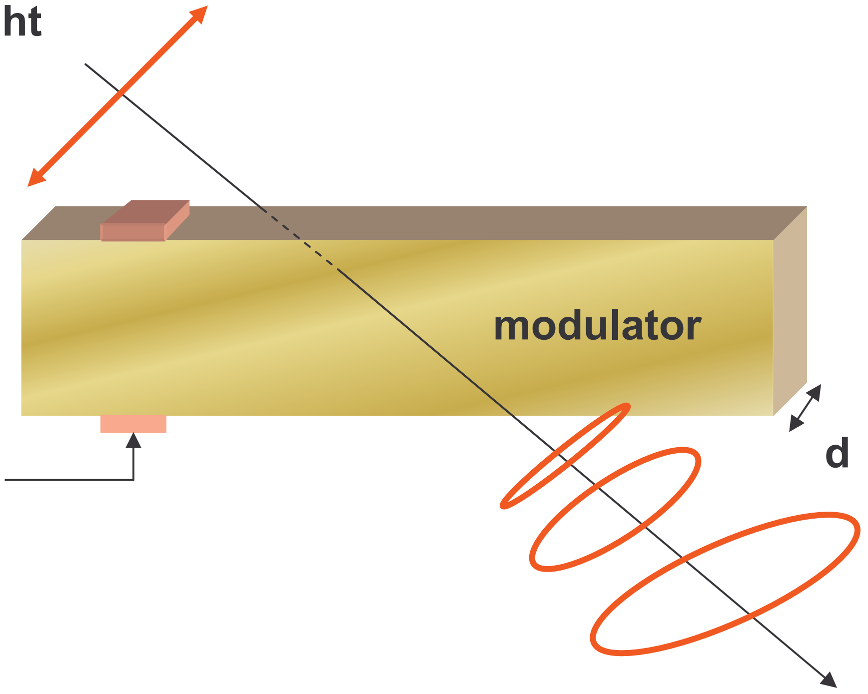
→ polarization modulated

- **Modulated phase shift $\delta(t)$**

$$\delta(t) = A \sin wt$$

with : $A = 2\Pi \, d \, (N1-N0)/\lambda$

Optical elements used in ellipsometry :
THE PHOTOELASTIC MODULATOR (PEM)



Linearly polarized light

modulator

d

Piezo electric transducer

(50 kHz)

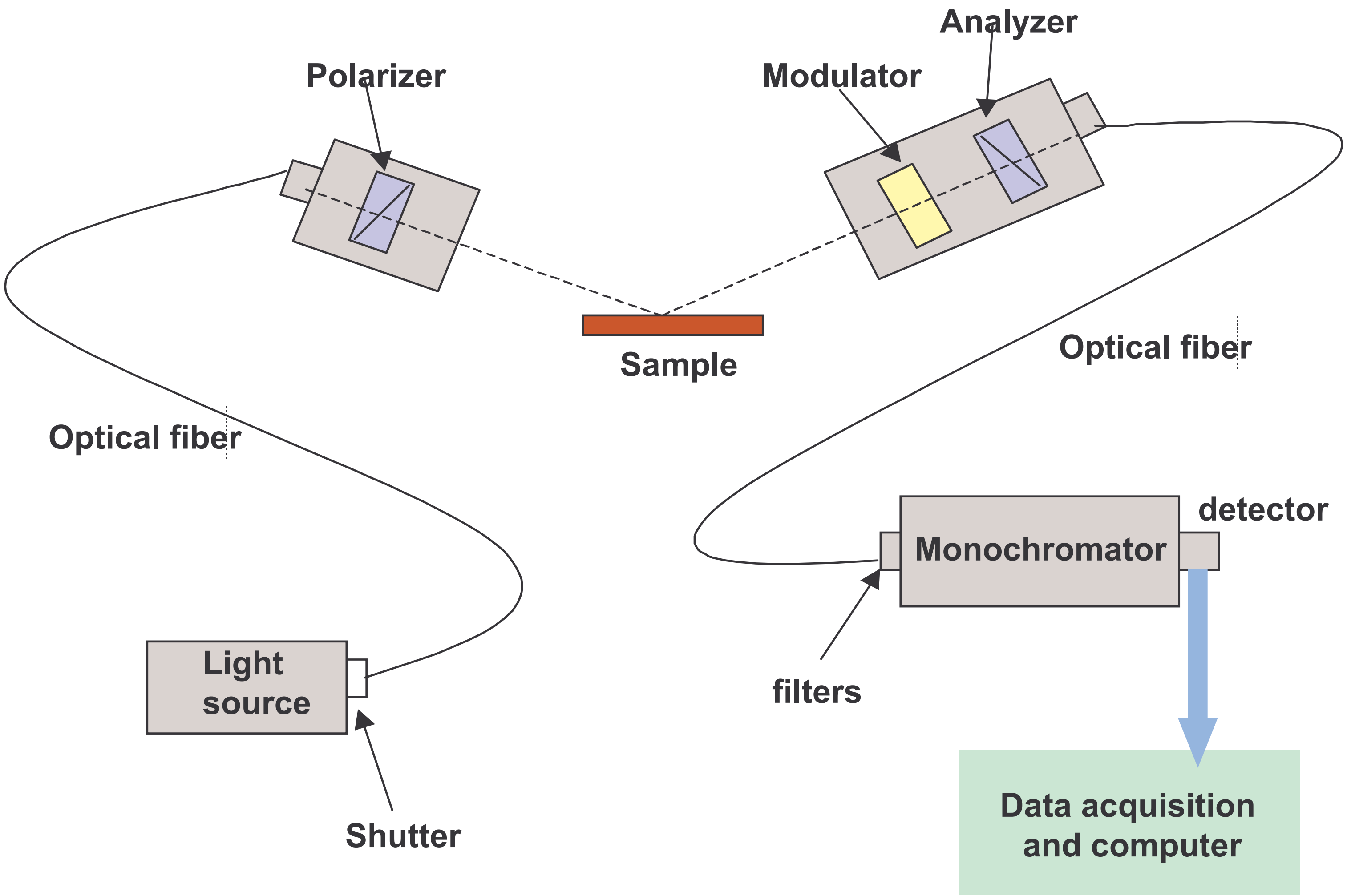
Elliptically modulated polarized light

Optical elements used in ellipsometry :
DETECTORS

✓ **3 types :**

- Photomultiplier tube (PMT) adapted within UV-Visible range
- InGaAs photodiode above 850 nm
- Multiwavelength system

OPTICAL SET-UP OF THE SPME



Polarizer

Modulator

Analyzer

Sample

Optical fiber

Optical fiber

Light source

Shutter

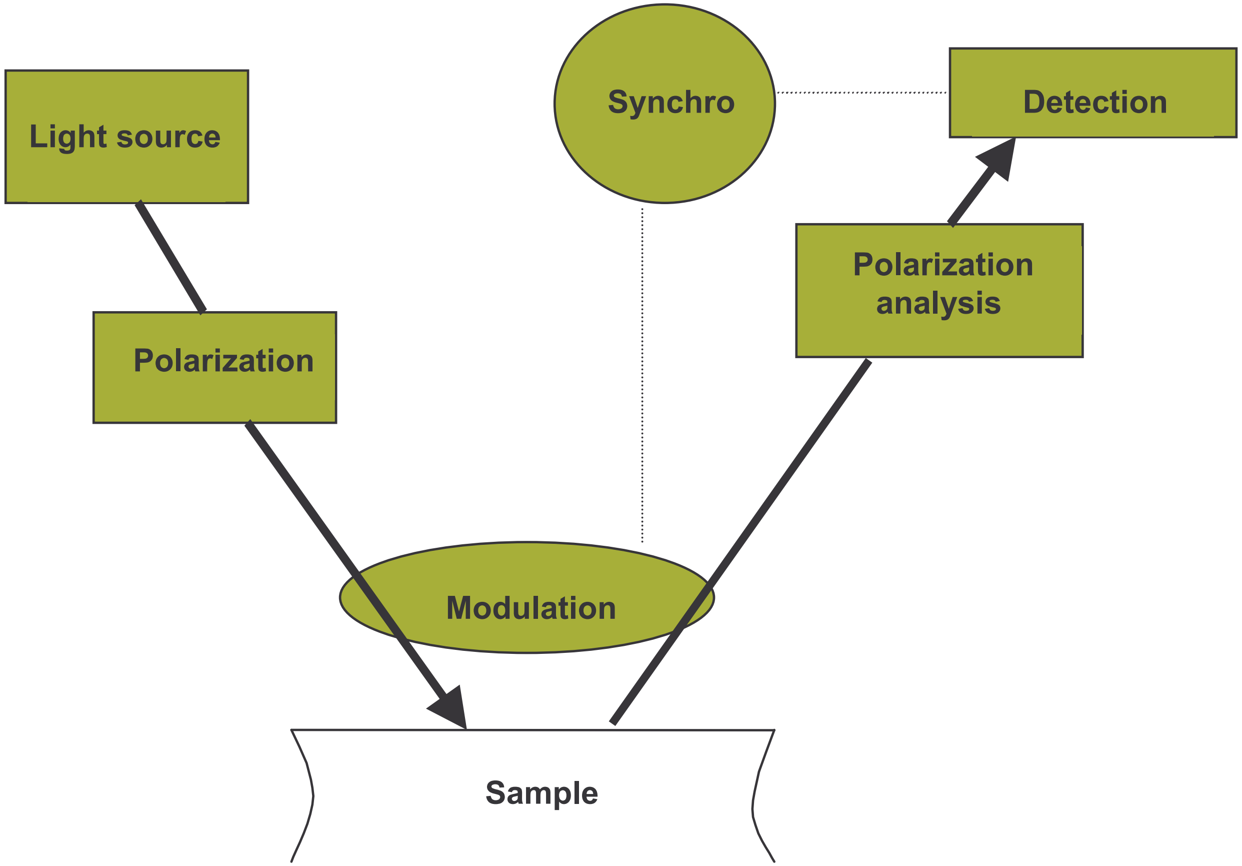
Monochromator

detector

filters

Data acquisition and computer

SCHEMATIC SE WORKING PRINCIPLE



Light source

Polarization

Synchro

Detection

Polarization analysis

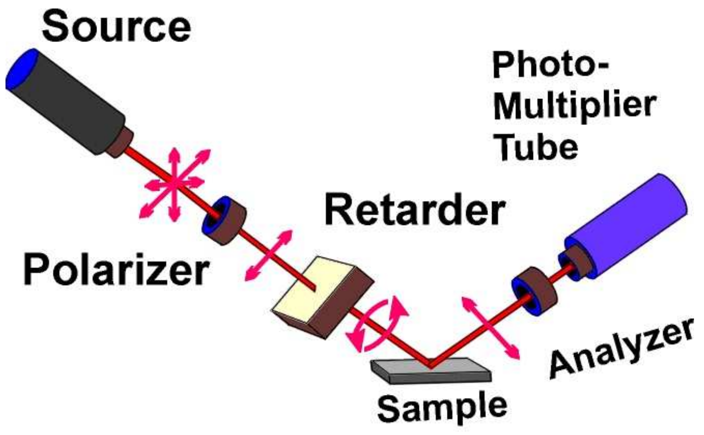
Modulation

Sample

DIFFERENT SE TECHNIQUES

✓ Null Ellipsometer

- Optical element adjustment to extinguish beam at detector



- **Advantages :**

– accurate, low systematic error

– direct calculus of Ψ and Δ parameters

- **Drawbacks :**

– slow technique (usually manual) and difficult to make spectroscopic

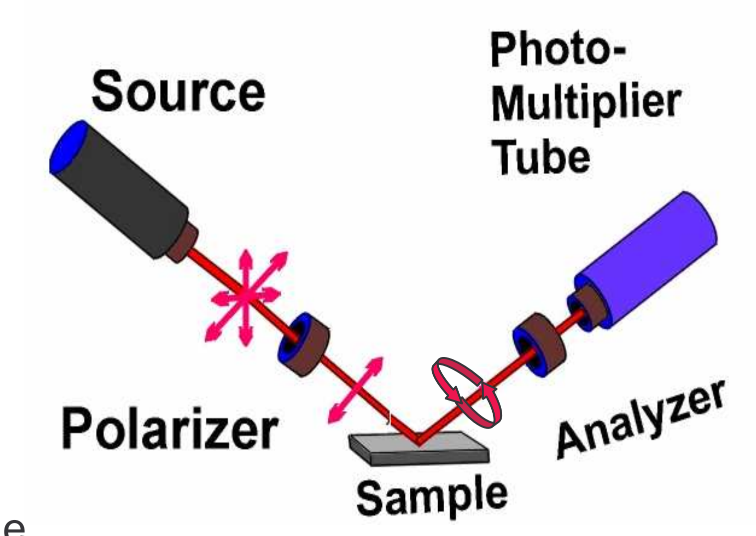
DIFFERENT SE TECHNIQUES

✓ Rotating Element Ellipsometer

- **Two ellipsometer configurations**

– rotating polarizer configuration

– rotating analyzer configuration



- **Advantages :**

– easy to construct

– highly accurate

– polarizers are achromatic over wide spectral range

- **Drawbacks :**

– sensitivity is lost when Δ is near 0° or 180°

→ $\mathrm{tg}\Psi$ / $\cos\Delta$ are the measured parameters

– slow measurements, limited by mechanical rotation speed (10 to 100 Hertz)

DIFFERENT SE TECHNIQUES

✓ Rotating Element Ellipsometer

- **Rotating Polarizer**

– monochromator after sample

  > solarize optics and modify photosensitive samples

  > ambient light filtering

– may cause beam deviation

- **Rotating Analyzer**

– fixed input polarizer

  > eliminates error due to residual polarization of light source

  > no beam deviation

– monochromator before input polarizer
  > detector sensibility to the ambient light

DIFFERENT SE TECHNIQUES

✓ Phase Modulated Ellipsometer

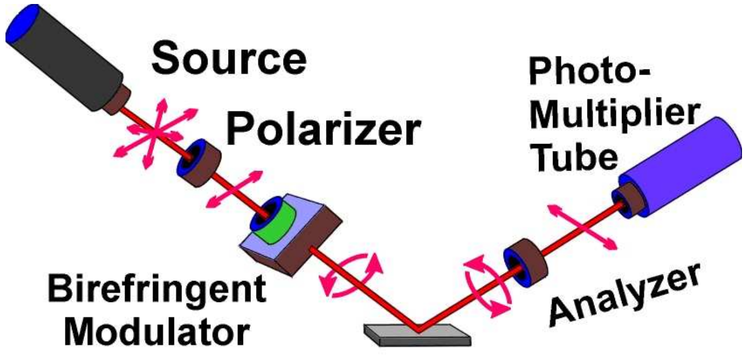
- **Advantages :**

– high modulation rate allows for very fast data acquisition (10 ms per point)

– highly accurate measurements : excellent Δ precision over the whole range

→ tg Δ / cos 2 Ψ are the measured parameters

– accurate and stable signal



- **Drawbacks :**

– difficult to construct (stable calibration)

– modulator : strong sensitivity to the ambient temperature

– loses sensitivity for Ψ near 45°

– longer integration time are required for good signal to noise ratio levels

– photoelastic modulator : chromatic optical element

– adjustment of the amplitude modulation at each wavelength

MEASUREMENT PRINCIPLE

JONES FORMALISM

- Reference axis are given by the sample (// and perpendicular to the surface)
- Each optical element has a 2x2 Jones Matrix

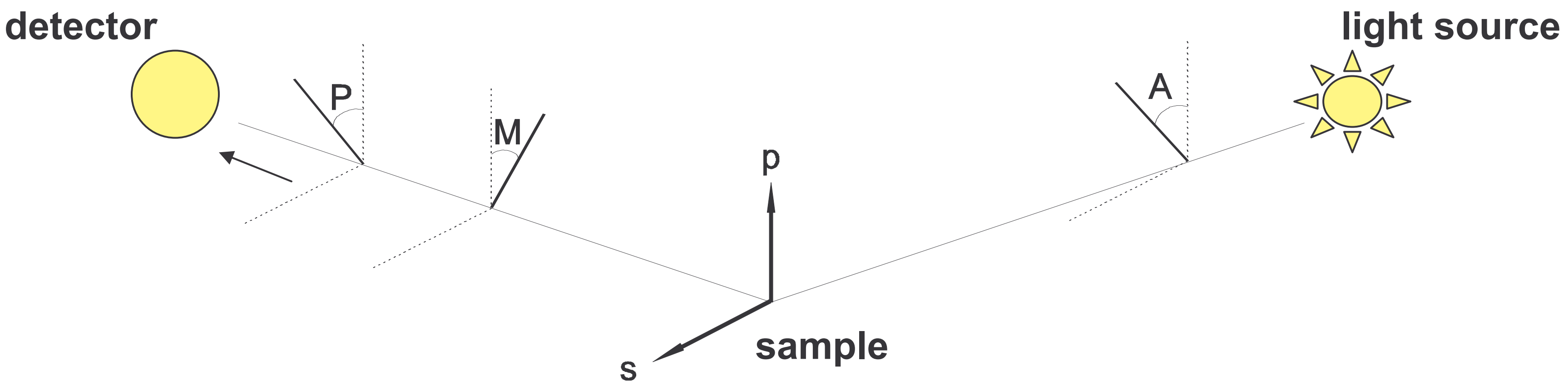
Sample $S = \begin{pmatrix} r_p & 0 \\ 0 & r_s \end{pmatrix}$

Polariser $P = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$

Modulator $M = \begin{pmatrix} e^{i\delta} & 0 \\ 0 & 1 \end{pmatrix}$

+ Rotation Matrix links two neighboring elements $R(\theta) = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}$

MEASUREMENT PRINCIPLE



- Jones formalism for transmitted field : $E_t = T(A\ R_A\ S\ R_M\ M\ R_{P\text{-}M}\ P)\ E_i$ (I)
- Leading to detected intensity : $I(t) = E_t E_t^* = I\ [I_0 + I_S \sin\delta(t) + I_C \cos\delta(t)]$
- Development of equation (I) leads to :

$$I_0 = 1 - \cos 2\Psi \cos 2A + \cos 2(P-M) \cos 2M (\cos 2A - \cos 2\Psi) + \cos 2(P-M) \sin 2A \sin 2M \sin 2\Psi \cos\Delta$$

$$I_S = \sin 2(P-M) \sin 2A \sin 2\Psi \sin\Delta$$

$$I_C = \sin 2(P-M) [\sin 2M (\cos 2\Psi - \cos 2A) + \sin 2A \cos 2M \sin 2\Psi \cos\Delta]$$

