Welcome

to today's episode

R&D Applications of Spectroscopic Ellipsometry (SE)

Advanced Insights for Process Control and Property Monitoring

Jianing Sun, PhD
Applications Engineer,
J.A. Woollam Co.

OCT 17, 2024
11 AM Pacific Time



COVALENT ACADEMY
Industrial Applications of Advanced Metrology
Episode 40

J.A. Woollam Co., Inc.
Ellipsometry Solutions

COVALENT METROLOGY

COVALENT METROLOGY

Modern, digitally-empowered analytical services platform delivering quality data and expert analysis to accelerate advanced materials and device innovation.



Comprehensive Solutions Stack

50+ Cutting-edge instruments in-house, 150+ Techniques

Analytical Services

Advanced Modeling

Method Development

Custom Consulting Solutions



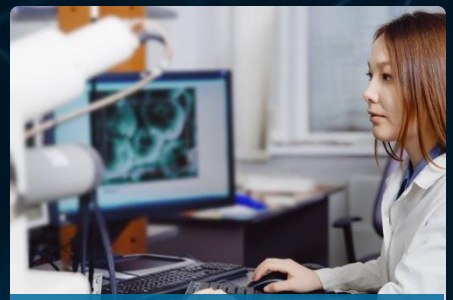
High-touch, High-Quality Services

Ionic Membership Program

Enterprise Metrology Solutions

Instant, Secure Access to Data and Reports

Expanding Toolkit in Custom Digital Platform



Flexible Business Models

LiveView™ (real-time collaboration)

Co-op and Tool-share Opportunities

Training and Certification on Instrumentation

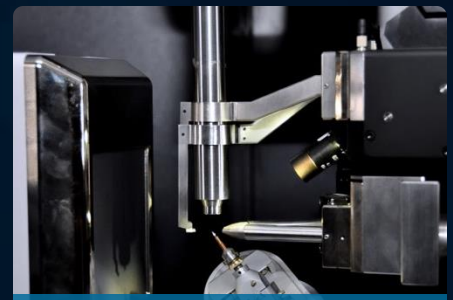
Laboratory Audits

Rich Network of Partnerships

Partner to World's Leading Instrument Manufacturers and Labs

Expanding access to Advanced Instruments and Analysis Tools

Lab Connections and Applications Learning



Who We Are, Who We Serve

50+ People, 14 PhDs

Comprehensive, Modern Analytical Capabilities

Headquarter Lab in Sunnyvale, CA

600+ Clients, 15-30 new clients / week

Covalent's Analytical Services & Technical Groups

COVALENT METROLOGY

Enterprise Metrology Solutions: Failure Analysis & EM



Electron Microscopy

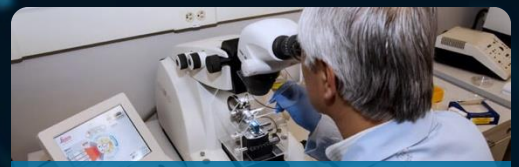
- S/TEM
  with EDS; EELS; Electron Diffraction; SAED
- FIB-SEM & HR-SEM
  with EDS; EBSD; 3D Tomography
- Lamella Preparation
  incl. specialized lift-outs



Failure Analysis

- DPA / Mechanical X-section
- Dye & Pry Test
- EBIC / OBIC failure analysis
- Hot Spot Detection
- NIR / IR Imaging
- Emission Microscopy
- Root-Cause Failure Analysis

Materials, Chemicals, and Surfaces



Microscopy & Profilometry

- Chromatic Aberration
- Digital Optical Microscopy
- Laser Scanning Confocal Microscopy
- White Light Interferometry
- Scanning Acoustic Microscopy (SAM)



Analytical Chemistry

- Mass Spectroscopy: ICP-MS and LA-ICP-MS; GCMS
- ICP-OES / GDOES
- Raman
- NMR (solid / liquid + 1,2,3 nuclei)
- XPS, UPS, ISS
- SIMS, TOF-SIMS



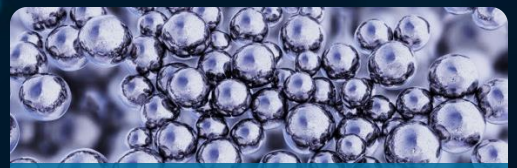
X-ray Characterization

- X-Ray Diffraction (XRD)
- X-Ray Reflectometry (XRR)
- Micro-computed X-ray Tomography (Micro-CT)
- 2D / 2.5D / 3D X-ray Inspection & X-ray Radiography
- ED-XRF / WD-XRF



Mechanical Testing

- AFM & Advanced AFM Modes (EFM, KPFM, MFM, PFM, PiFM)
- Nano-indent / Nano-scratch
- Rheometry / Viscosity
- DMA / TMA (bend/stretch/compression)
- Tensile testing



Misc. Material Properties

- Thermal Analysis: DSC, TGA
- Surface Zeta Potential
- Porometry / Pycnometry
- Gas Adsorption / Chemisorption
- Foam Density / Skeletal Density / Tap Density
- Particle Analysis: DLS / ELS / size distribution / zeta potential



Optical Characterization

- Fourier Transformed Infrared Spectroscopy (FTIR and ATR-FTIR)
- **Spectral Ellipsometry & Advanced Optical Modeling**
- UV-Vis-NIR Spectroscopy

Introducing today's speaker…

COVALENT METROLOGY

Dr. Jianing Sun

Applications Engineer, J.A. Woollam

- Dr. Jianing Sun joined the J.A. Woollam Company in 2008
- Has since worked as an applications engineer for over 16 years
- Extensive track record in developing ellipsometry techniques for thin-film research
    - Particularly w/ focus on semiconductors and materials science
- Dr. Sun completed her Bachelor's and Master's of Science degrees in Chemical Engineering at Tsinghua University
- She received her PhD in Materials Science and Engineering at the University of Michigan.



J.A. Woollam Co., Inc.
Ellipsometry Solutions

Covalent Webinar
October 2024

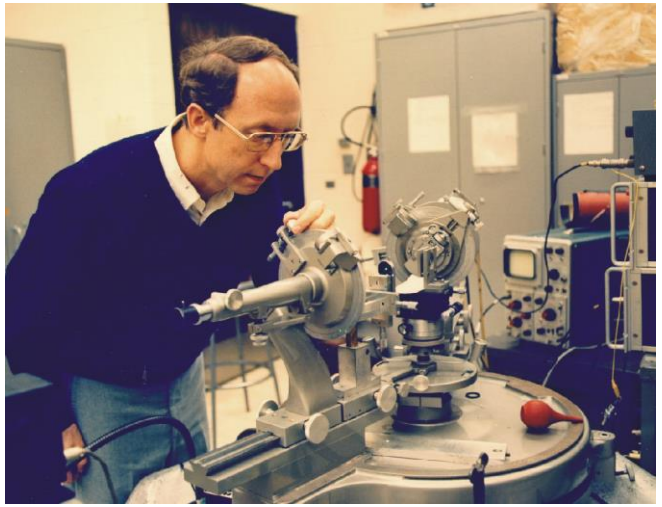
R&D Applications of Spectroscopic Ellipsometry (SE)