MEASUREMENT PRINCIPLE

✓ Measurement configuration

- **Configuration II : P – M=45 [90]; M = 0 [90]; A = 45 [90]**

  Is = $\sin 2\Psi \cdot \sin\Delta$ and Ic = $\sin 2\Psi \cdot \cos\Delta$

  - Accurate determination of Δ
  - Indetermination between Ψ and 90-Ψ: critical point at 45°

- **Configuration III : P – M=45 [90]; M = 45 [90]; A = 45 [90]**

  Is = $\sin 2\Psi \cdot \sin\Delta$ and Ic’ = $\cos 2\Psi$

  - Accurate determination of Ψ
  - Indetermination for Δ between [90;270]

MEASUREMENT PRINCIPLE

✓ Electric periodical signal S from PM with the frequency 50kHz

$$S(t) = S_0 + S_1\,e^{i\omega t} + S_2\,e^{2i\omega t} \qquad \text{(II)}$$

✓ Measurement formalism = identification (I) et (II)

✓ Abstract

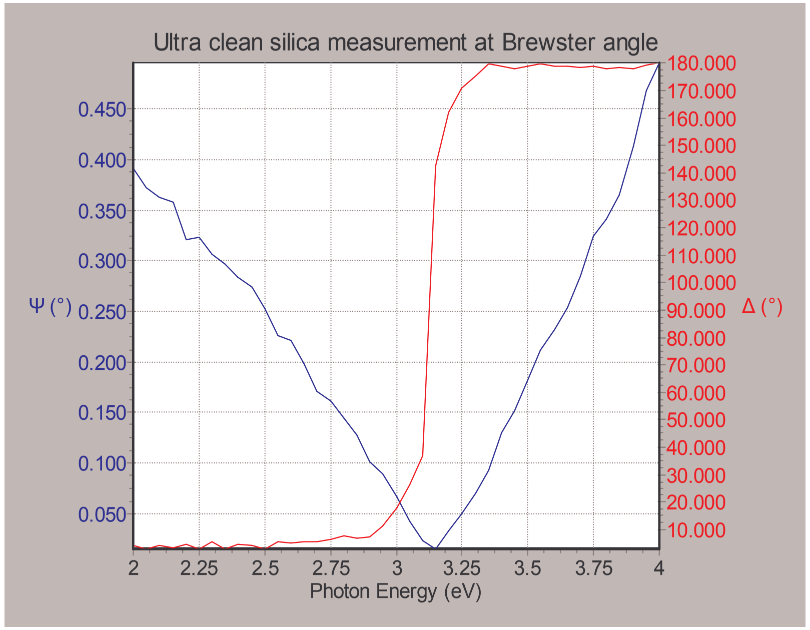
- Fourier analysis of the signal → harmonic amplitude S_o, S_1 et S_2
- Corrective coefficients calculus
- Io, Is et Ic determination
- Ellipsometric angles Ψ, Δ deduced

The most accurate measurement of Δ parameter

✓ Unique capabilities of SPME :

Accurate measurement of Δ parameter

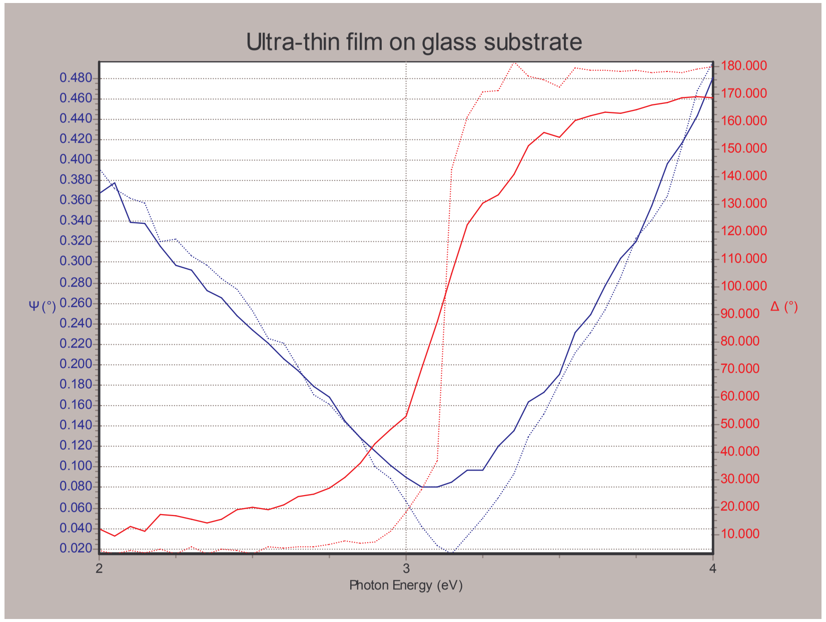
around 0° and 180°



Measurement on ultra-clean silica

at the Brewster angle

✓ High sensitivity to ultra-thin film



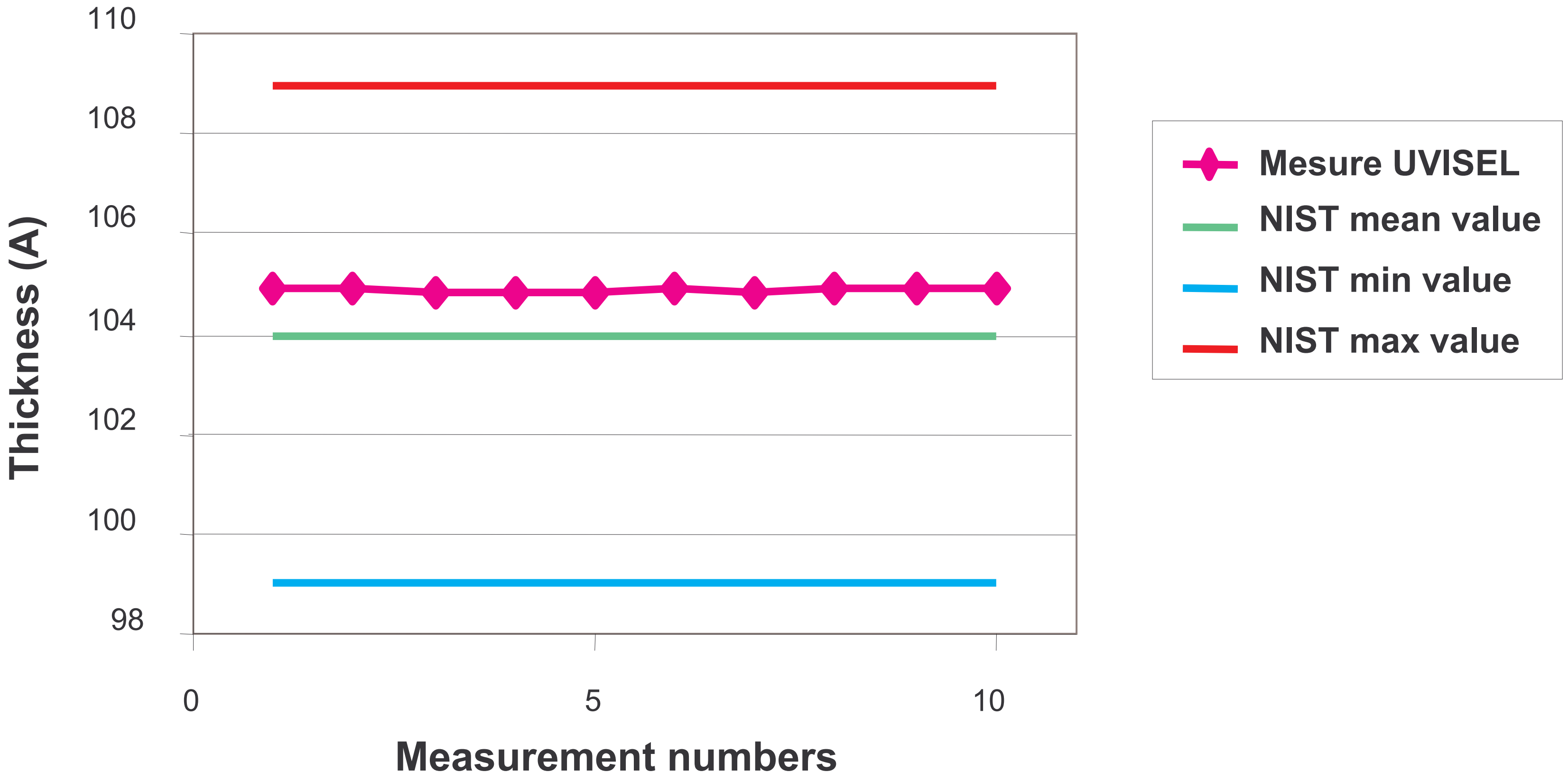
10 A monolayer effect evidenced at the Brewster angle

—— Ultra-thin monolayer

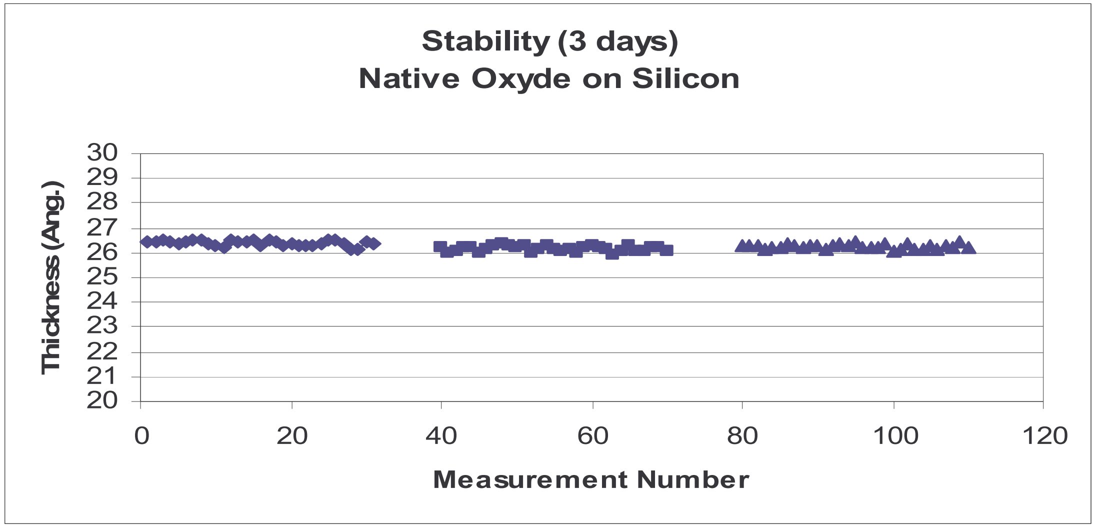
⋯⋯ Fused silica substrate

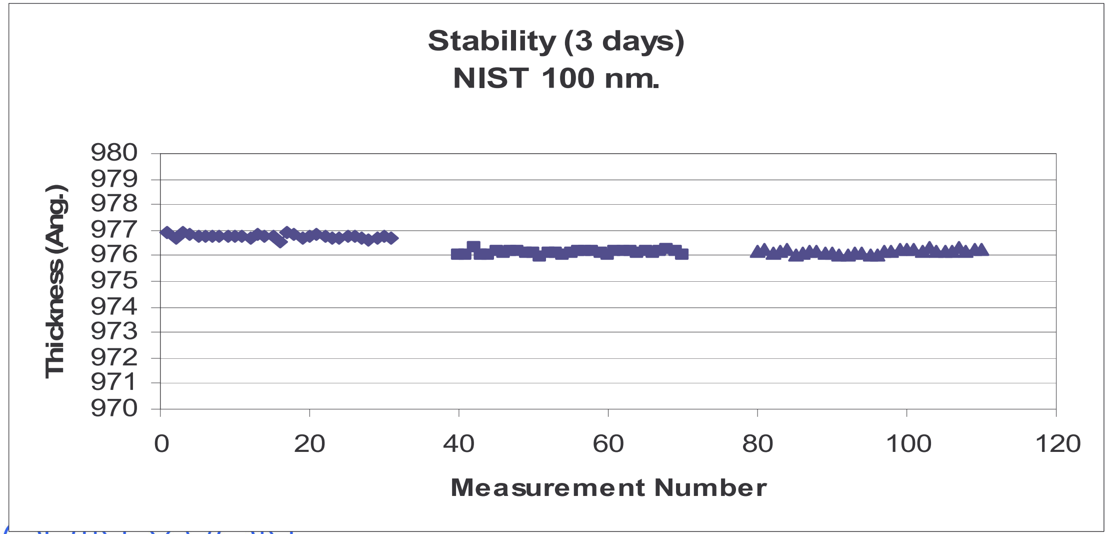
SYSTEM PRECISION
NIST 10 nm

NIST = Traceable standard reference materials



MID TERM REPRODUCIBILITY



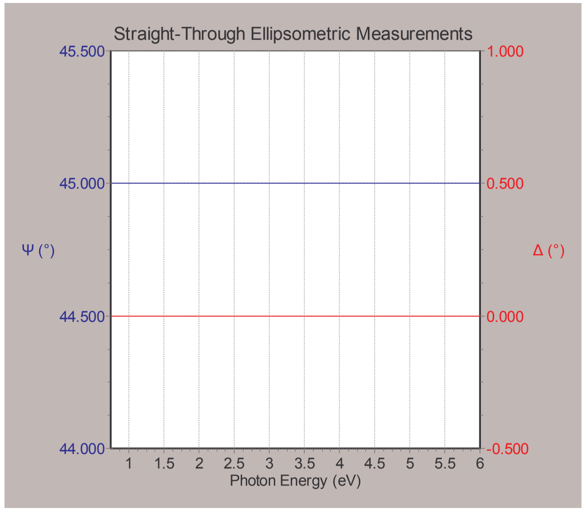


Verification of Ellipsometric Accuracy

✓ **Reference standards - NIST**

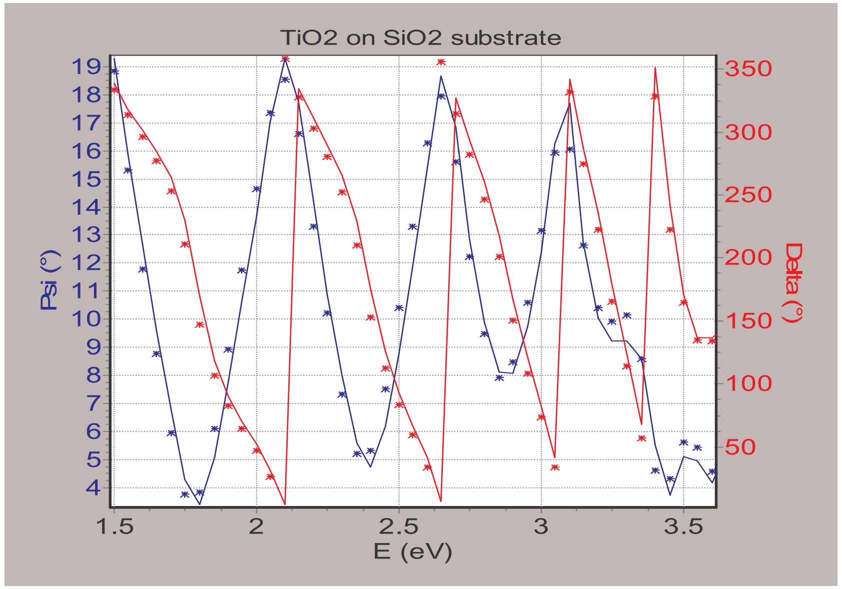
✓ **Straight-Through air measurements**

- the only material for which the ellipsometric parameters are absolutely known is « Air »
- an ellipsometric measurement in the straight-through configuration should by definition return Ψ=45° and Δ=0°



ANALYSIS OF ELLIPSOMETRIC DATA

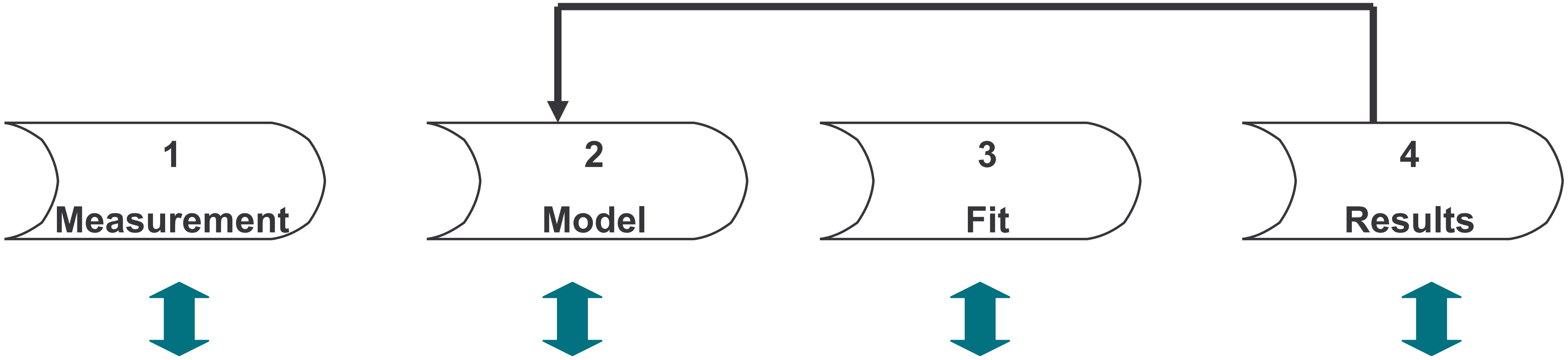
- Ellipsometry does not measure film thicknesses or optical constants, it measures Ψ and Δ



- To extract these informations from a sample, it is necessary to perform a **model dependant analysis** of the ellipsometric angles

- A model is an idealized mathematical representation of the sample

SE DATA ANALYSIS FLOWCHART

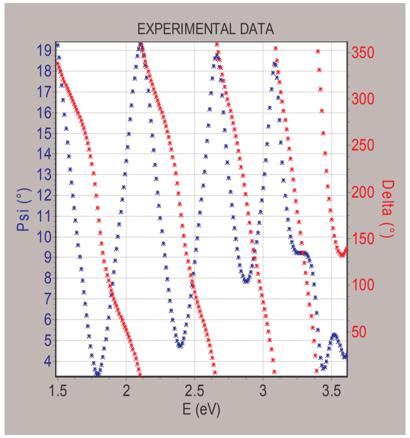


1 Measurement

2 Model

3 Fit

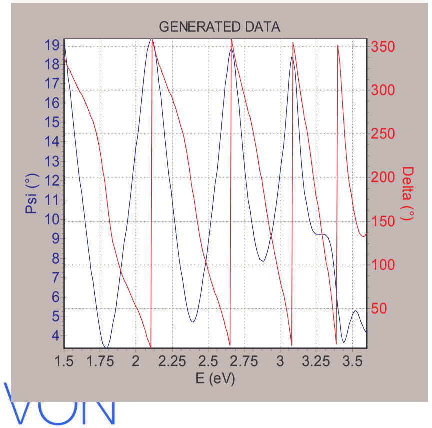
4 Results

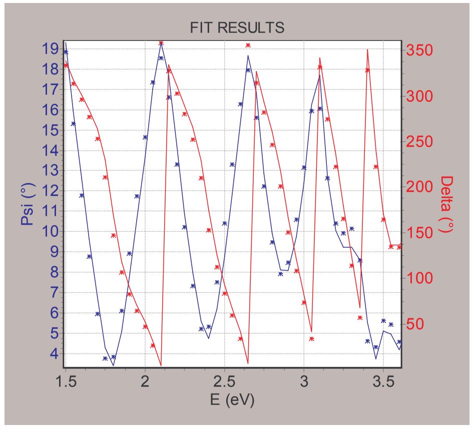


roughness

TiO_2

SiO_2 substrate

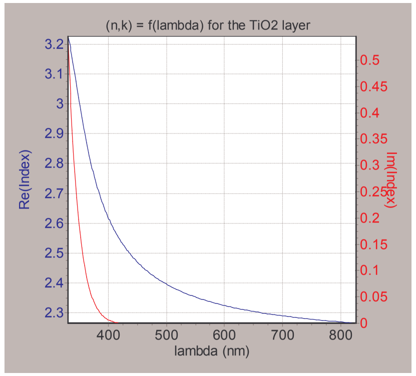




$\chi^2 = 1.6$

$d_{TiO2} = 4200$ Å

$d_{rough} = 20$ Å



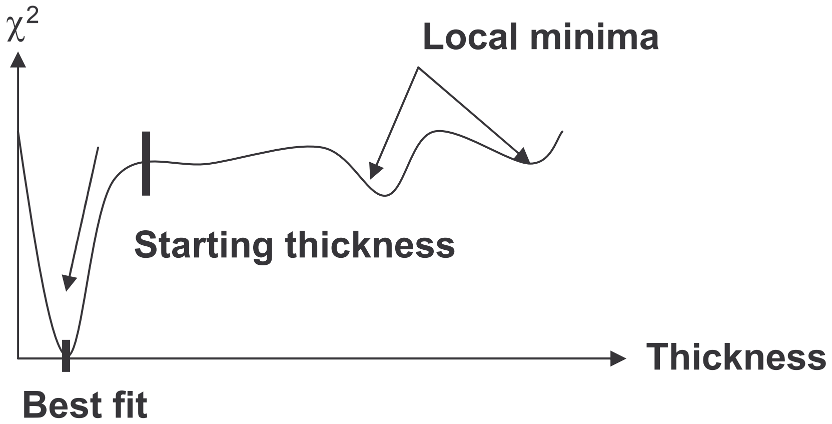
DATA FITTING ALGORITHM

$$\chi^2 = \min \sum_{i=1}^{n} \left[\frac{(\Psi_{th} - \Psi_{exp})_i^2}{\Gamma_{\Psi,i}} + \frac{(\Delta_{th} - \Delta_{exp})_i^2}{\Gamma_{\Delta,i}} \right]$$

- χ^2 parameter quantifies the difference between experimental and model data
- A smaller χ^2 implies a better fit

✓ Minimization methods

- Levenberg-Marquardt algorithm : based on partial derivative
- Simplex : geometrical method



✓ Difficulties

- Local minimum
- Many variables
- Theoretical parameters initialization : have to be close to the final solution

General Rules for Ellipsometric Data Analysis

3 essential steps

1 - Experimental measurement

→ Check the good working of the ellipsometer (NIST)

→ Sample preparation

→ Acquisition parameter choices
  - spectral range (NIR-FUV) / sample properties
  - step / layer thickness
  - angle of incidence (brewster)
  - beam diameter
  - configuration

General Rules for Ellipsometric Data Analysis

3 essential steps

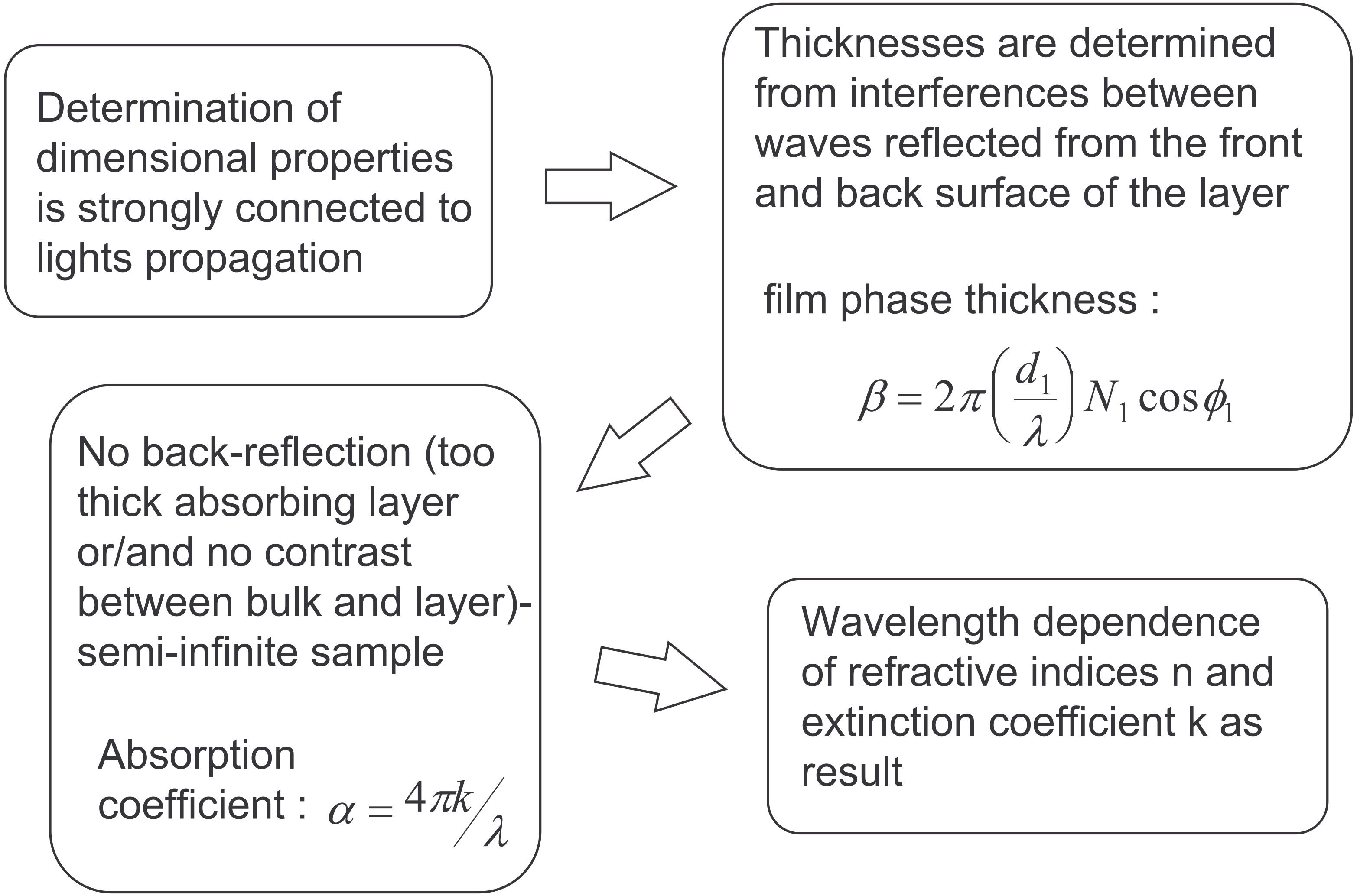
2 - Modeling

→ Build the most realistic optical model

3 - Reliable model choice

→ Criteria and quality of a good fit
- physical result (model and parameter values)
- slight correlation between parameters : uniqueness of the solution
- final result independent of initial parameters
- quick convergence

How and what can we learn from Ellipsometric data ?



Determination of dimensional properties is strongly connected to lights propagation

Thicknesses are determined from interferences between waves reflected from the front and back surface of the layer

film phase thickness :

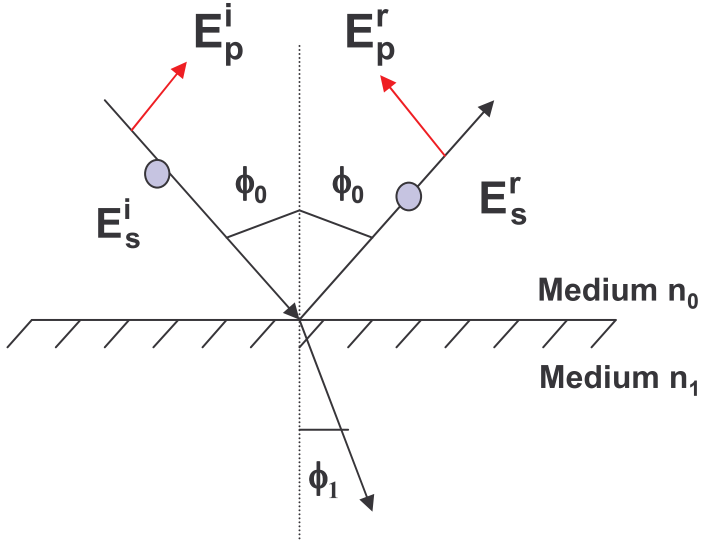
$$\beta = 2\pi\left(\frac{d_1}{\lambda}\right)N_1\cos\phi_1$$

No back-reflection (too thick absorbing layer or/and no contrast between bulk and layer)- semi-infinite sample

Absorption coefficient : $\alpha = {4\pi k}/{\lambda}$

Wavelength dependence of refractive indices n and extinction coefficient k as result

Modeling ellipsometric data : BULK SAMPLE



$$r^p_{01} = \frac{n_1\cos\Phi_0 - n_0\cos\Phi_1}{n_1\cos\Phi_0 + n_0\cos\Phi_1}$$

$$r^s_{01} = \frac{n_0\cos\Phi_0 - n_1\cos\Phi_1}{n_0\cos\Phi_0 + n_1\cos\Phi_1}$$

Measurement of a bulk sample gives directly the (n,k) of the material

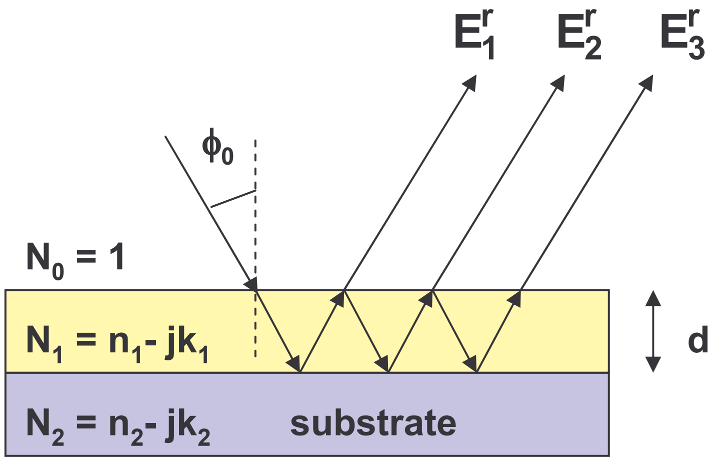
$$\varepsilon = n_1^2 = \varepsilon_0 \sin^2\Phi_0 \left[1 + \mathrm{tg}^2\Phi_0 \left(\frac{1-\rho}{1+\rho} \right)^2 \right]$$

Ratio $\rho \Rightarrow (\Psi,\Delta) = f(\varepsilon_0, \varepsilon_1, \Phi_0)$

2 measured parameters : (Ψ,Δ)

2 unknowns : n_1 k_1

Modeling ellipsometric data :
THE TWO PHASE MODEL



R = Σ r related to the 1&2 interfaces

$$R = \frac{r_{01} + r_{12}e^{-2j\beta}}{1 + r_{01}r_{12}e^{-2j\beta}}$$

β : Phase shift introduced by reflection

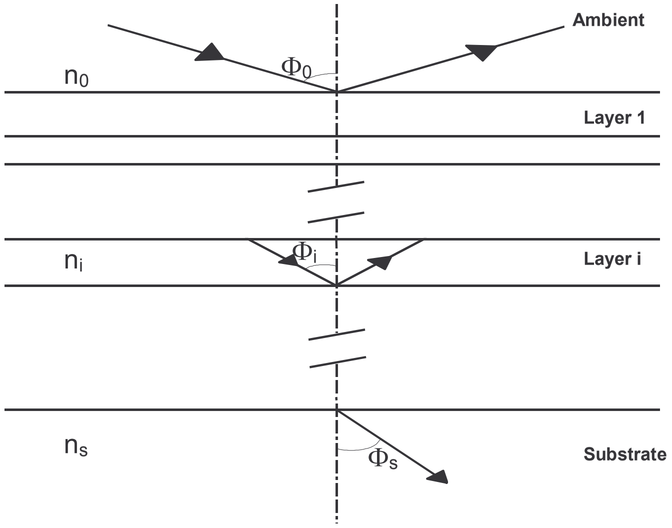
$$\beta = 2\pi\left(\frac{d}{\lambda}\right)n_1\cos\phi_1$$

Ratio $\rho \Rightarrow (\Psi,\Delta) = f(\varepsilon_0, \varepsilon_1, \varepsilon_2, \Phi_0, d, \lambda_0)$

2 measured parameters : (Ψ,Δ)

3 unknowns : n_1 k_1 and d

Modeling ellipsometric data :
THE MULTILAYER MODEL

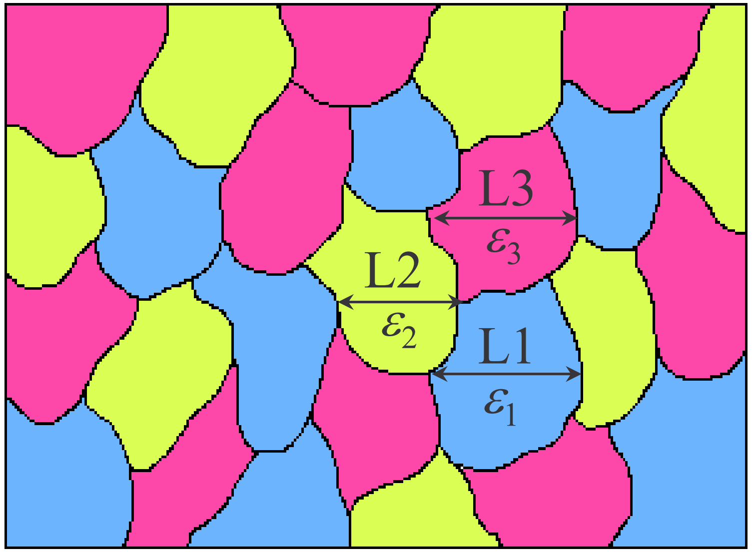


Each layer involves one thickness and 2 interfaces.