Dr. Jianing Sun



J.A. Woollam

J.A. Woollam Company



FOUNDED IN 1987

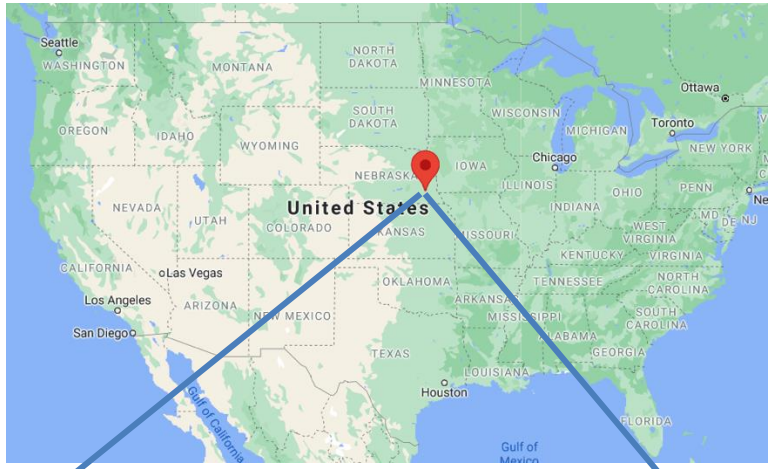
PROF. JOHN A WOOLLAM



70+ EMPLOYEES



200+ PATENTS





Woollam Ellipsometers

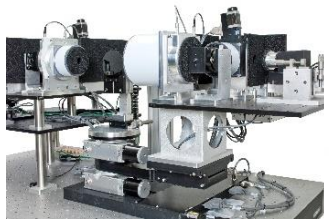














Start SBIR Contracts

M-44/M-88©

IR-VASE©

VUV-VASE©

RC2©

RC2-XF©

THZ-VASE©

Theta-SE©

1987

1997

Timeline

2007

2017

VASE©

M-2000©

Alpha-SE©

T-Solar©

AccuMap-SE©

iSE©

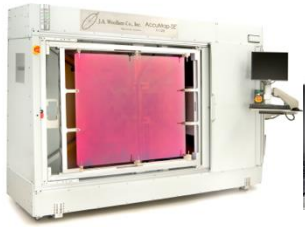
Alpha 2.0©

















Monochromator-Based | Diode-array & CCD Detection | FTIR | THz

140 nm | 193 nm | 370 nm | 1µm | 2.5µm | 40µm | 200µm | 3mm

VUV | UV | VISIBLE | NIR | IR | Far-IR | THz

1987

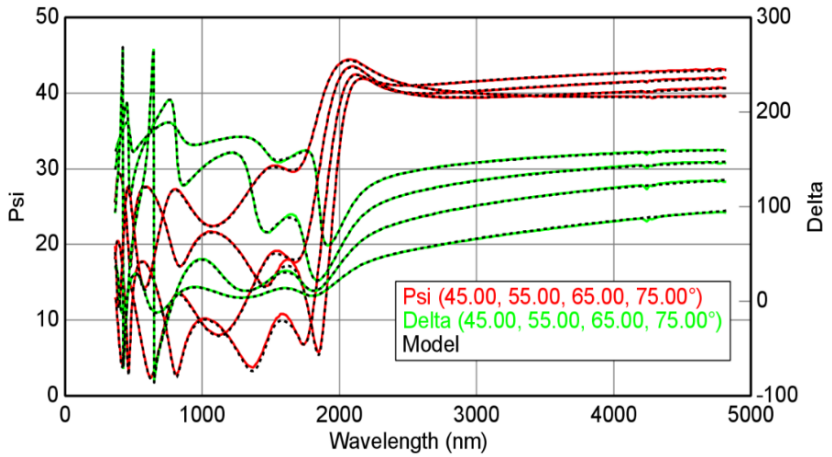
Current

Current

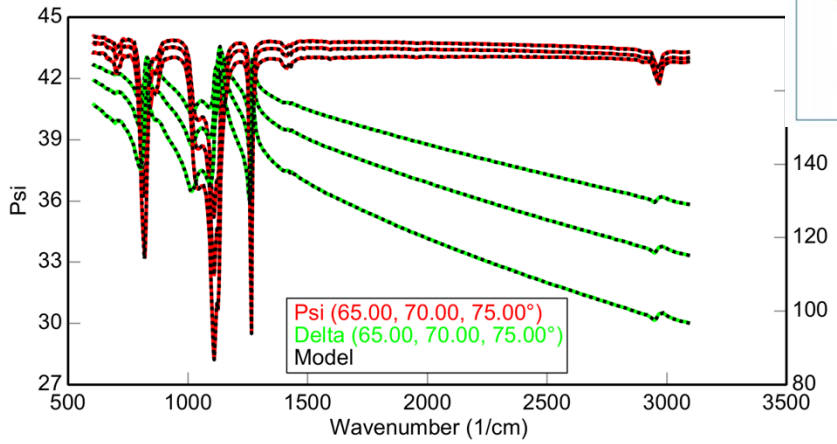
Current

Current

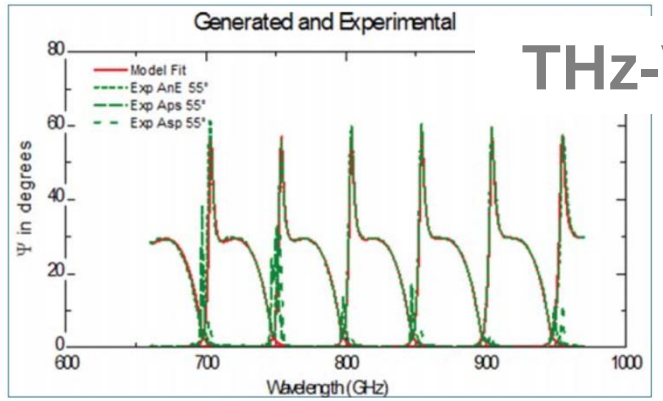
VASE (190nm to 4um)

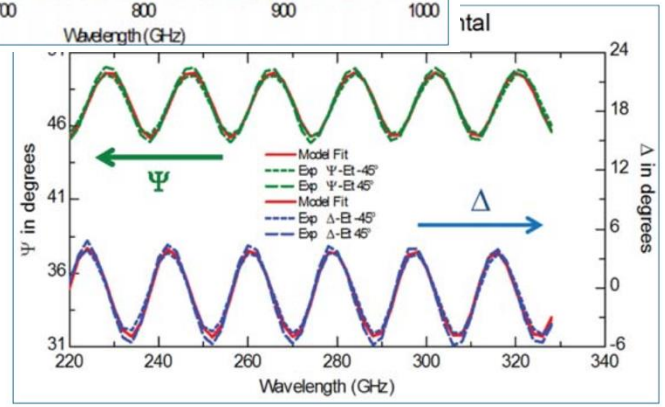


IR-VASE (1.7um to 30um)



THz-VASE





Light and Polarization

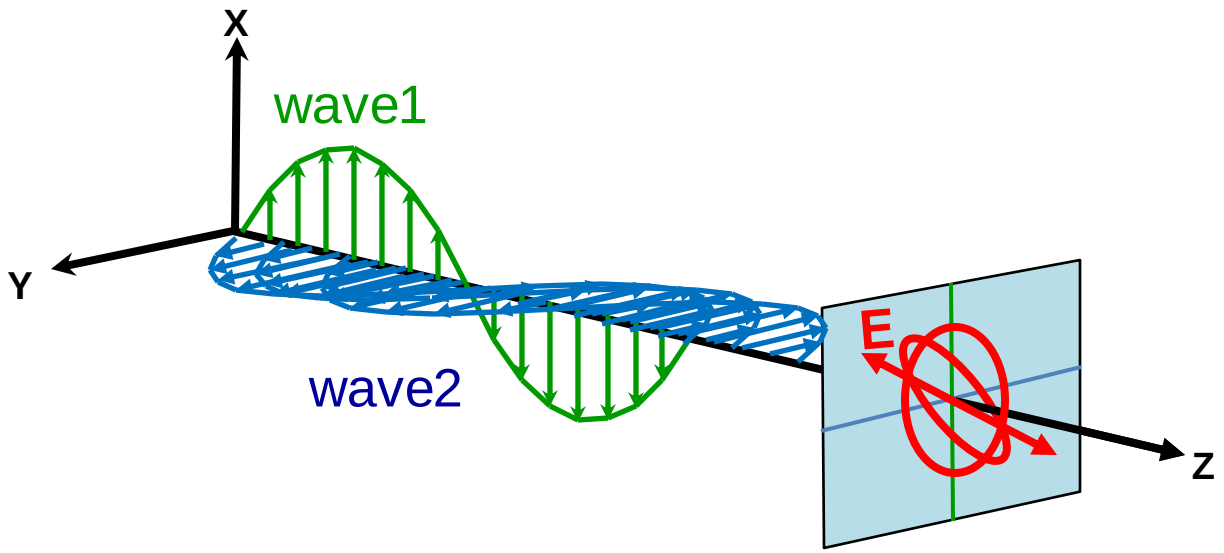
- **Light**
  - Electromagnetic plane Wave

$$\vec{E}(z,t) = \vec{E}_0 \sin\left(-\frac{2\pi}{\lambda}(z - vt) + \xi\right)$$

  - Particle (photon)

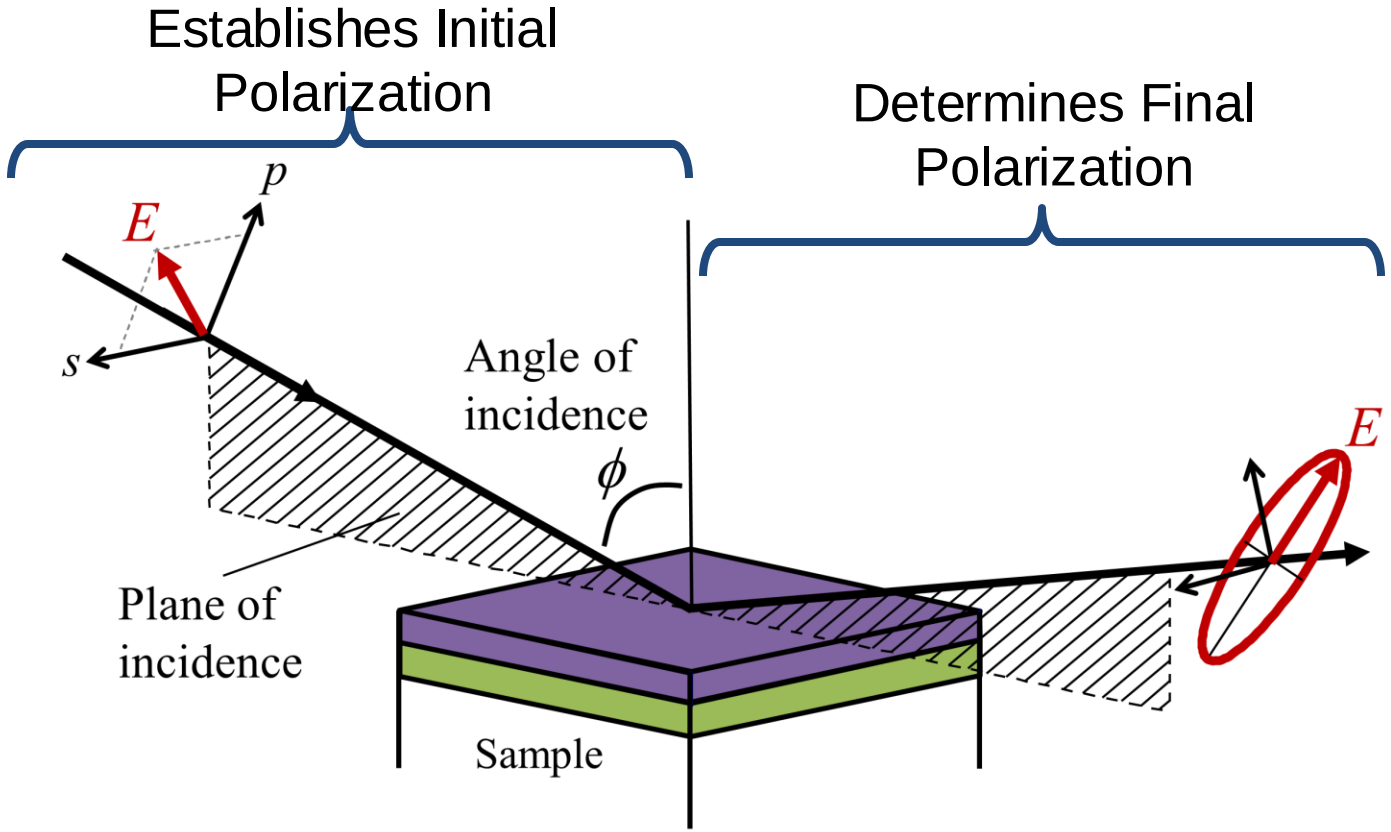
$$E(eV) = h\upsilon \cong \frac{1{,}240}{\lambda(nm)}$$

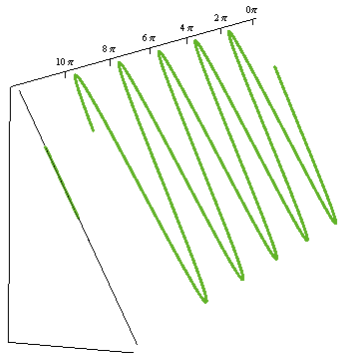
- **Polarization:** Describes <u>shape</u> of Electric Field relative to direction of travel.

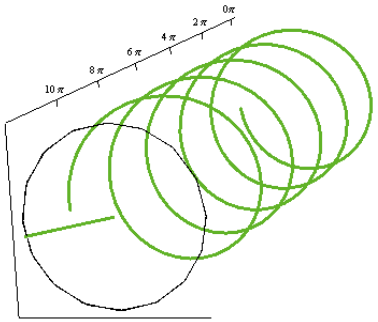


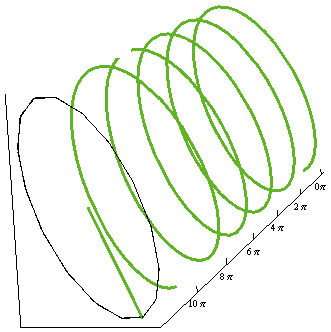
© 2024 J.A. Woollam

Optical Technique - Measures **POLARIZATION** changes







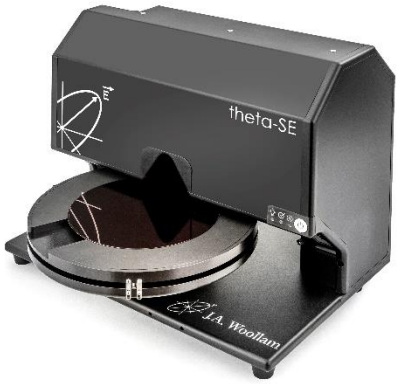


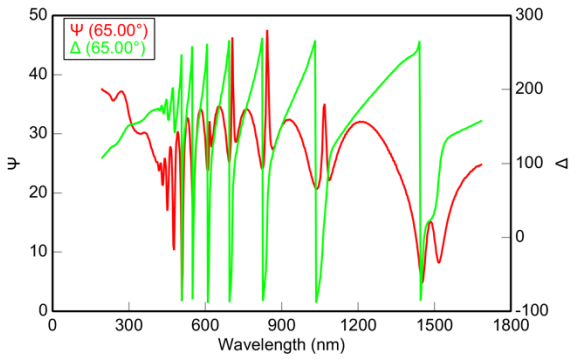
$$\frac{\tilde{E}_p}{\tilde{E}_s}$$

$$\frac{r_p}{r_s} = \frac{E_{out_p} / E_{in_p}}{E_{out_s} / E_{in_s}} = \frac{\left|E_{out_p}\right| / \left|E_{in_p}\right|}{\left|E_{out_s}\right| / \left|E_{in_s}\right|} e^{i\left(\delta_p - \delta_s\right)} = \tan(\psi) e^{i\Delta}$$

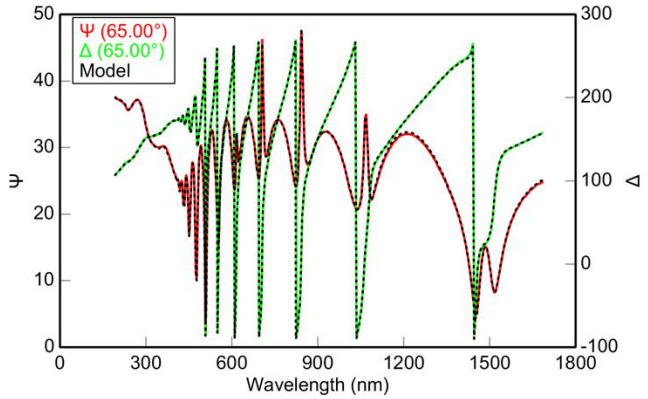
Basics Of Spectroscopic Ellipsometry (SE)

MEASUREMENT

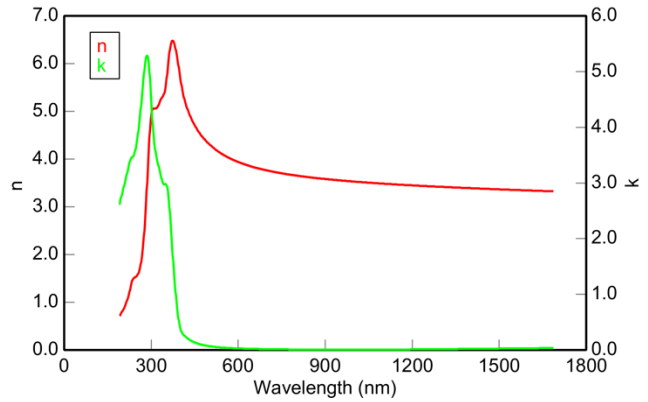




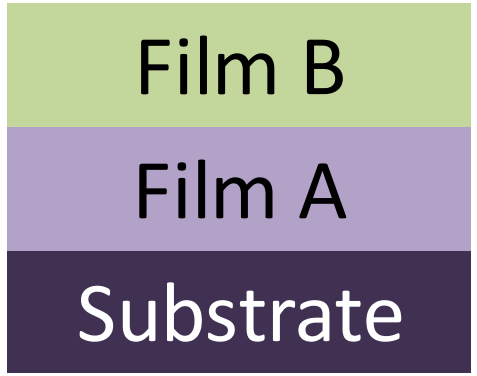
FIT

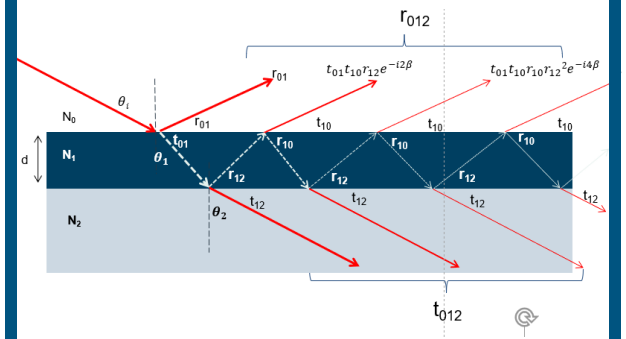


RESULTS



MODEL





H.G. Tompkins and J.N. Hilfiker “Spectroscopic Ellipsometry: Practical Application to Thin Film Characterization” (2016) Momentum Press.

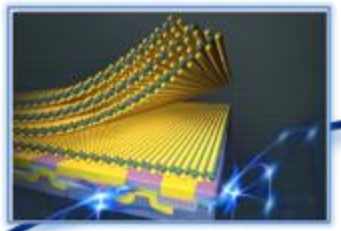
What does Spectroscopic Ellipsometry do?