Multilayer global response is given by :

$$S = I_0\ L_1\ I_1\ L_2\ \ldots.I_{n-1}\ L_n$$

EFFECTIVE MEDIUM THEORY
Microscopically inhomogeneous materials



Consider a mixture of 2 or 3 phases. Consider volumic fractions f_i. If each separate region is large enough to possess their own dielectric identities (εi) and small compared to wavelength of light, the resulting material dielectric function ε follows :

$$\sum_i f_i \frac{\varepsilon_i - \varepsilon}{\varepsilon_i + 2\varepsilon} = 0$$

EFFECTIVE MEDIUM THEORY
Microscopically inhomogeneous materials

Using EMA one can describe :

Microscopic roughness ⇨ Material + Ambient

Interfaces ⇨ Mixture of neighboring materials

Native oxide ⇨ Oxide + Voids

Polycrystalline ⇨ Material (crystalline) + Amorphous material + Voids

LARGE PRODUCT VARIETY

✓ **Several instruments dedicated to 3 main markets**

- fundamental research : UVISEL NIR/FUV/ER
- Industrial R&D : UVISEL - full integrated model
- Industry : UT300 – FF1000

✓ **Large range of standard configurations**

- wide variety of spectral ranges (190 to 2100 nm)
- in situ or ex situ model
- automated or manual angle
- automated or manual sample stage
- sequential (monochromator) or simultaneous (mwl) acquisition

UVISEL : bench top configuration

Auto collimating system

Detection head

Manual sample stage with height, tilt, theta adjustment

Automatic goniometer

Excitation head with manual microspot

UVISEL : bench top configuration

UVISEL : full integrated model

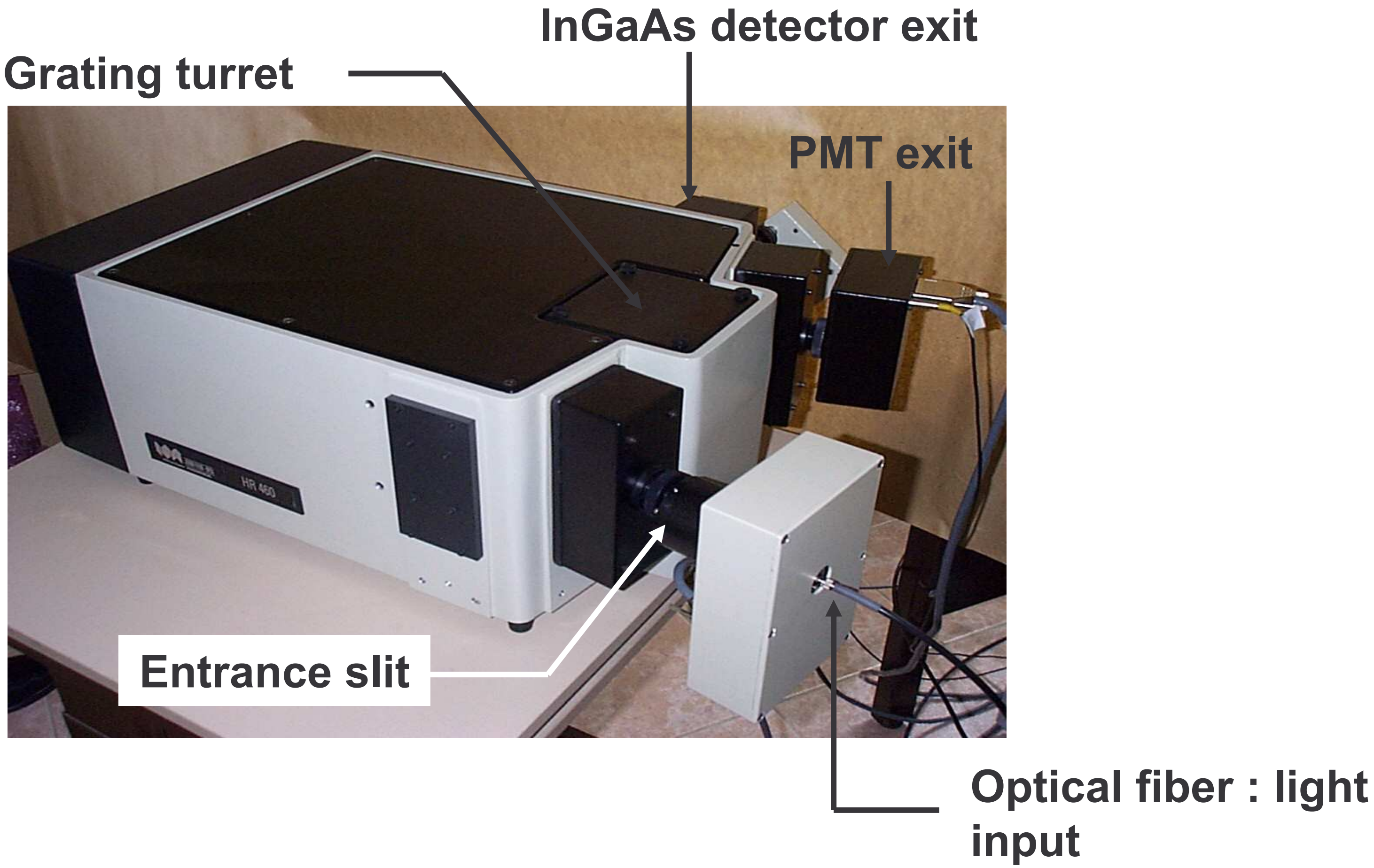
- 15 inches flat screen display
- Integration of all the components into a single rack

UT300
A fully automated system for industrial environment

- For ultra thin film from 10 Å to several microns
- For single or complex multiple layer stack measurements
- Fully automated system
- Provides highly accurate measurements of material and thin film optical and structural properties
- Allows a high throughput > 130 wafers/h
- Available for 6 ”, 8 ” or 12 ” sample size

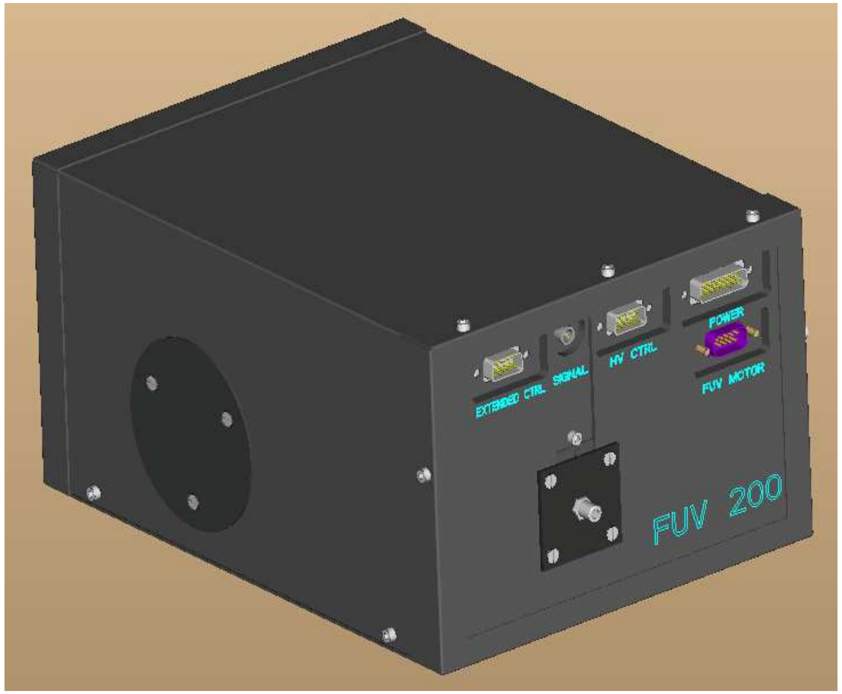
FF-1000
A fully automated system for the display industry

UVISEL COMPONENTS : 460 monochromator



Spectral range : 0.75 - 4.5 eV ⇔ 1700 - 275 nm

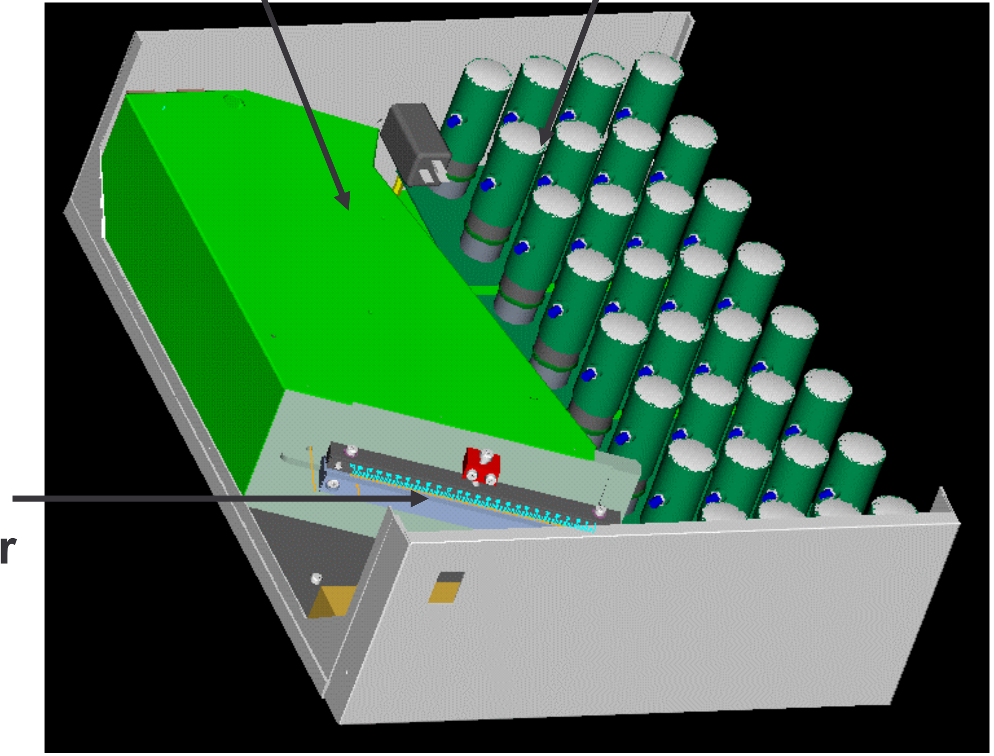
UVISEL COMPONENTS : M-200



Spectral range : 1.5 - 6.5 eV ⇔ 830 - 190 nm

UVISEL COMPONENTS : MWL

For simultaneous acquisition



Optical system

32 PM

Comb with optical fiber

UVISEL COMPONENTS : FUV source

Integrated light source model FUV 150 W

MgF$_2$ polarizer

3 microspots

UVISEL - INSITU

MATERIALS STUDIED BY UVISEL

✓ **Dielectrics**

oxides, nitrides, ITO, DLC, glass

✓ **Semiconductors**

polysilicon, III-V

✓ **Metals**

Cu, Al, Au, TiN, TaN, WSi, MoSi

✓ **Polymers**

photoresists, anti-reflective coatings, organic material

✓ **Multilayers**

ONO/Si, photoresist/arc/Si, optical coatings

✓ **Liquid**

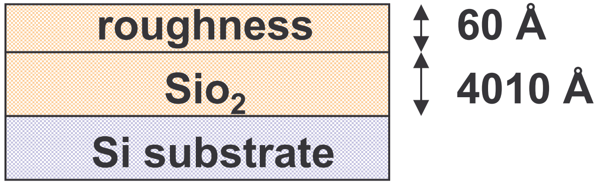
water, protein adhesion on surface

INFORMATIONS DEDUCED FROM ELLIPSOMETRY

- layer thickness
- optical constants
- surface and interfacial roughness
- composition / crystallinity
- optical anisotropy
- uniformity (over film area and depth)
- any physical effect which induces changes in a material ’s optical properties

SiO_2 on Si
Film thickness and index

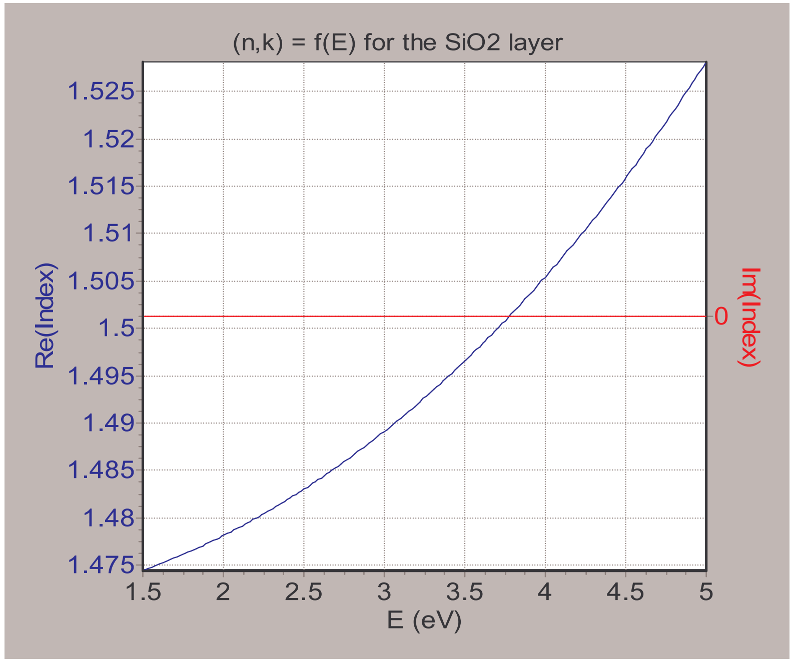
Optical model

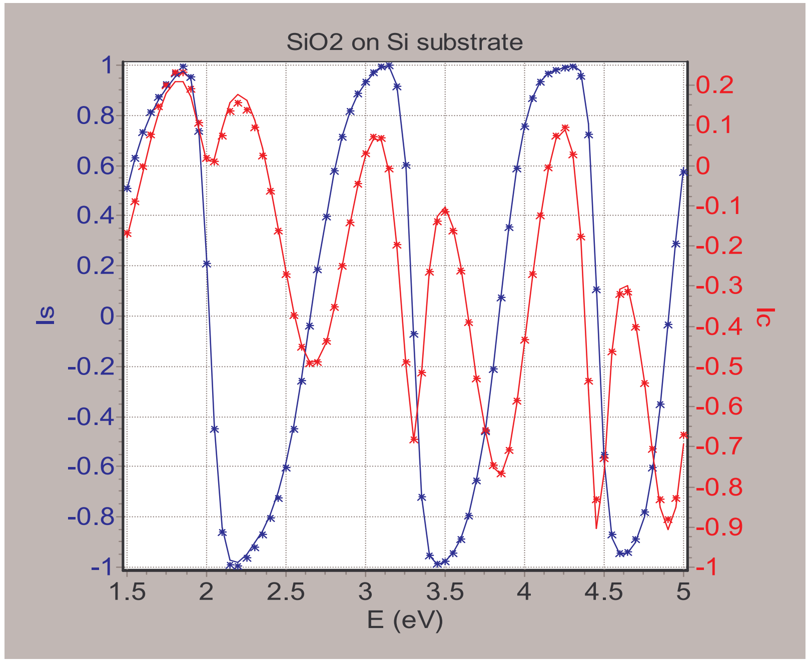


Parameter values

$\chi^2 = 2.2$

$$\left.\begin{aligned} \varepsilon_\infty &= 1.000 \\ \varepsilon_s &= 2.160 \\ \omega_t &= 13.803 \end{aligned}\right\} \quad \textbf{Lorentz oscillator}$$

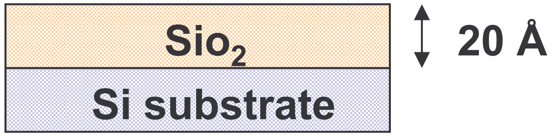


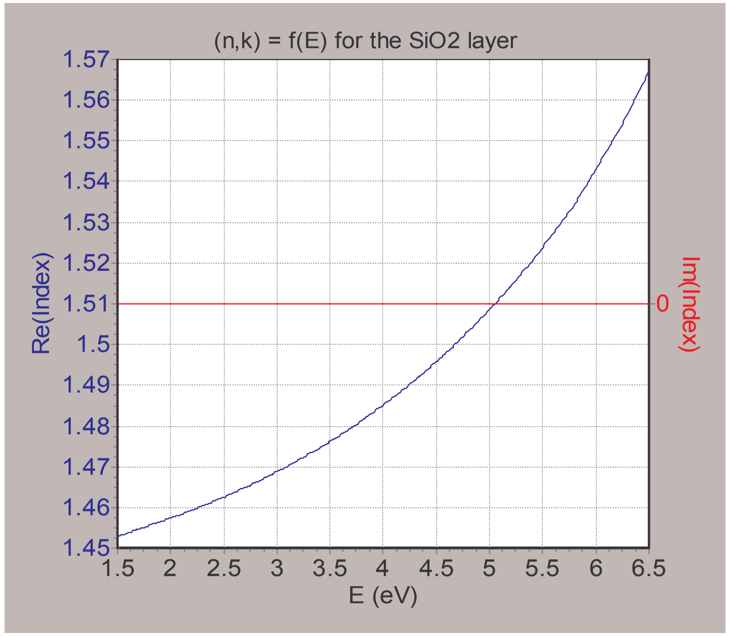


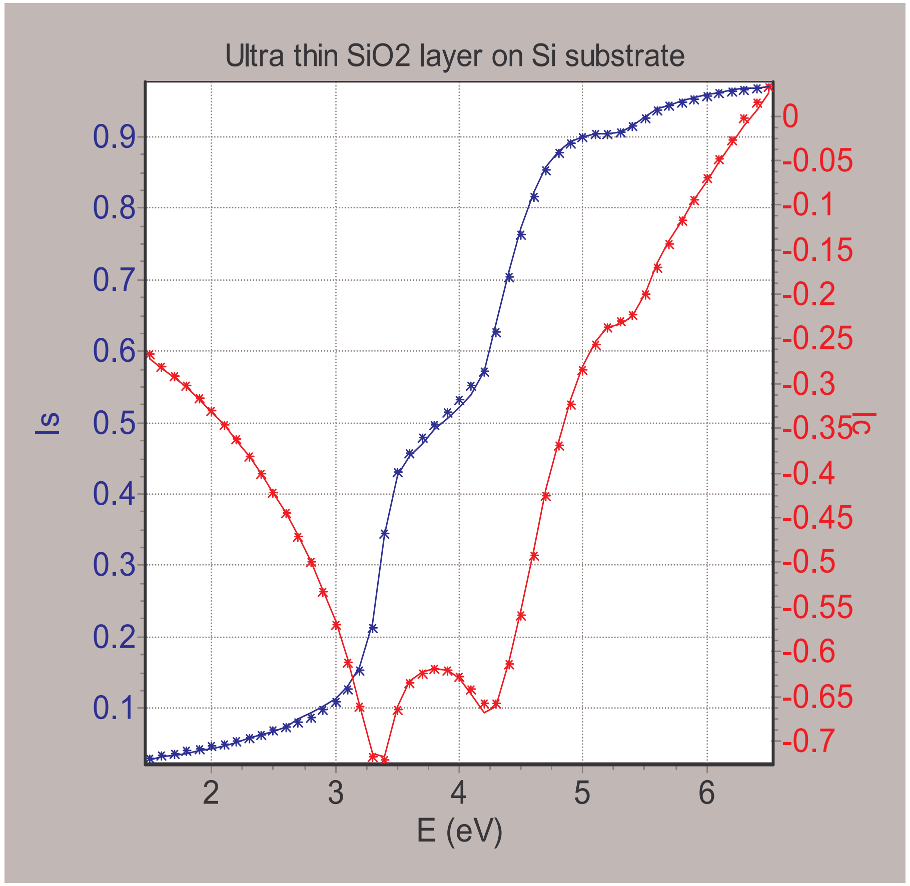
Ultra thin SiO_2 layer on Si

Film thickness and index

Optical model



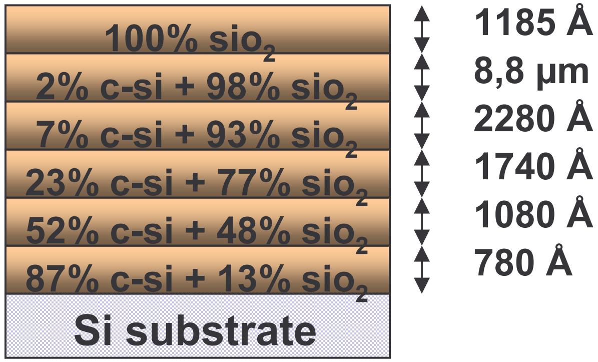




Ultra thick OPSL layer on Si

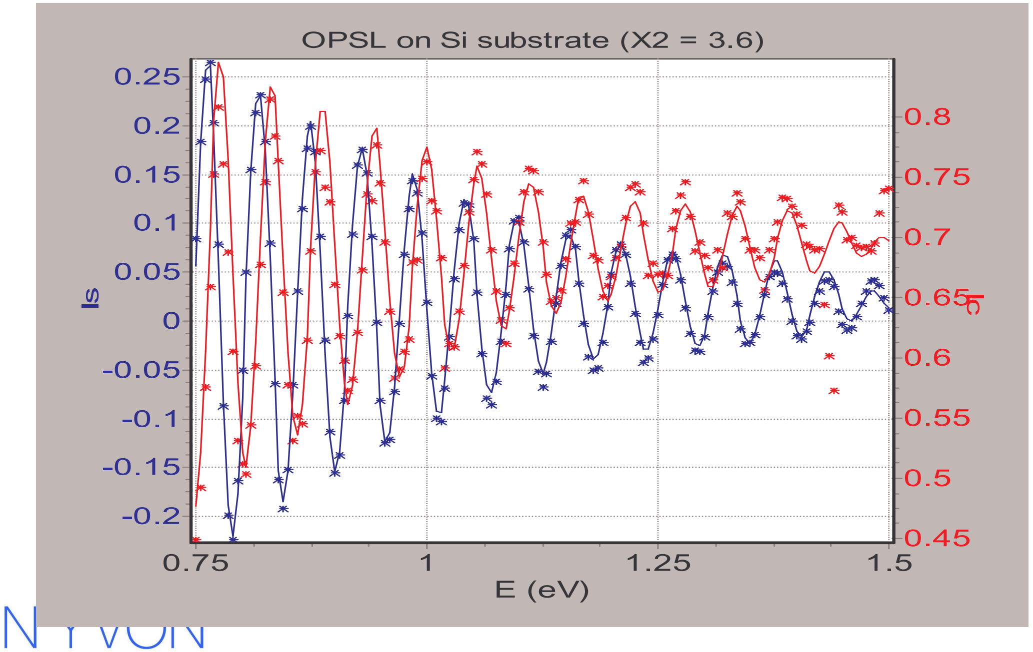
Film thickness and index - Importance of the NIR range