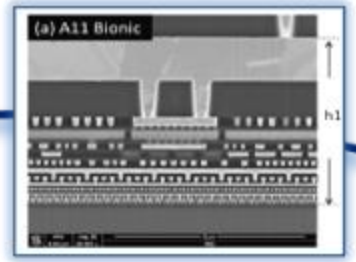
Sensitive to physical effects or processes that change material optical properties or film thickness

- Layer thickness and Uniformity
- Refractive Index / Optical Constants
- Grading and Roughness
- Composition / Bandgap / Conductivity/ Porosity /Chemical bonds
- Anisotropy
- Retardance/ Chirality
- In-situ Monitoring / Dynamic Properties

Spectroscopic Ellipsometry Applications



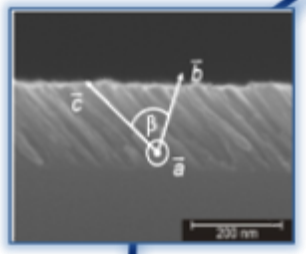
2D Materials



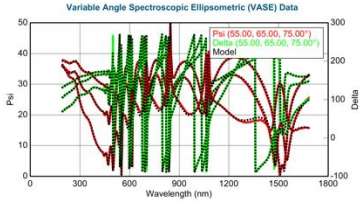
Semiconductor



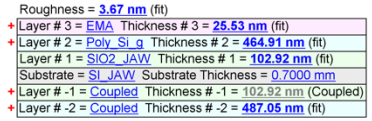
Compound Photonics

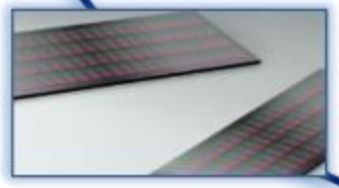


Structural Materials









Biotech/Chemistry



Optical Coatings



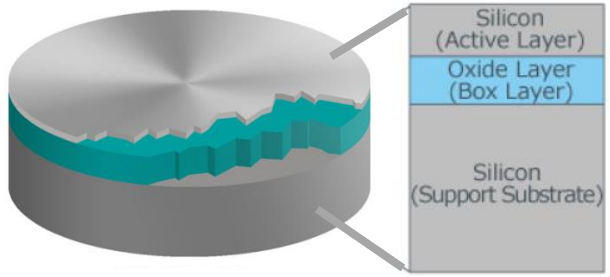
Photovoltaic



Display AR/VR

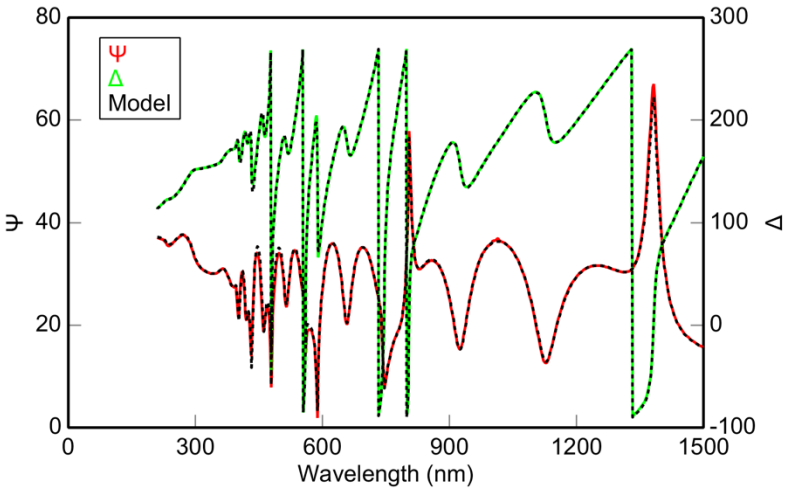
SPECTROSCOPIC ELLIPSOMETRY IS USED ON THIN FILMS FROM SUB-NM TO TENS OF MICRONS

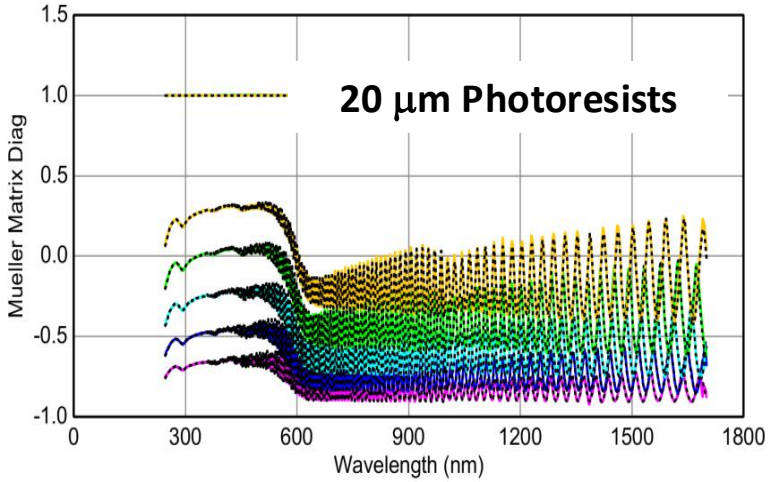
Layer thickness and Uniformity

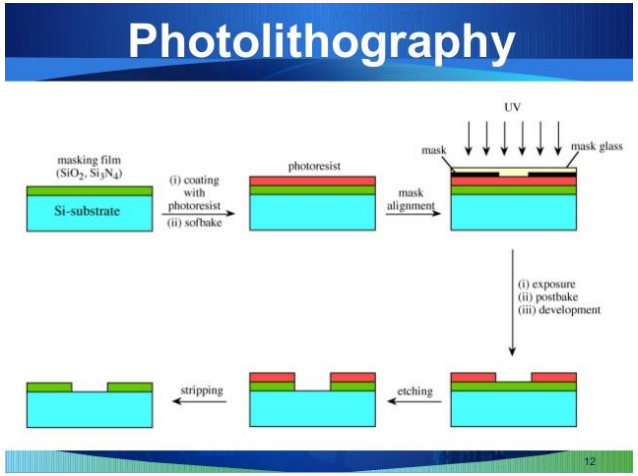


Layer # 4 = NTVE_JAW Thickness # 4 = **1.83 nm** (fit)
Layer # 3 = Si_JAW Thickness # 3 = **218.56 nm** (fit)
Layer # 2 = SIO2_JAW Thickness # 2 = **2007.69 nm** (fit)
Layer # 1 = INTR_JAW Thickness # 1 = 1.00 nm
Substrate = SI_JAW

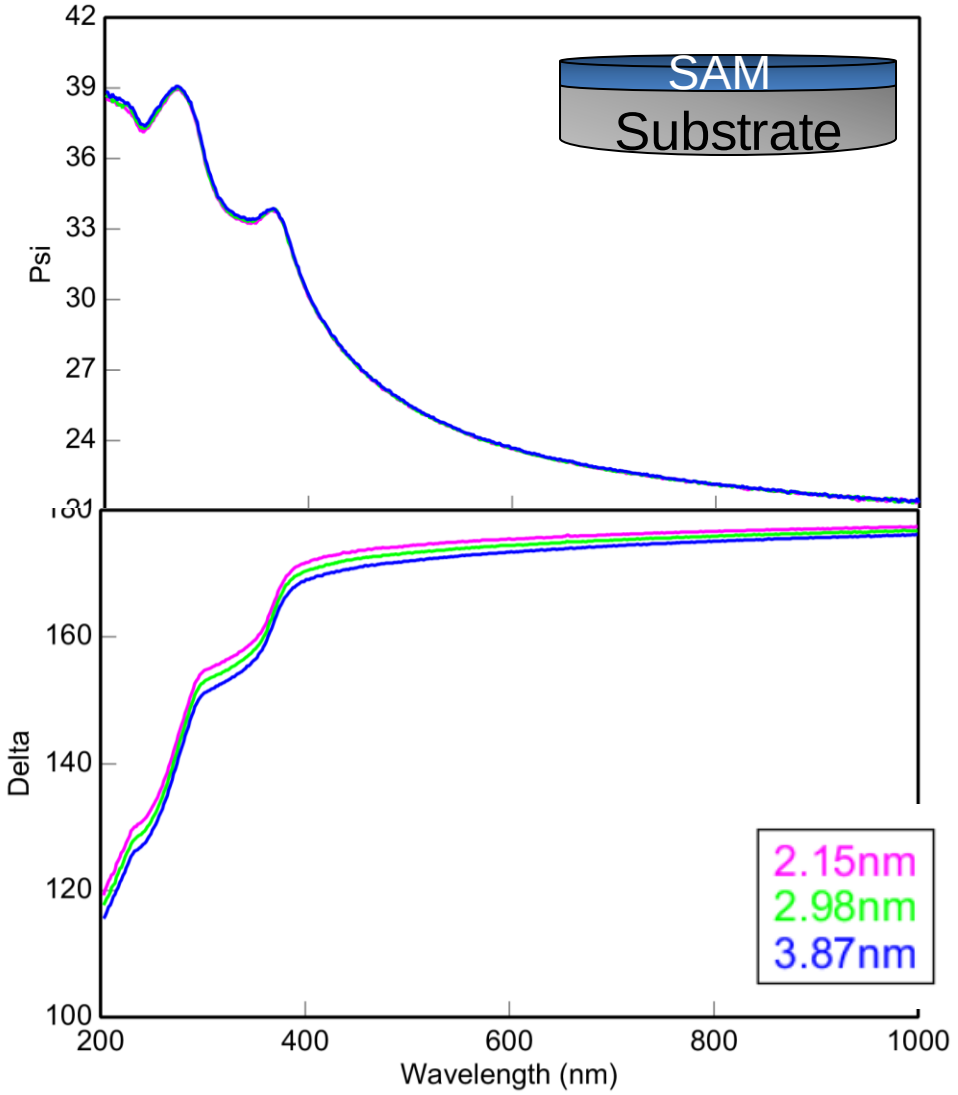
Spectroscopic Ellipsometric (SE) Data





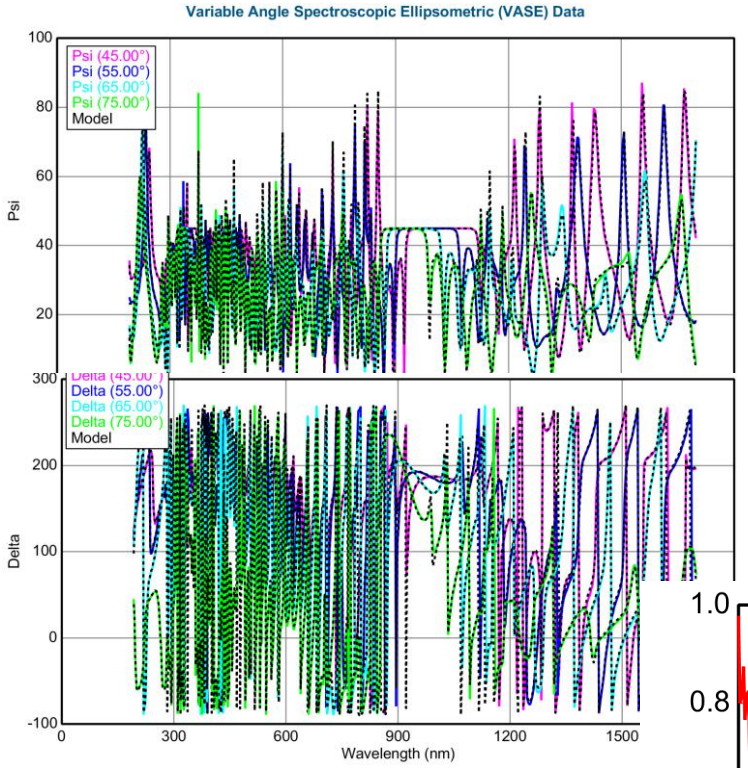


SAM thickness

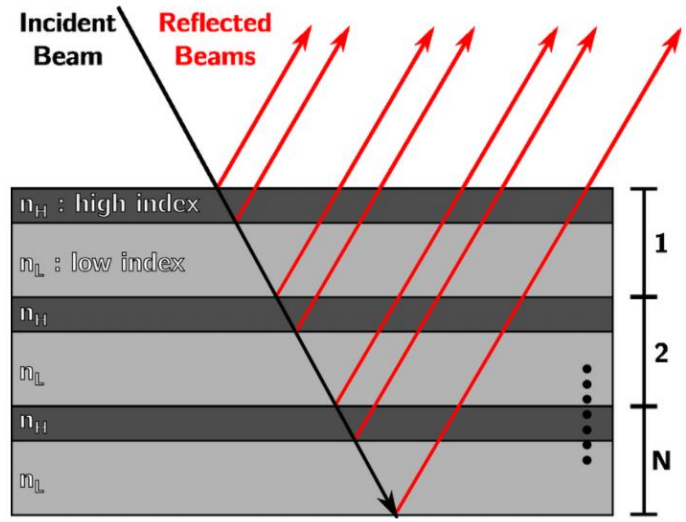


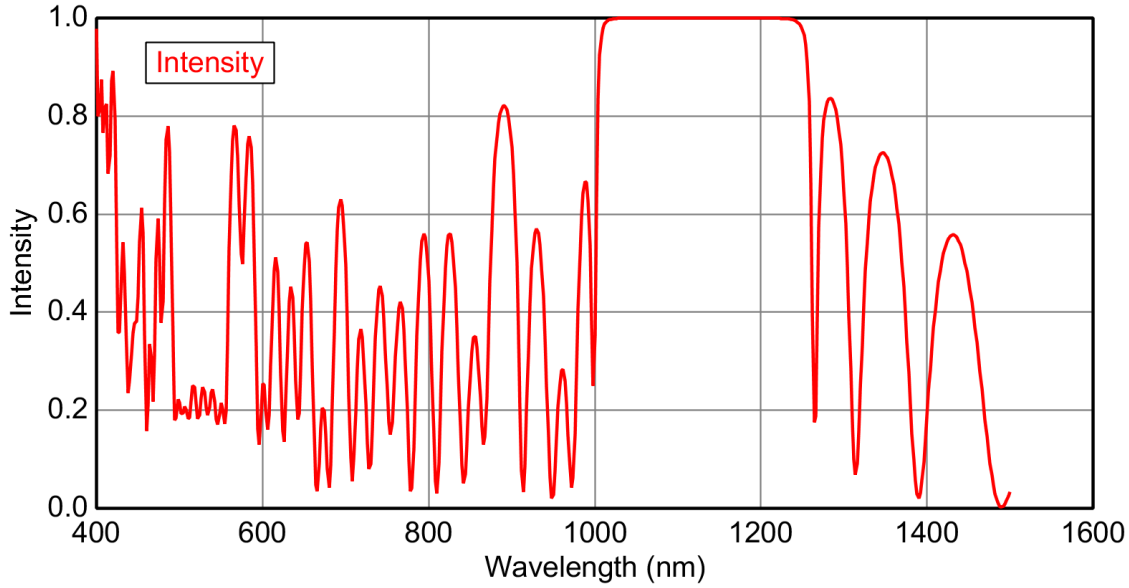
Distributed Bragg Reflector (DBR)

- Layer # 37 = Coupled Thickness # 37 = 2178.27 Å (Coupled)
Coupled to Layer # = 1 (Low-N)
- Layer # 36 = Coupled Thickness # 36 = 1123.46 Å (Coupled)
Coupled to Layer # = 2 (High-N)
+ Layer # 35 = Coupled Thickness # 35 = 2173.29 Å (Coupled)
+ Layer # 34 = Coupled Thickness # 34 = 1057.20 Å (Coupled)
+ Layer # 33 = Coupled Thickness # 33 = 2180.22 Å (Coupled)
+ Layer # 32 = Coupled Thickness # 32 = 1331.27 Å (Coupled)
+ Layer # 31 = Coupled Thickness # 31 = 2177.20 Å (Coupled)
+ Layer # 30 = Coupled Thickness # 30 = 1052.14 Å (Coupled)
+ Layer # 29 = Coupled Thickness # 29 = 2174.35 Å (Coupled)
+ Layer # 28 = Coupled Thickness # 28 = 1356.36 Å (Coupled)
+ Layer # 27 = Coupled Thickness # 27 = 1912.56 Å (Coupled)
+ Layer # 26 = Coupled Thickness # 26 = 1172.64 Å (Coupled)
+ Layer # 25 = Coupled Thickness # 25 = 2022.40 Å (Coupled)
+ Layer # 24 = Coupled Thickness # 24 = 1130.44 Å (Coupled)
+ Layer # 23 = Coupled Thickness # 23 = 2115.53 Å (Coupled)
+ Layer # 22 = Coupled Thickness # 22 = 1299.21 Å (Coupled)
+ Layer # 21 = Coupled Thickness # 21 = 2174.35 Å (Coupled)
+ Layer # 20 = Coupled Thickness # 20 = 1175.68 Å (Coupled)
+ Layer # 19 = Coupled Thickness # 19 = 2171.33 Å (Coupled)
+ Layer # 18 = Coupled Thickness # 18 = 1189.74 Å (Coupled)
+ Layer # 17 = Coupled Thickness # 17 = 1672.44 Å (Coupled)
+ Layer # 16 = Coupled Thickness # 16 = 1319.23 Å (Coupled)
+ Layer # 15 = Coupled Thickness # 15 = 2123.35 Å (Coupled)
+ Layer # 14 = Coupled Thickness # 14 = 1298.20 Å (Coupled)
+ Layer # 13 = Coupled Thickness # 13 = 2073.40 Å (Coupled)
+ Layer # 12 = Coupled Thickness # 12 = 1242.93 Å (Coupled)
+ Layer # 11 = Coupled Thickness # 11 = 1717.59 Å (Coupled)
+ Layer # 10 = Coupled Thickness # 10 = 1333.30 Å (Coupled)
+ Layer # 9 = Coupled Thickness # 9 = 1841.11 Å (Coupled)
+ Layer # 8 = Coupled Thickness # 8 = 1155.58 Å (Coupled)
+ Layer # 7 = Coupled Thickness # 7 = 2052.79 Å (Coupled)
+ Layer # 6 = Coupled Thickness # 6 = 1341.28 Å (Coupled)
- Layer # 5 = Coupled Thickness # 5 = 2060.61 Å (Coupled)
Coupled to Layer # = 1 (Low-N)
- Layer # 4 = Coupled Thickness # 4 = 1260.06 Å (Coupled)
Coupled to Layer # = 2 (High-N)
- Layer # 3 = Coupled Thickness # 3 = 2172.40 Å (Coupled)
Coupled to Layer # = 1 (Low-N)
+ Layer # 2 = High-N Thickness # 2 = **1267.03 Å** (fit)
+ Layer # 1 = Low-N Thickness # 1 = **1777.31 Å** (fit)
Substrate = SI_JAW