Optical model



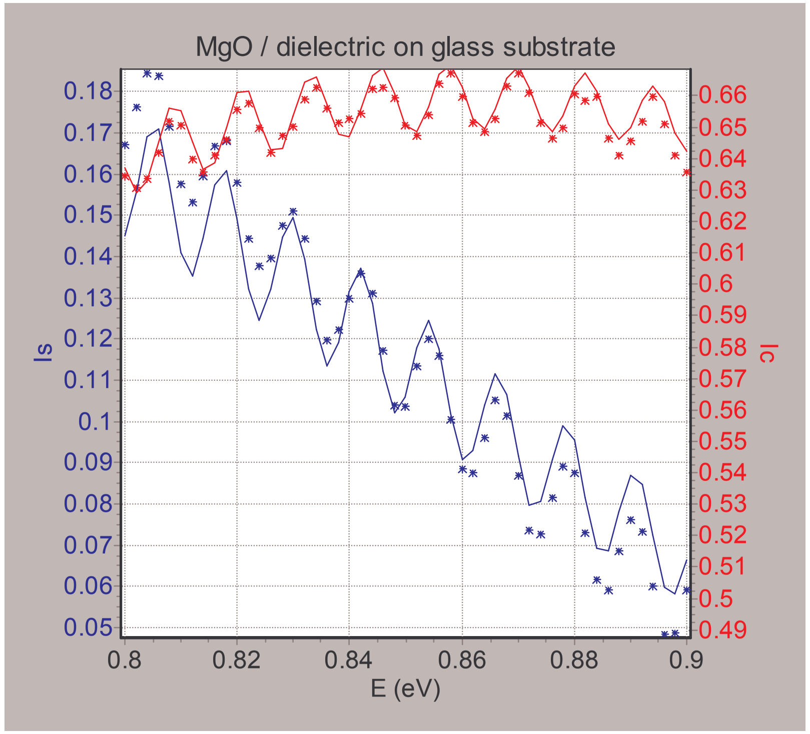
Layer	Thickness
100% sio_2	1185 Å
2% c-si + 98% sio_2	8,8 µm
7% c-si + 93% sio_2	2280 Å
23% c-si + 77% sio_2	1740 Å
52% c-si + 48% sio_2	1080 Å
87% c-si + 13% sio_2	780 Å
Si substrate	

- **Inhomogeneity of OPSL layer**
- **Proportion of materials**
- **Total OPSL layer thickness**
- **Refractive index evolution**

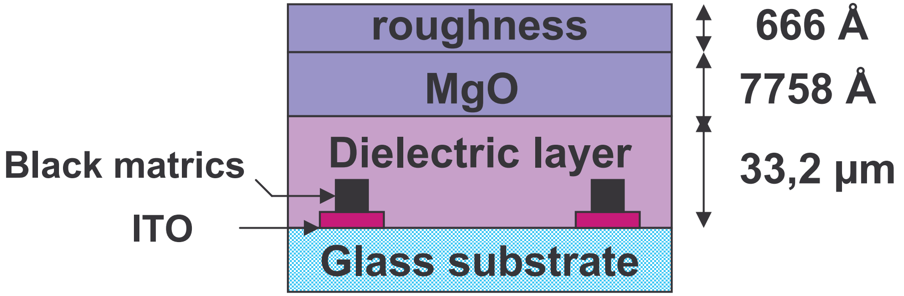


MgO / dielectric on glass substrate

PDP Applications



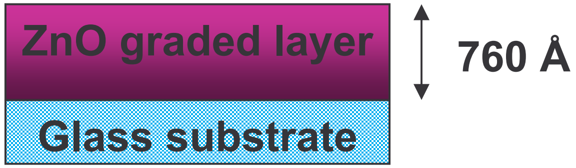
Optical model



- **Fit on a reduced range ($\chi^2 = 0.56$)**
- **Fixed index dispersion formula**
  - **- Dielectric layer : n = 1.764**
  - **- MgO layer : n = 1.642**

ZnO on glass
A graded layer model

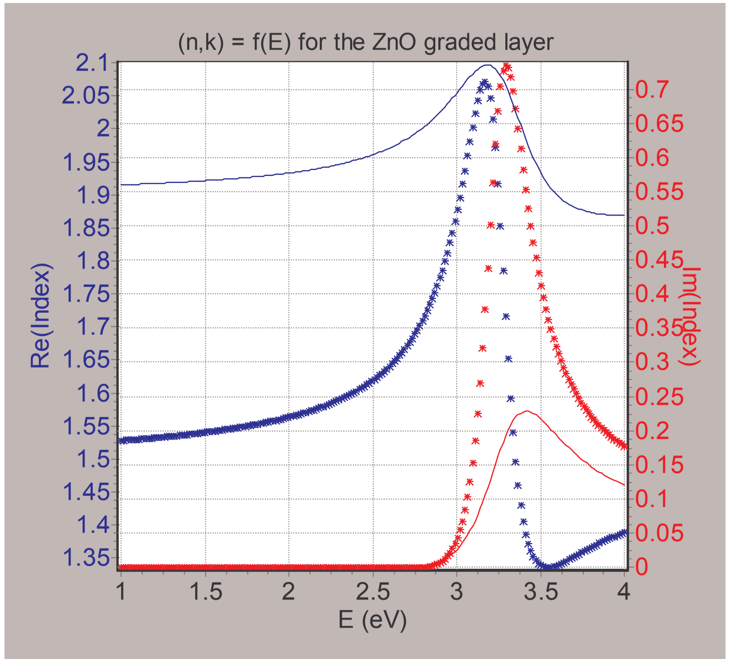
Optical model

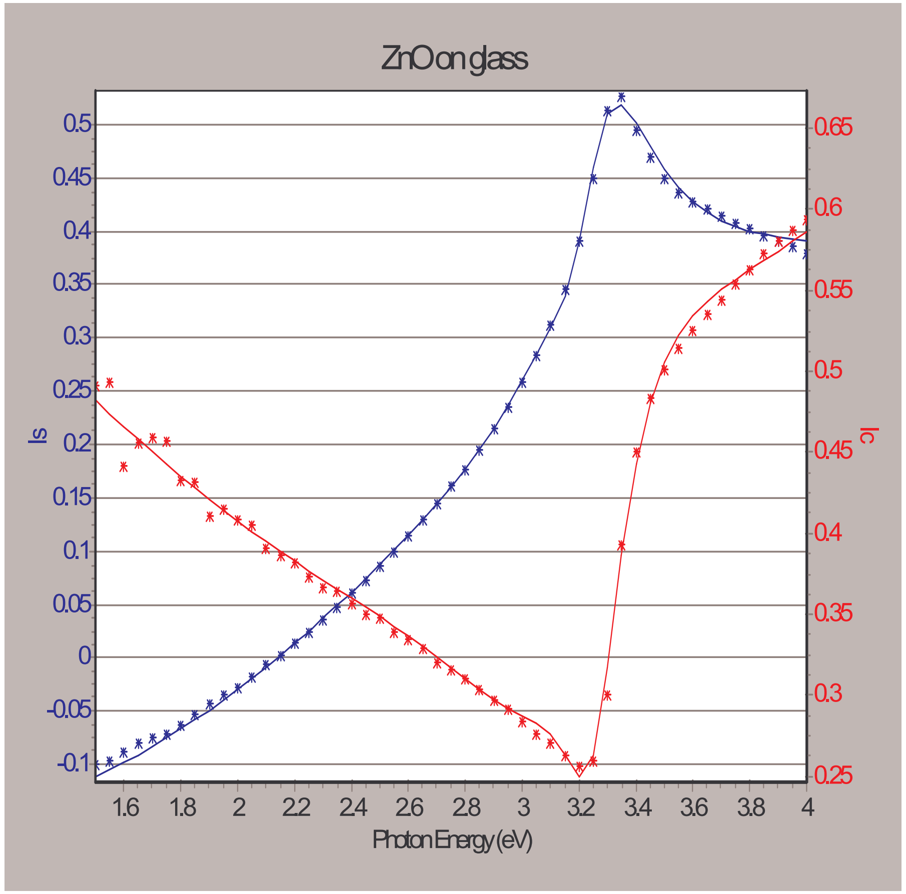


ZnO graded layer

Glass substrate

760 Å

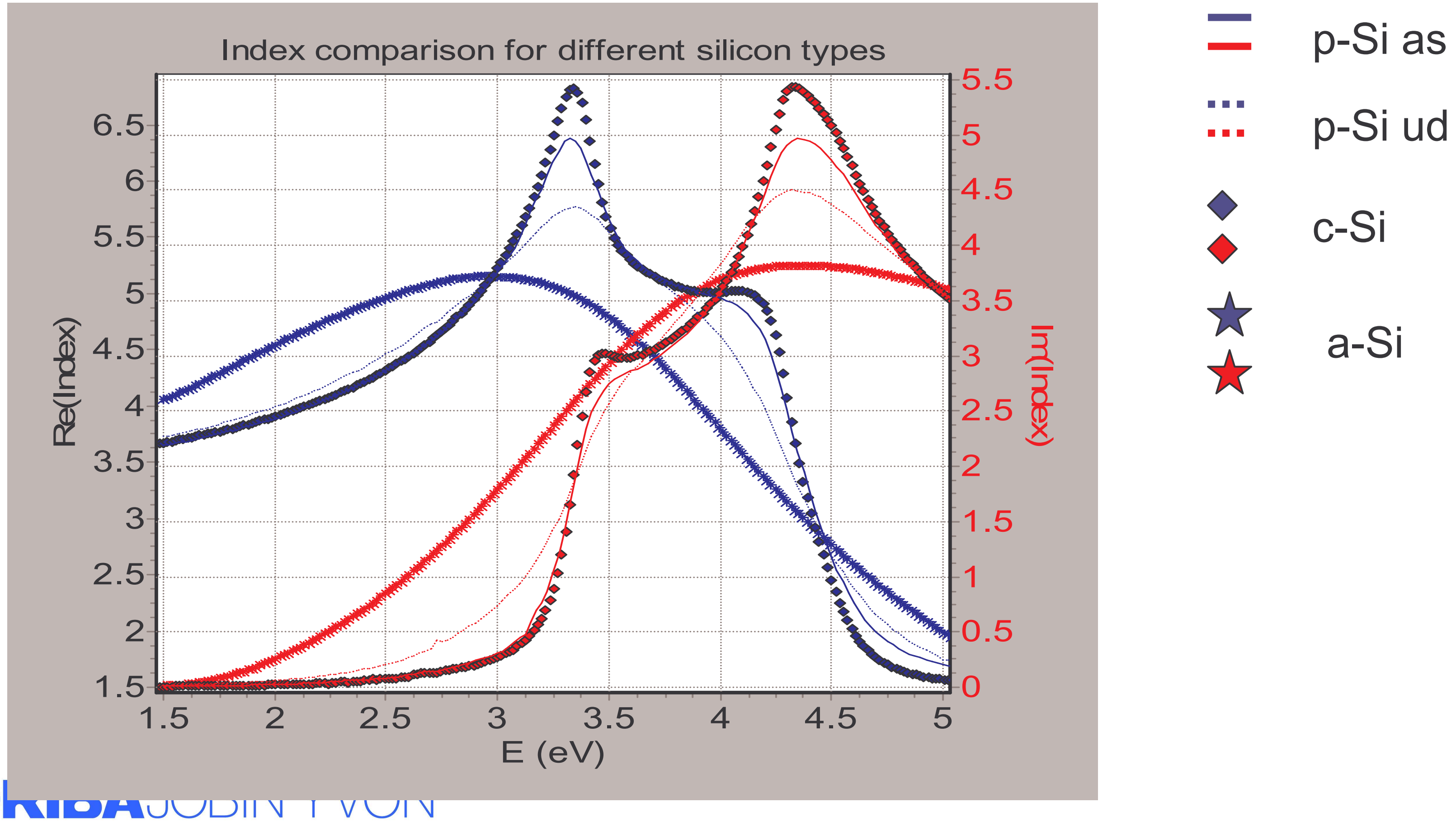




HORIBA JOBIN YVON

Crystallinity : Polysilicon

- Optical constants depend strongly on crystallinity, which depends on process conditions

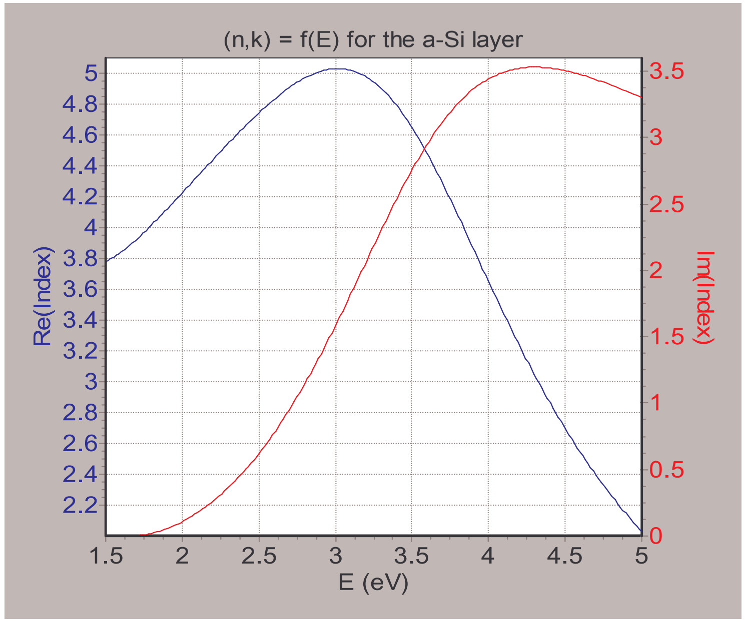


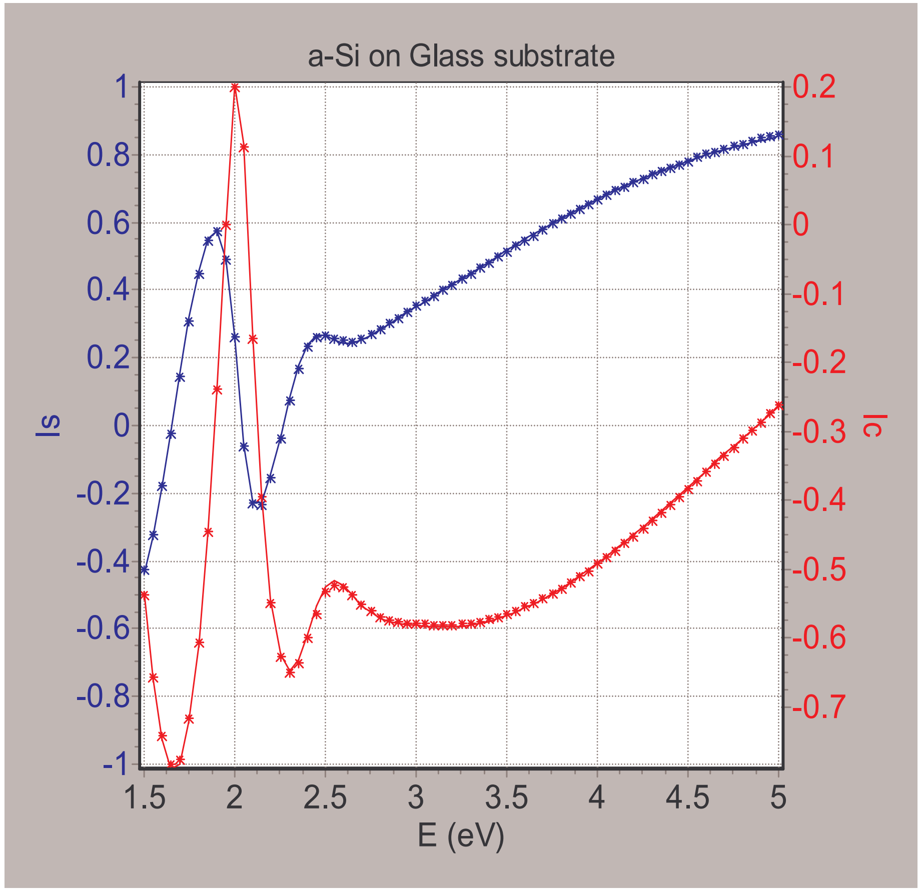
a-Si on glass substrate

Importance of the NIR range

Optical model

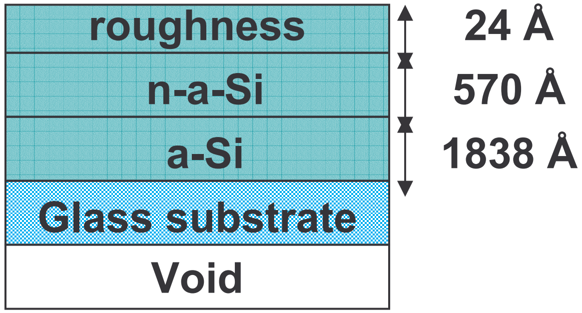
roughness
a-Si
Glass substrate



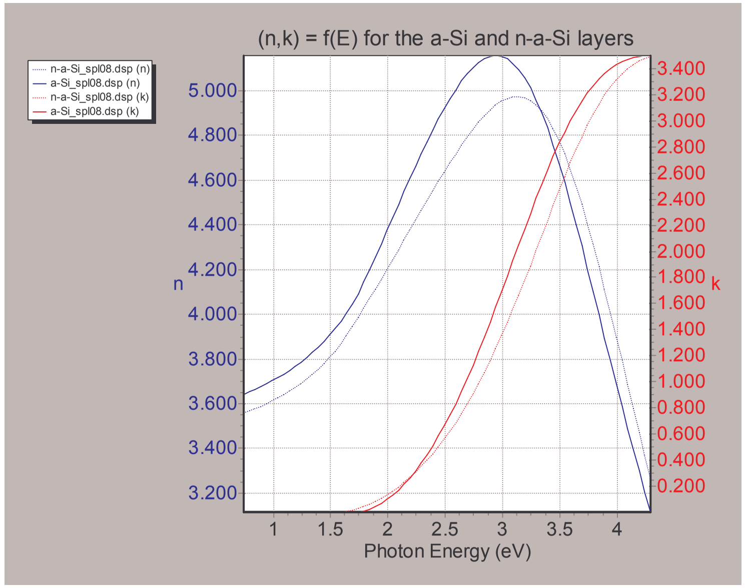


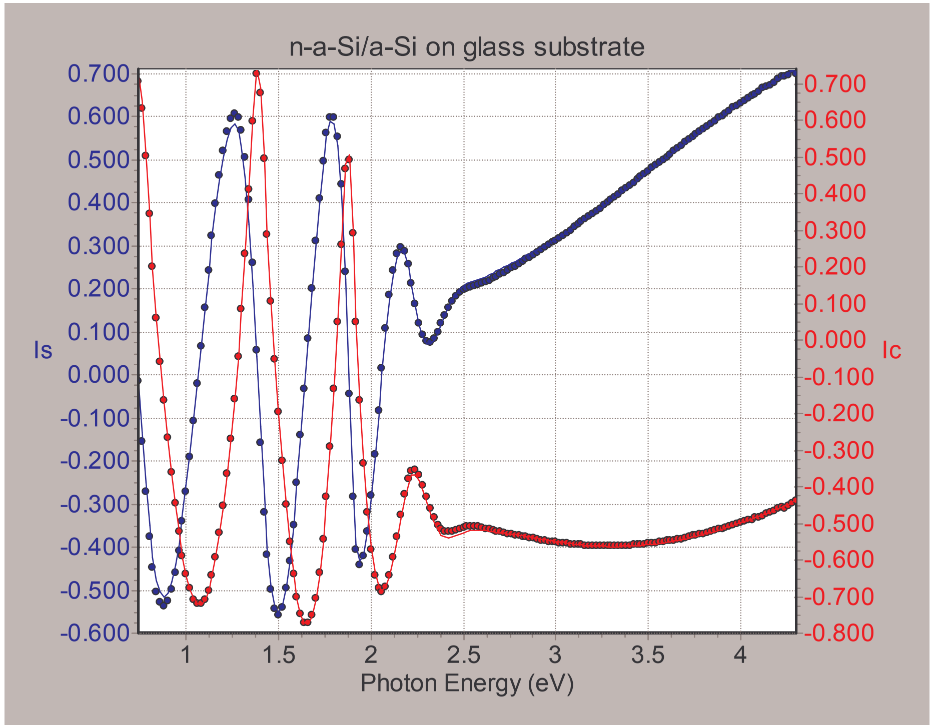
n-a-Si/a-Si on glass substrate

Optical model


roughness
n-a-Si
a-Si
Glass substrate
Void

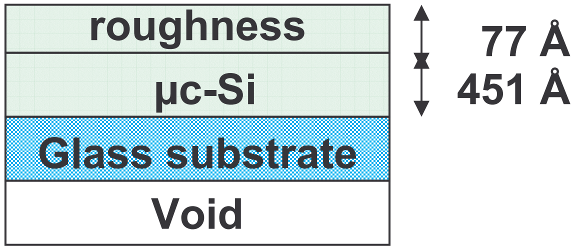
24 Å
570 Å
1838 Å





µc-Si layer on Glass substrate

Optical model

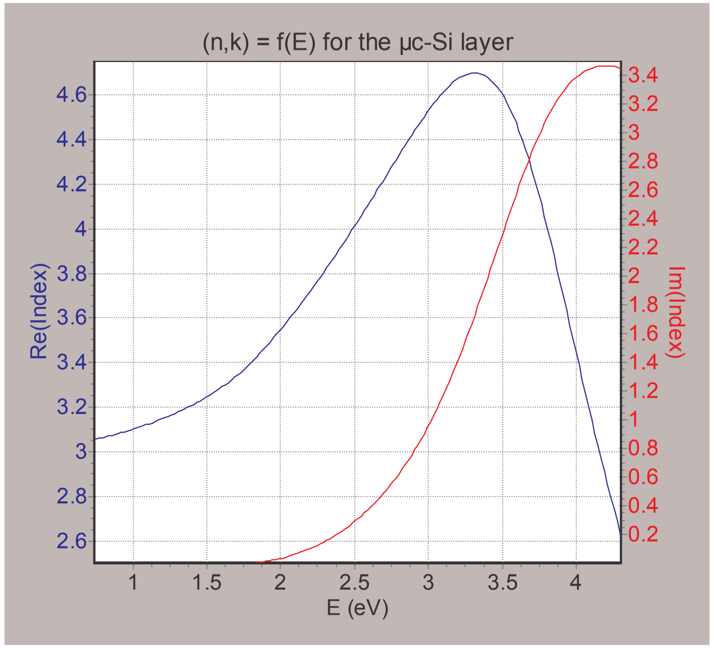


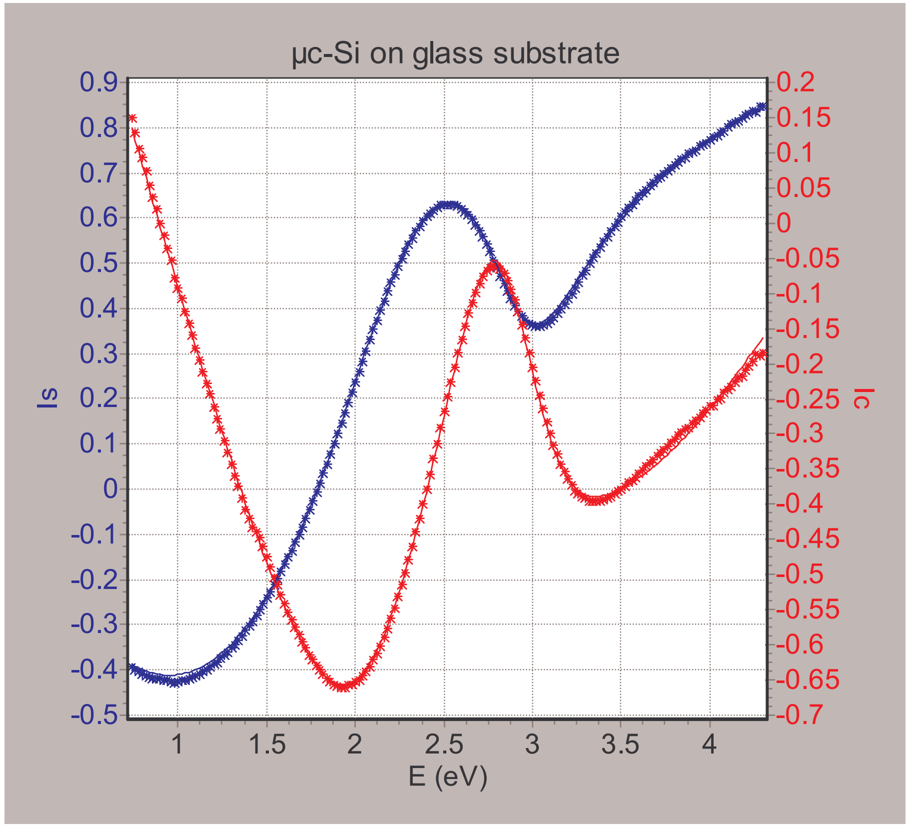
roughness — 77 Å

µc-Si — 451 Å

Glass substrate

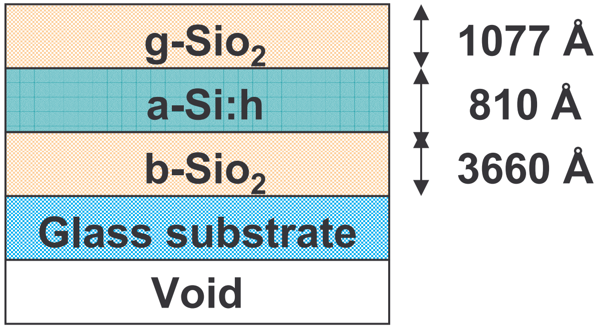
Void





g-SiO$_2$ / a-Si:h / b-SiO$_2$ / Glass
Film thickness and index

Optical model



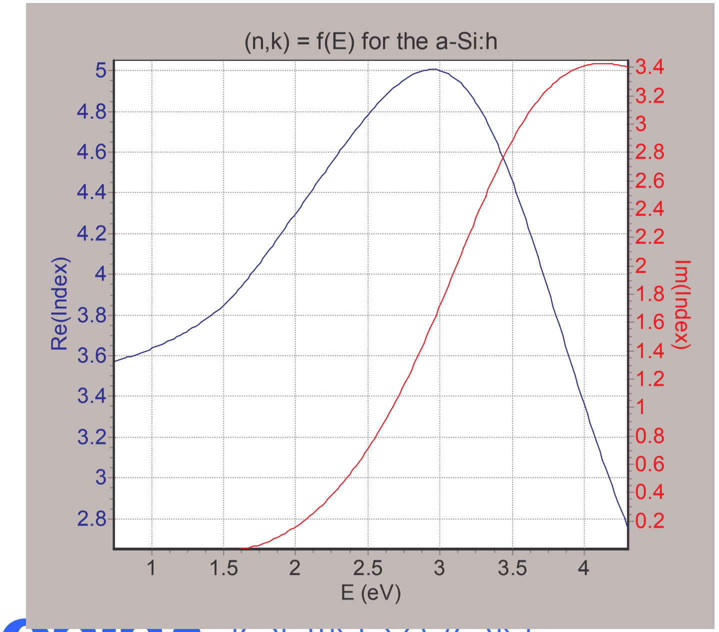
g-Sio$_2$ — 1077 Å

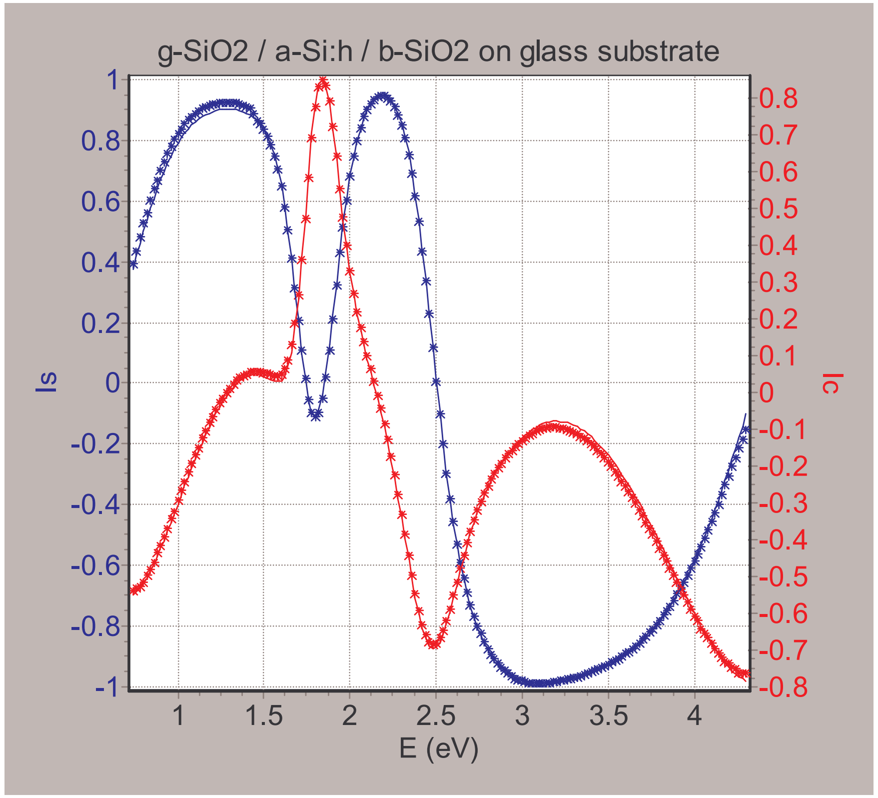
a-Si:h — 810 Å

b-Sio$_2$ — 3660 Å

Glass substrate

Void

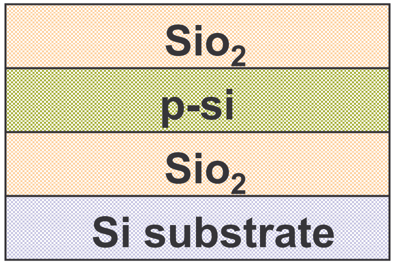




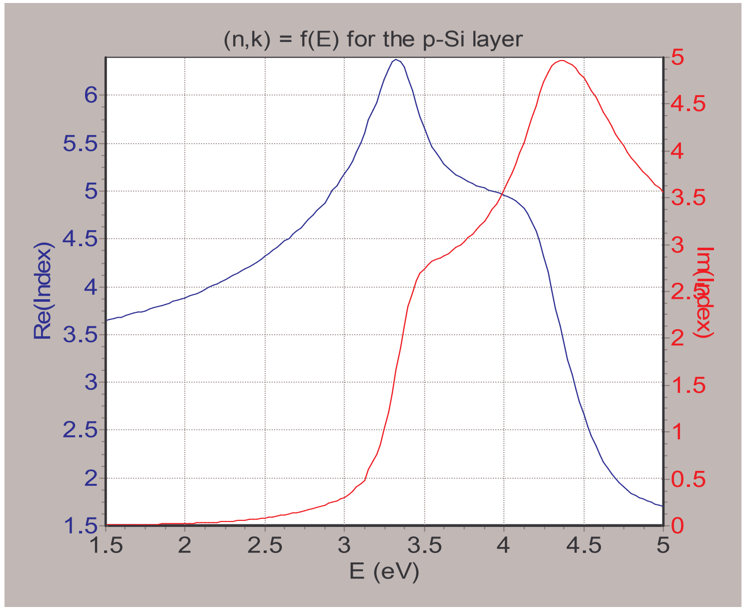
MULTI LAYER :