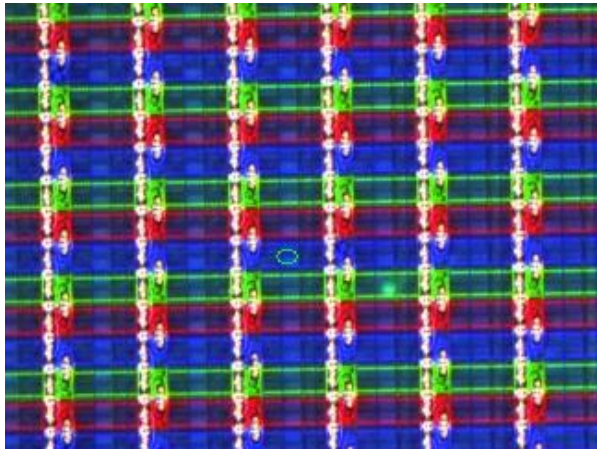


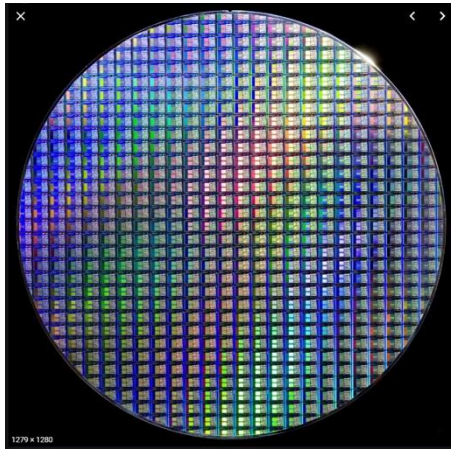




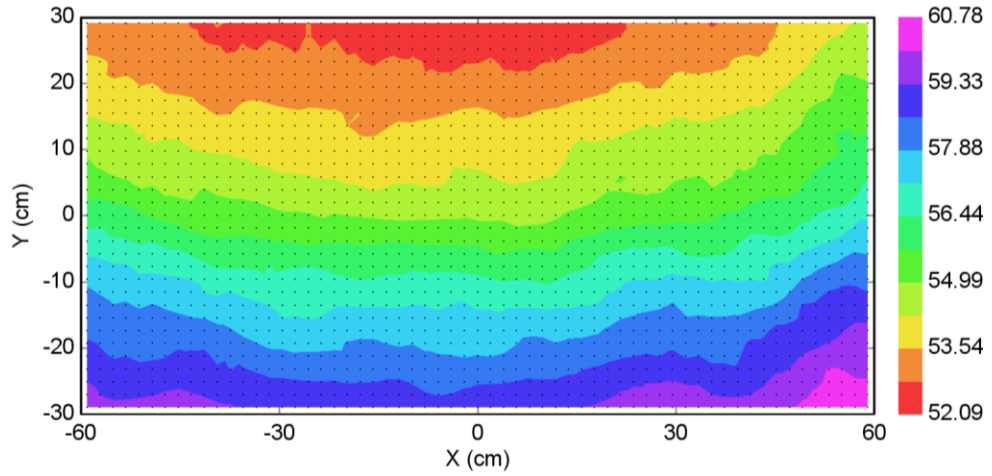


Uniformity

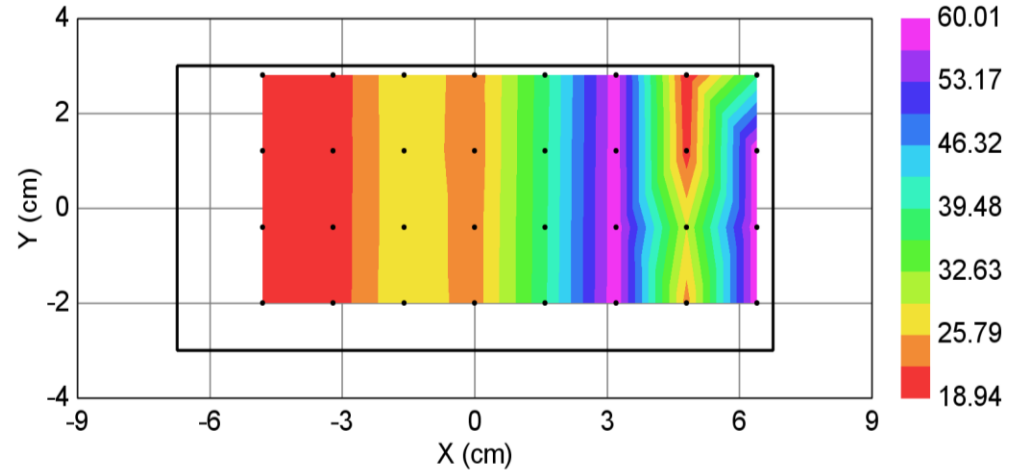




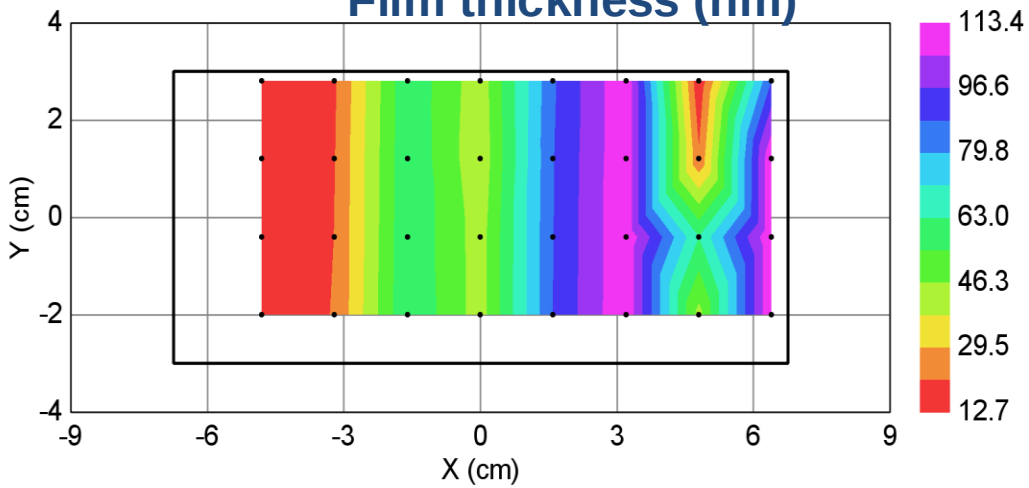
Film on PV Panels (nm)



Ellipsometry Raw Data: Psi



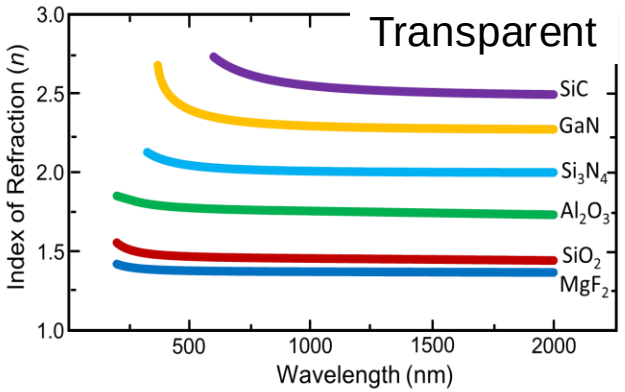
Film thickness (nm)