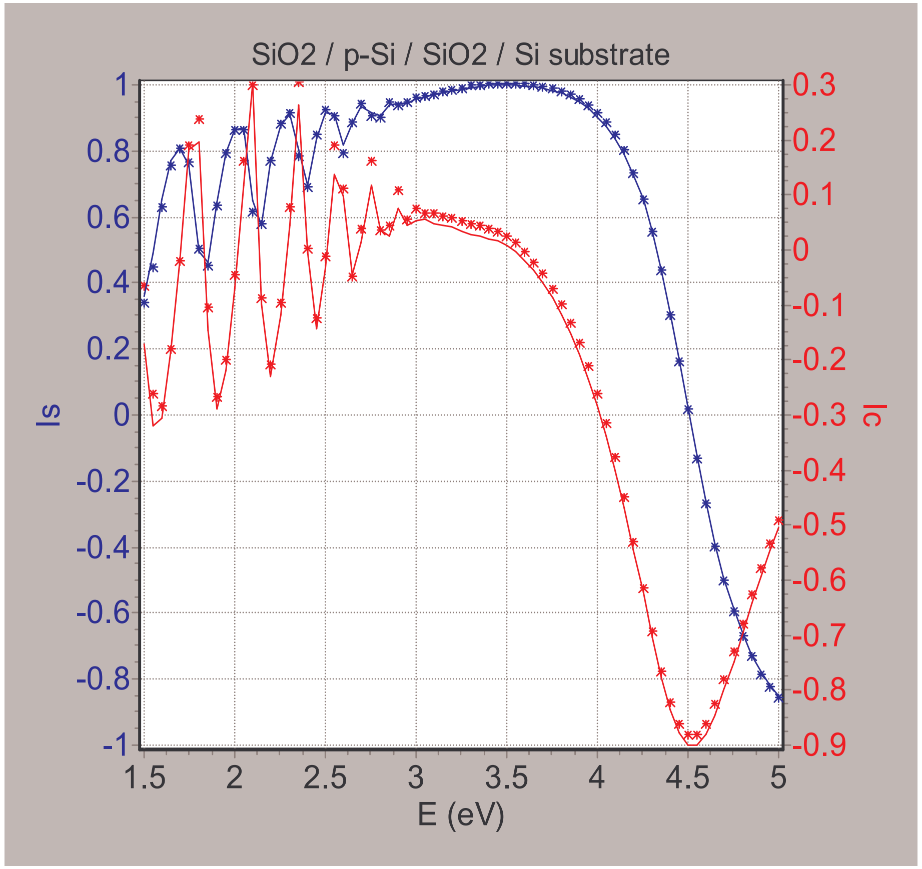
Importance of the UV range

Optical model



Sio$_2$
p-si
Sio$_2$
Si substrate

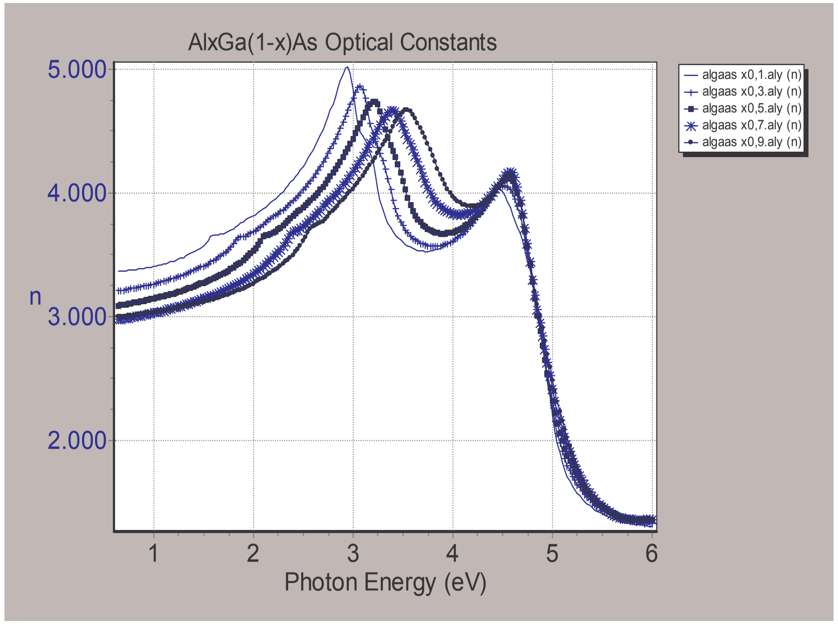


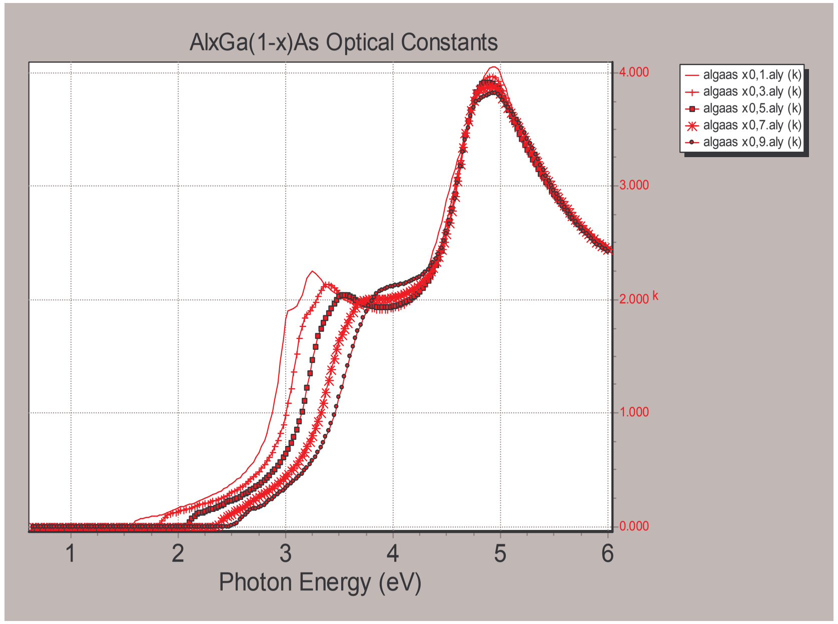


III-V Semiconductor
$Al_xGa_{1-x}As$

⇒ **Optical constants shift with varying alloy ratio x**

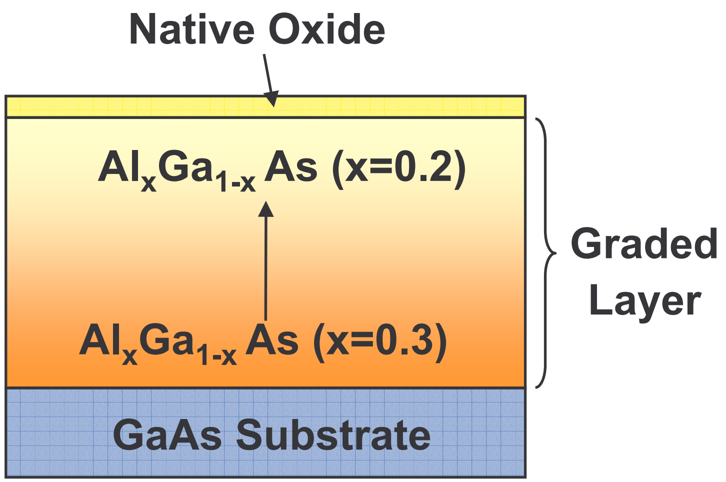
- Increasing Al increases the bandgap, which shifts the absorption edge to shorter wavelengths





Graded Layer Application

Optical Model



Native Oxide

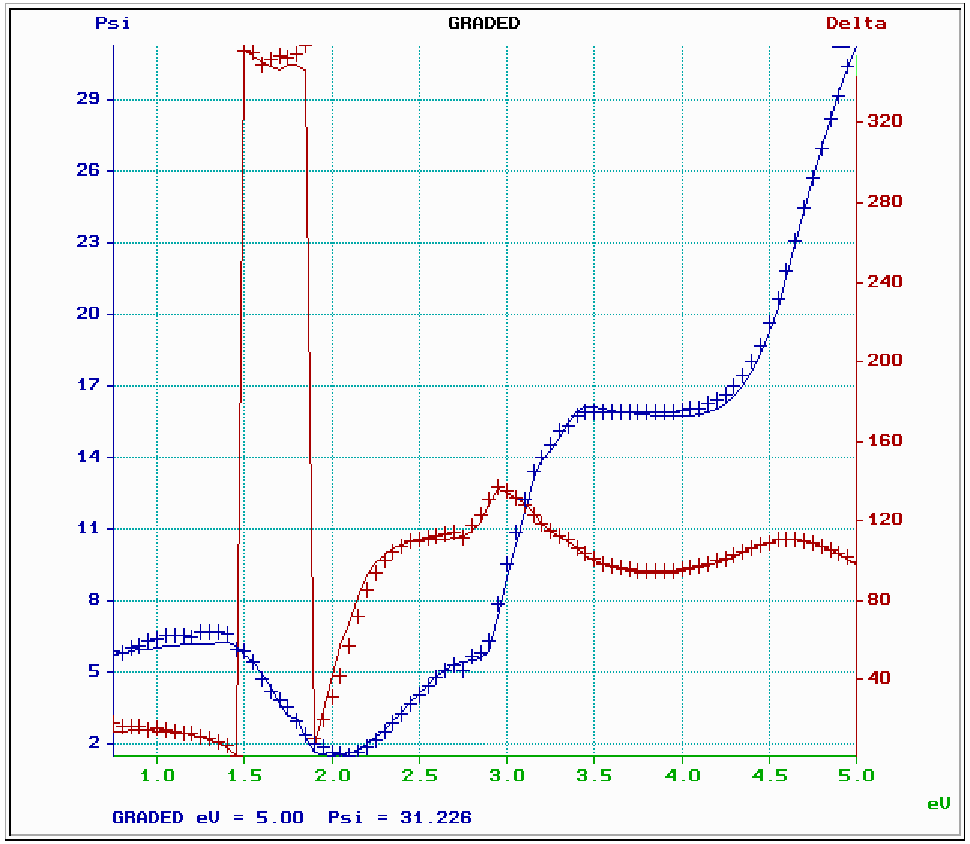
$Al_xGa_{1-x}As$ (x=0.2)

$Al_xGa_{1-x}As$ (x=0.3)

GaAs Substrate

Graded Layer

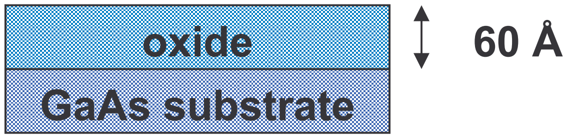
Measured Data & Simulated Data

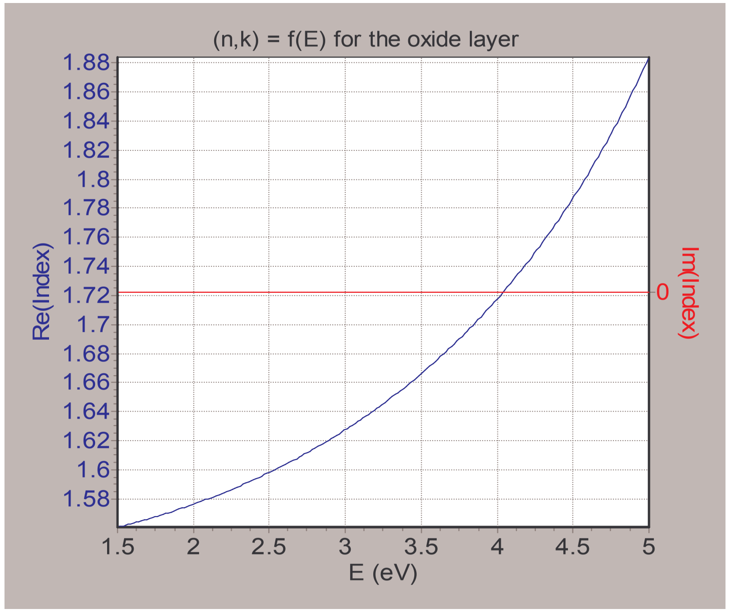


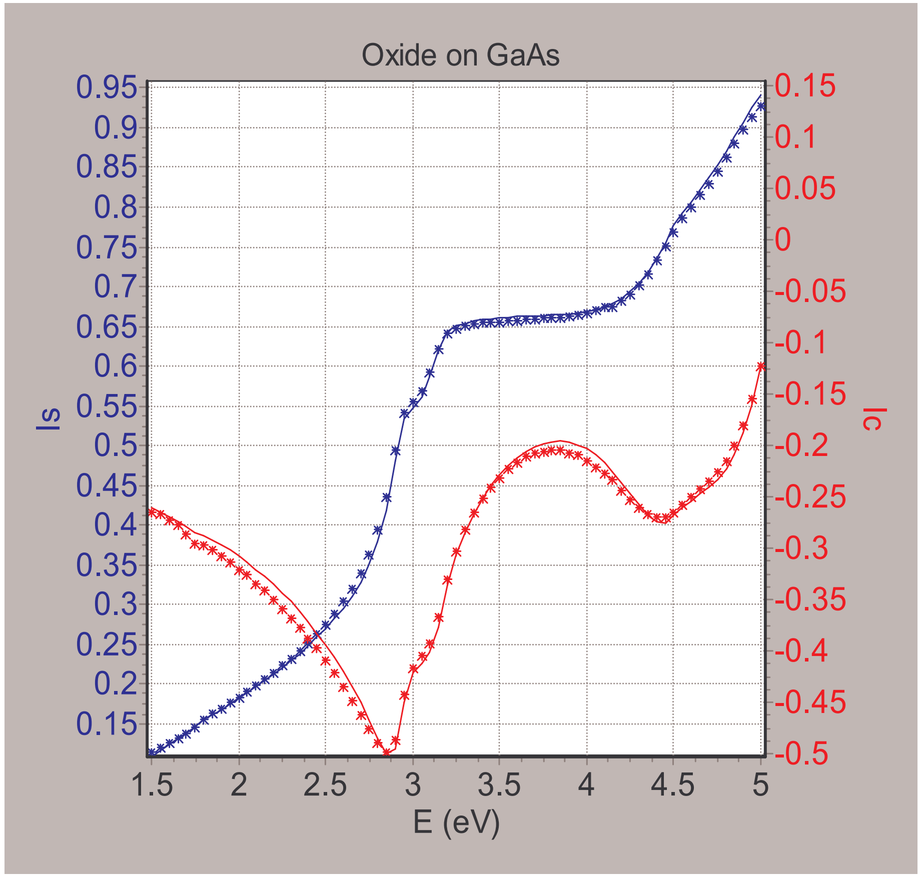
+++ Measured data
—— Simulated data

Native oxide on GaAs

Optical model

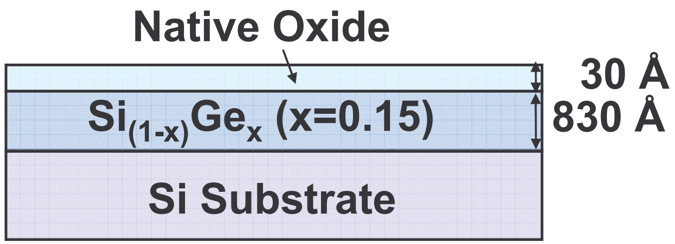






SiGe Application

Optical Model



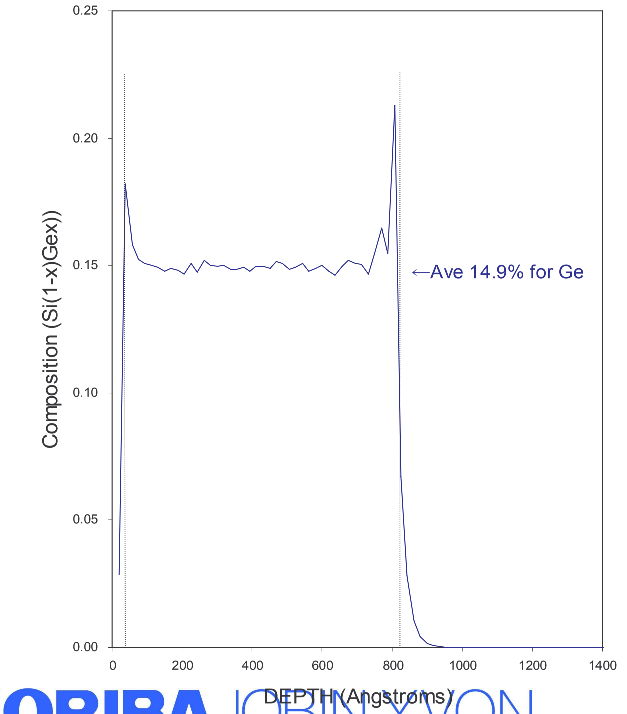
Native Oxide

$Si_{(1-x)}Ge_x$ (x=0.15)