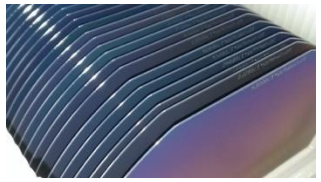


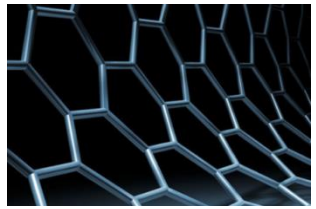
© 2024 J.A. Woollam

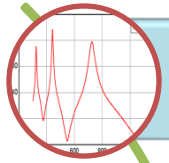




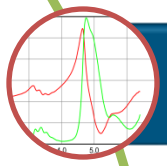








Layer thickness and Uniformity

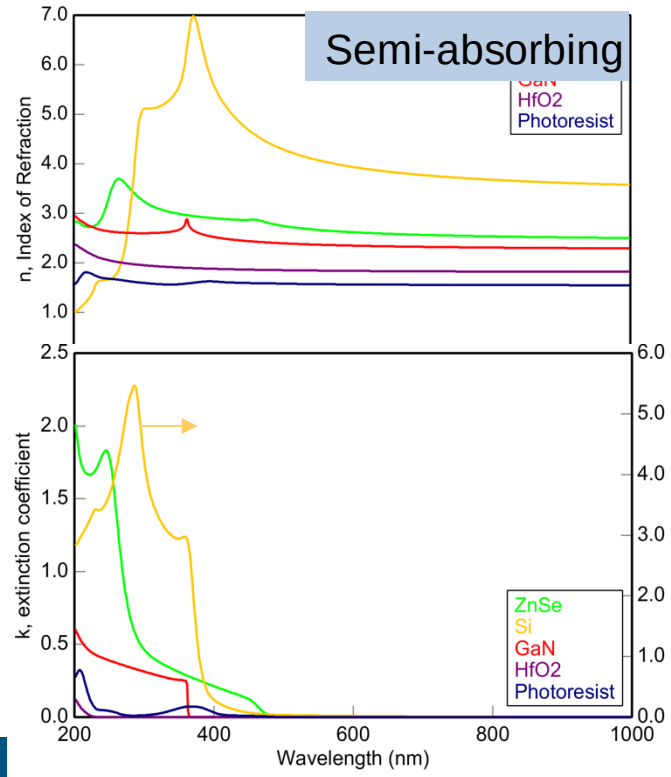


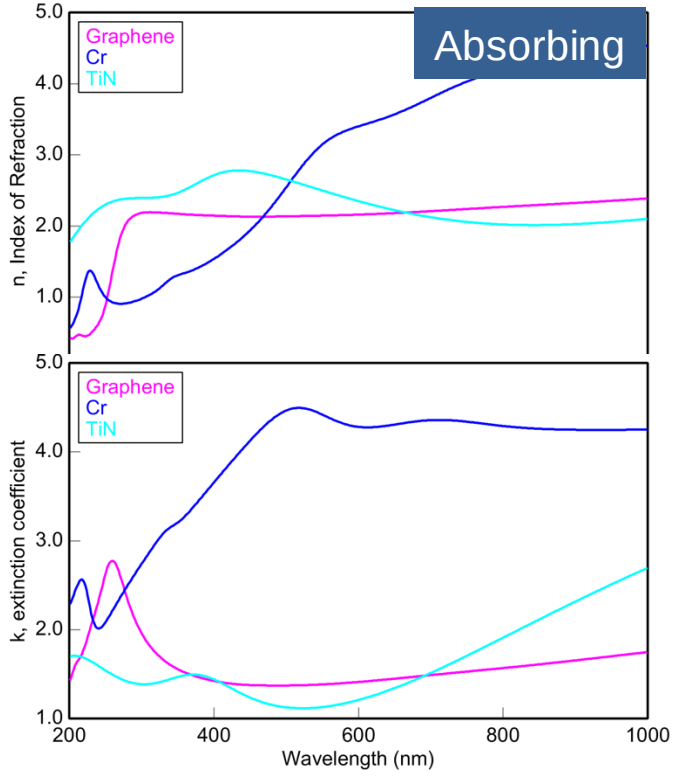
Refractive Index / Optical Constants

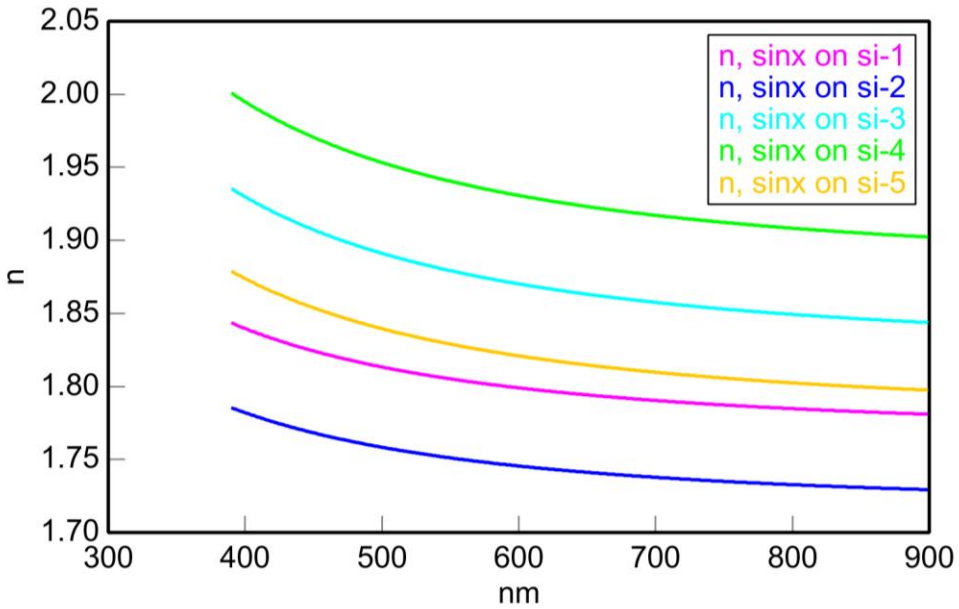
$$\tilde{n} = n - ik$$

$$\tilde{\varepsilon} = \varepsilon_1 - i\varepsilon_2$$

$$\tilde{\varepsilon} = \tilde{n}^2$$

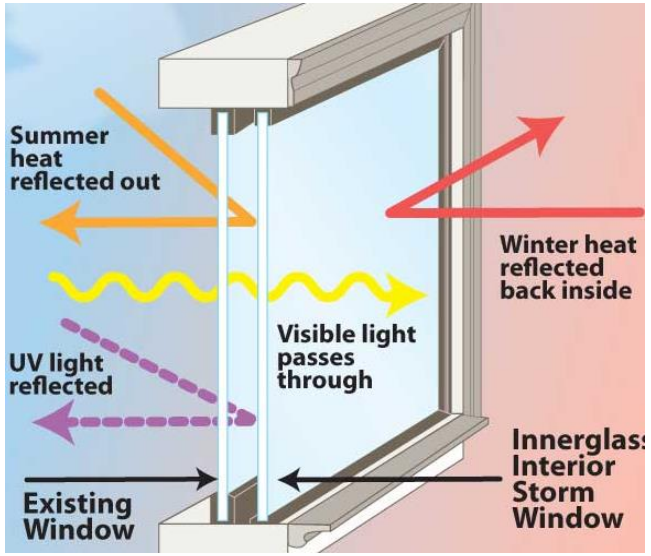


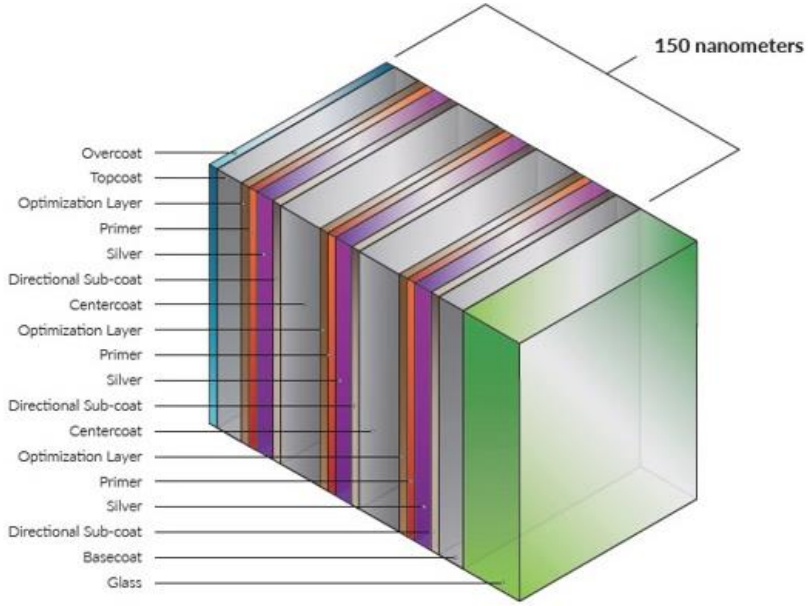


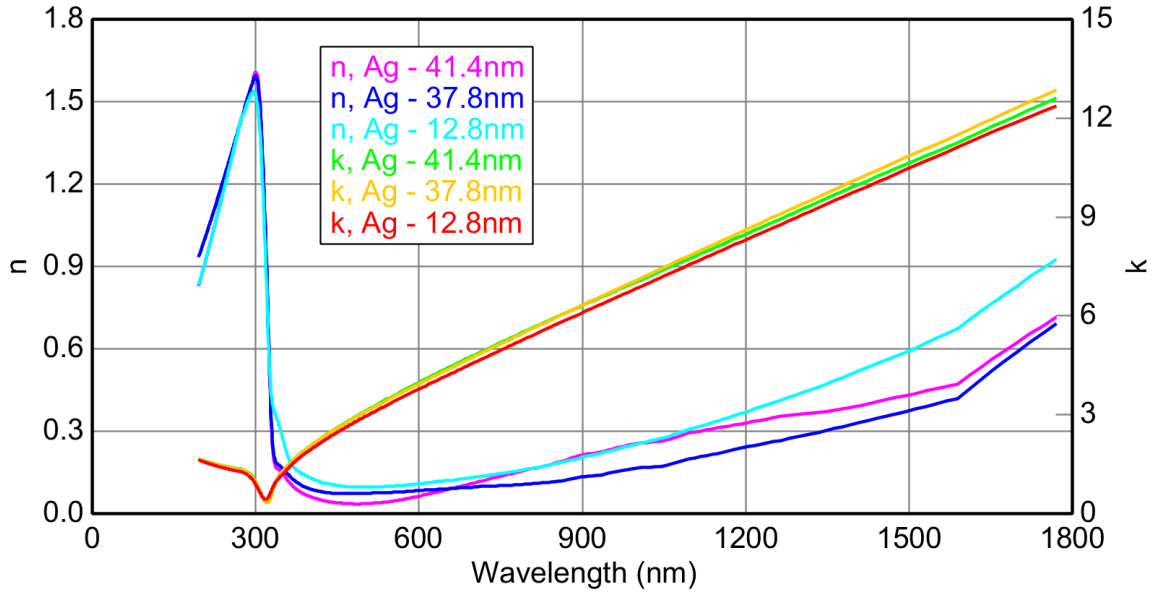


Low-E Glass



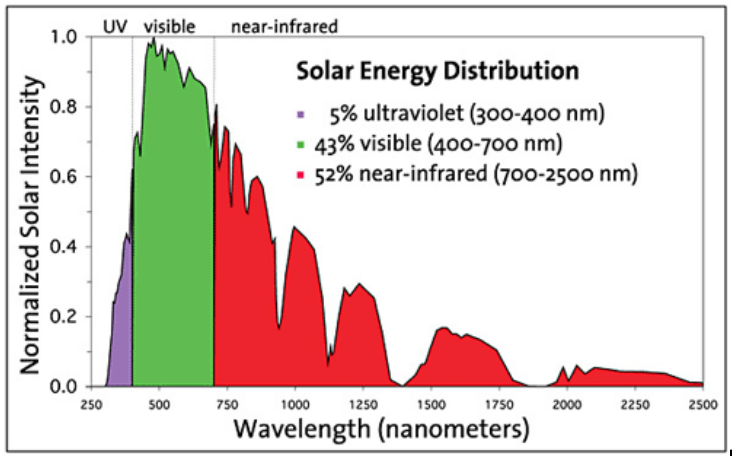

Summer heat reflected out
Winter heat reflected back inside
Visible light passes through
UV light reflected
Existing Window
Innerglass Interior Storm Window