Si Substrate

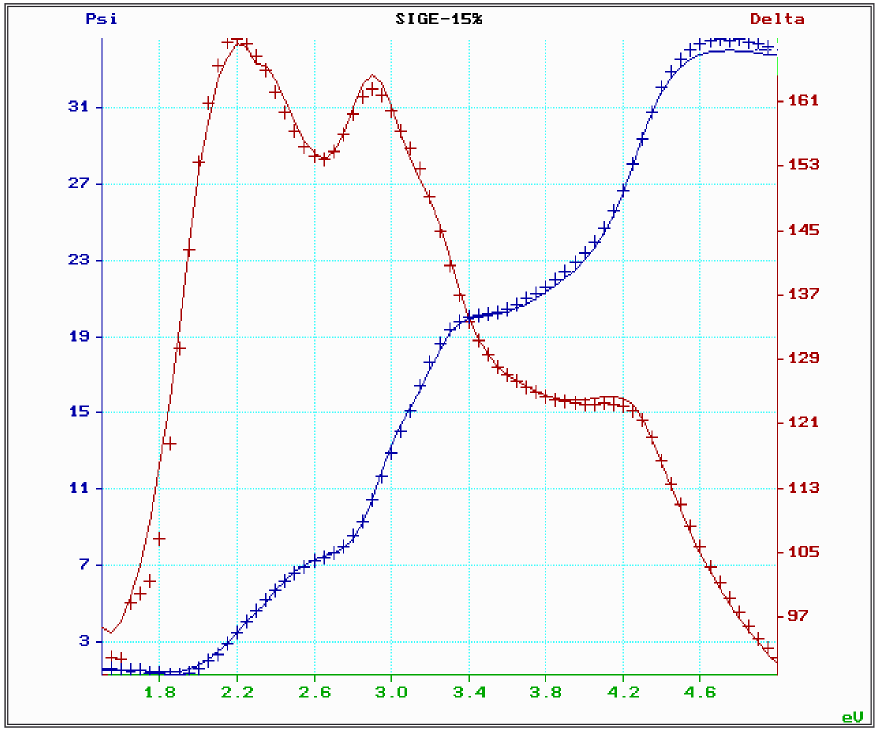
30 Å

830 Å



SIMS Data

Measured Data & Simulated Data

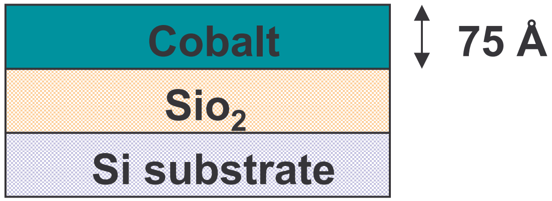


+++ Measured data

—— Simulated data

Metal Films
Thin Co on SiO_2

Optical model



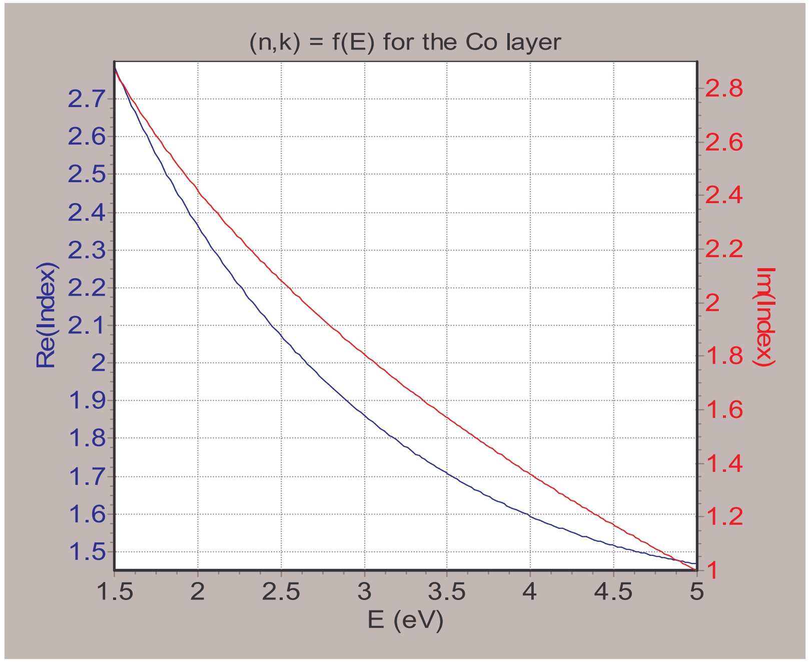
Cobalt

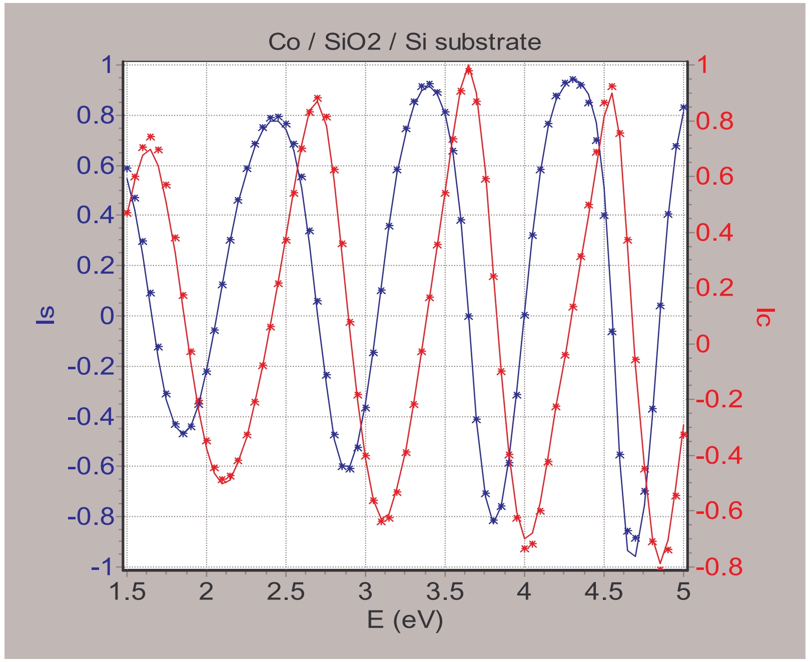
Sio_2

Si substrate

75 Å

Metal film **Usually opaque after 500-1000 Å**

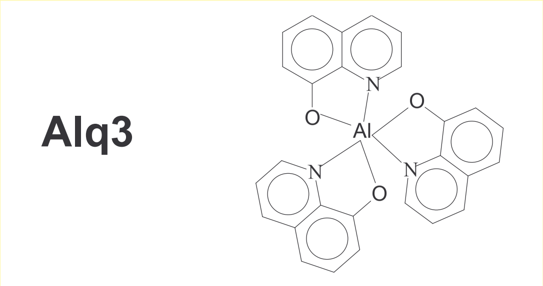


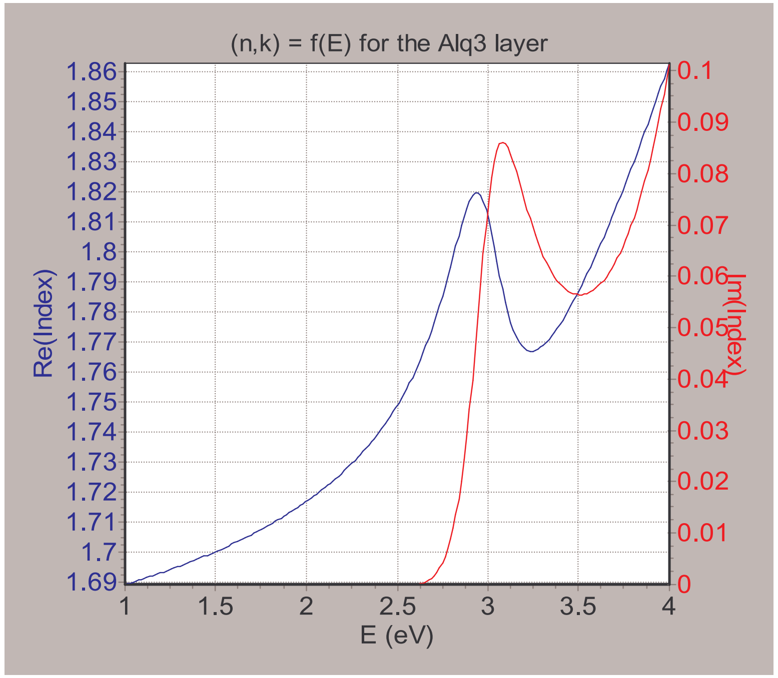


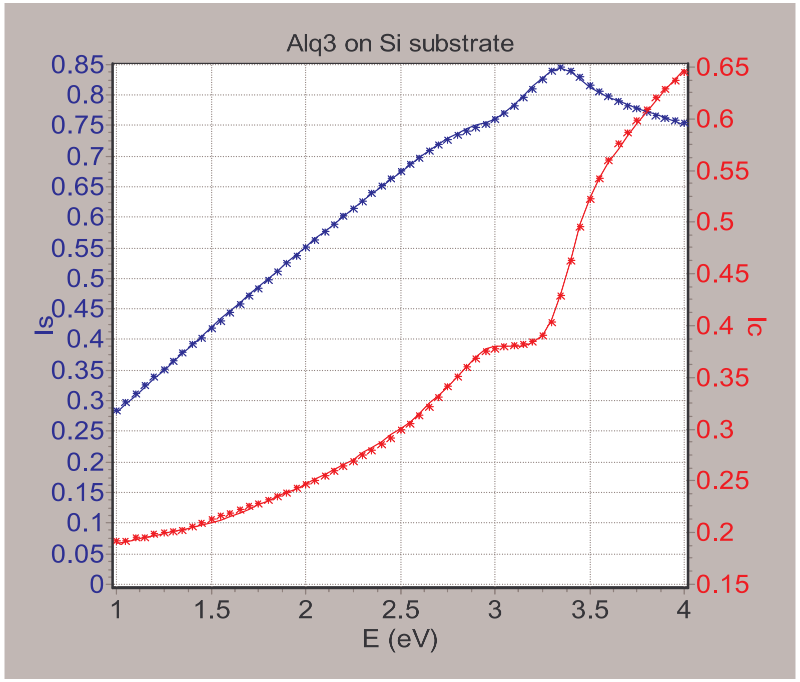
Electro luminescent Organic film on Si

Isotropic model

Optical model



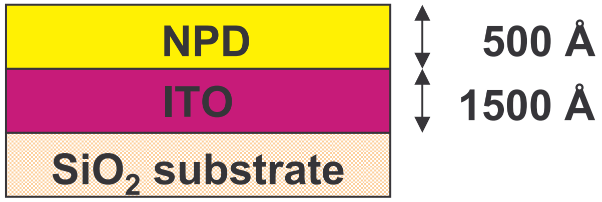




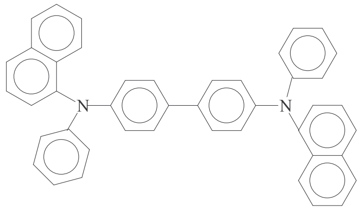
Electro luminescent Organic film on ITO on SiO_2 substrate

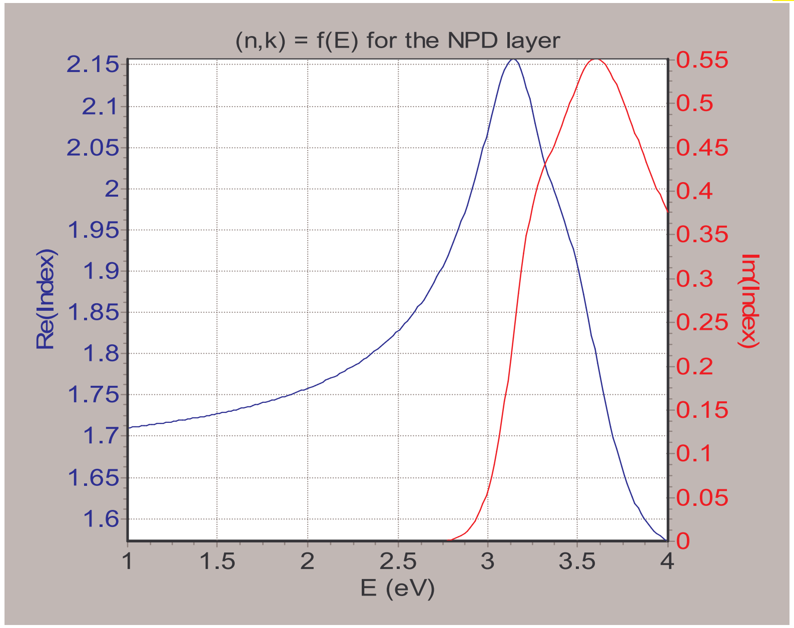
Isotropic model

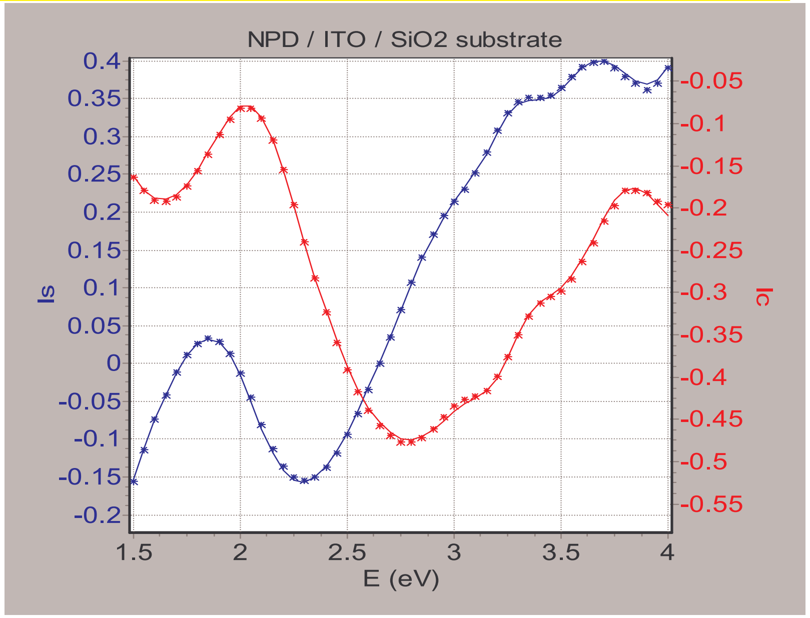
Optical model



- **Advanced dispersion formula included several oscillators has to be used**
- **NPD**



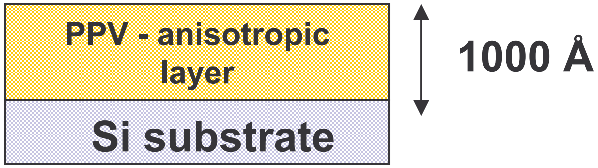




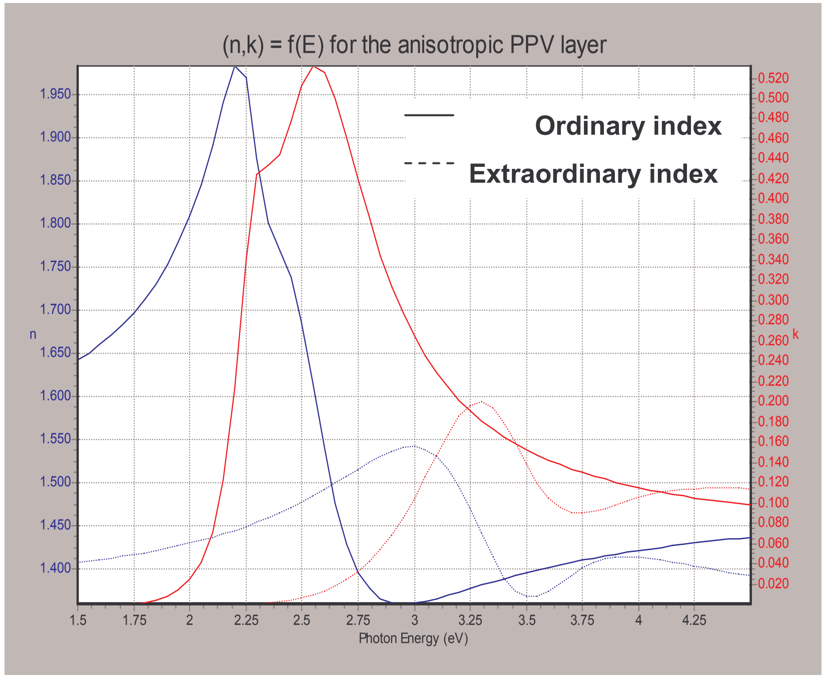
Conjugated Polymer Organic film on Si

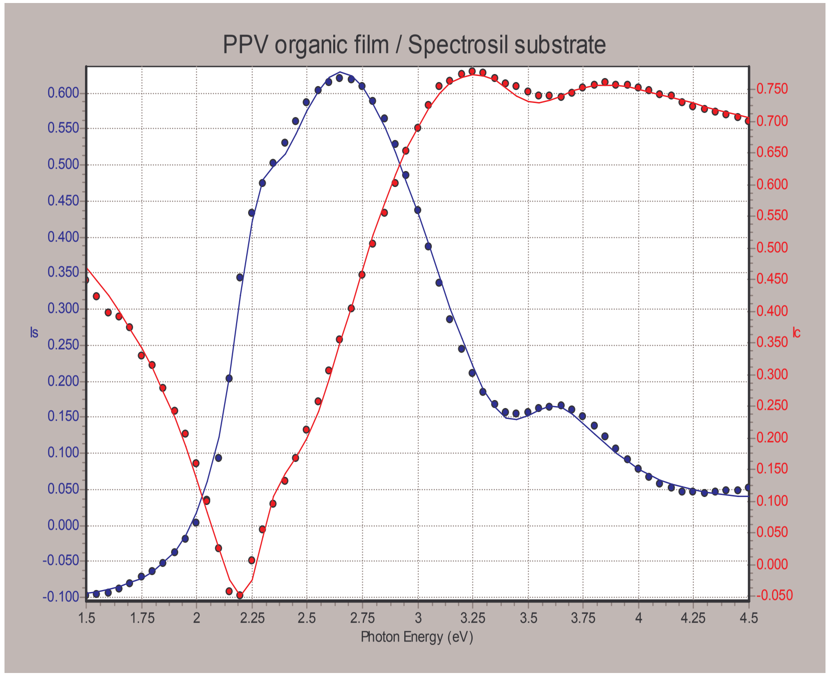
Anisotropic model

Optical model



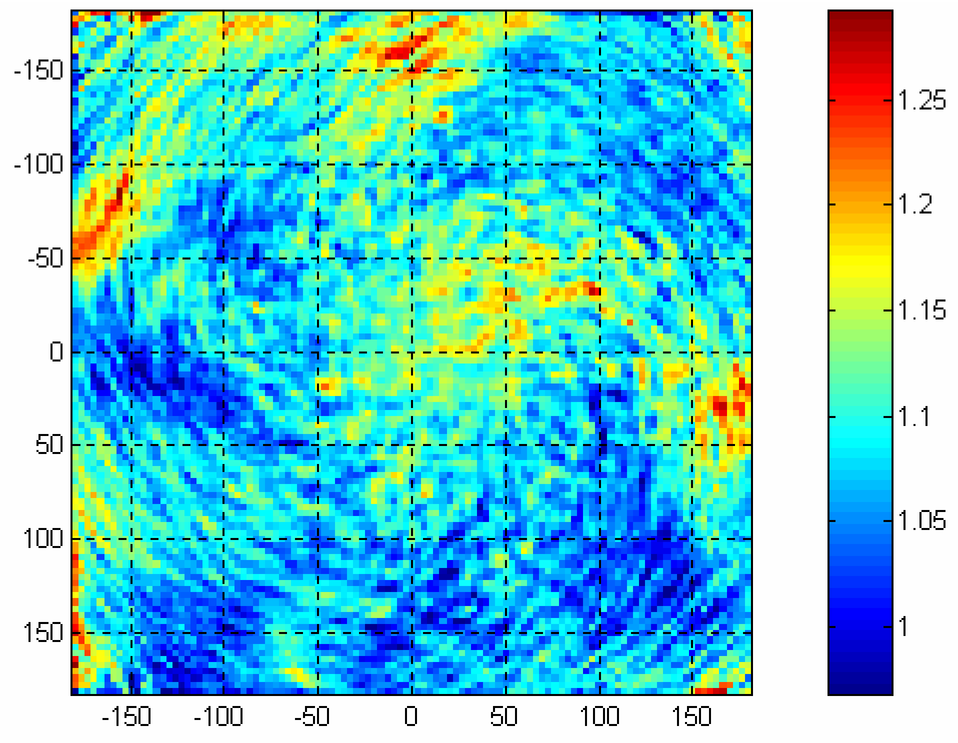
- **Uniaxial anisotropy model**
- **Optical axis normal to surface**





FILM UNIFORMITY

⇒ **Automated sample mapping for areal uniformity**



IN-SITU SE APPLICATIONS

In-situ spectroscopic ellipsometers are used in a wide variety of applications :

- plasma deposition
- plasma etching
- thermal oxidation
- CVD, sputtering
- MBE
- surface cleaning
- implantation
- corrosion
- electrochemistry

IN-SITU SE CAPABILITIES

- ✓ Thickness monitoring
- ✓ Growth and etch rates
- ✓ Endpoint detection
- ✓ Alloys detection
- ✓ Crystallinity
- ✓ Surface damage
- ✓ Contamination
- ✓ Surface temperature

CONCLUSION

- Spectroscopic Ellipsometry (SE) is a powerful tool for :
  - materials research
  - process development
  - manufacturing control

- JY offers :
  - a wide range of SE hardware options
  - powerful analysis software to extract results
  - our experience and support with a wide variety of applications