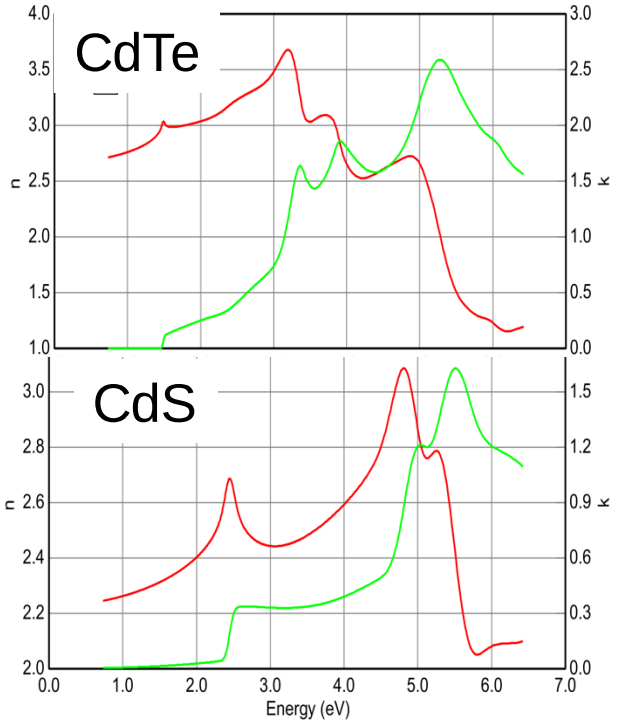

150 nanometers
Overcoat
Topcoat
Optimization Layer
Primer
Silver
Directional Sub-coat
Centercoat
Optimization Layer
Primer
Silver
Directional Sub-coat
Centercoat
Optimization Layer
Primer
Silver
Directional Sub-coat
Basecoat
Glass

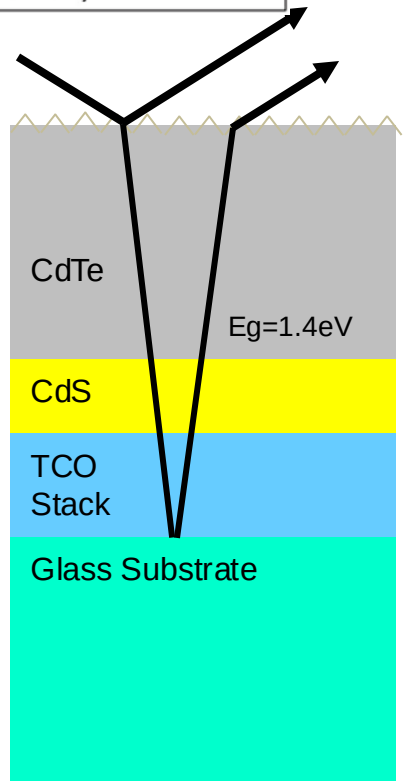

n, Ag - 41.4nm
n, Ag - 37.8nm
n, Ag - 12.8nm
k, Ag - 41.4nm
k, Ag - 37.8nm
k, Ag - 12.8nm
n
k
Wavelength (nm)
0
300
600
900
1200
1500
1800
0.0
0.3
0.6
0.9
1.2
1.5
1.8
0
3
6
9
12
15

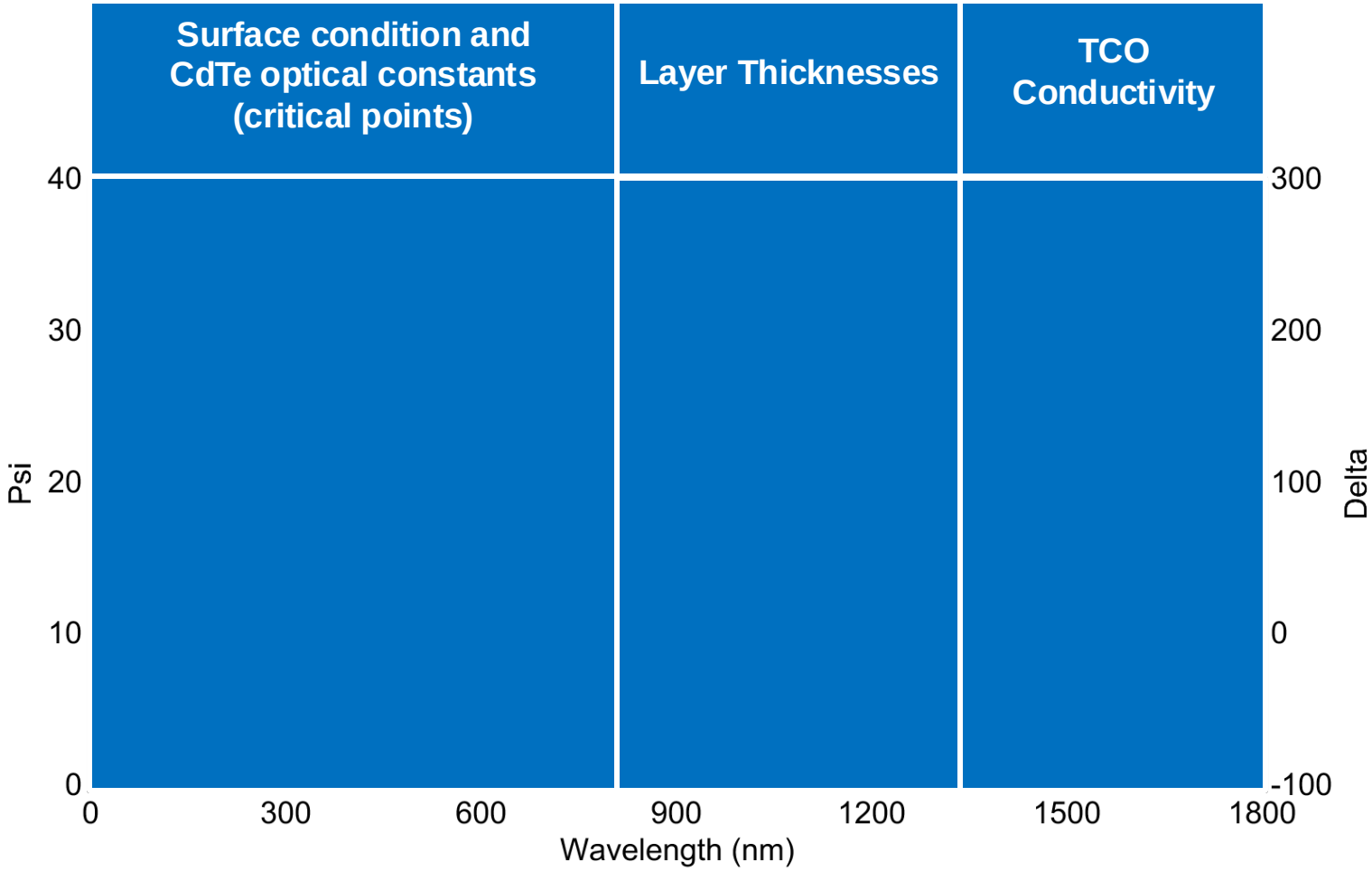
Photovoltaic Multilayer



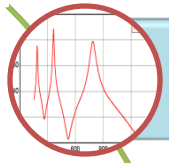




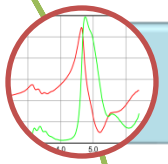




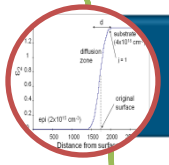




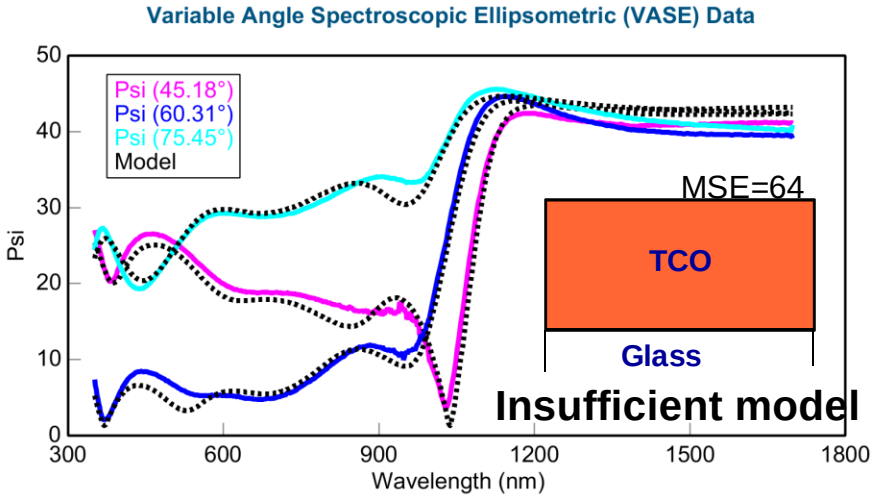
Layer thickness and Uniformity

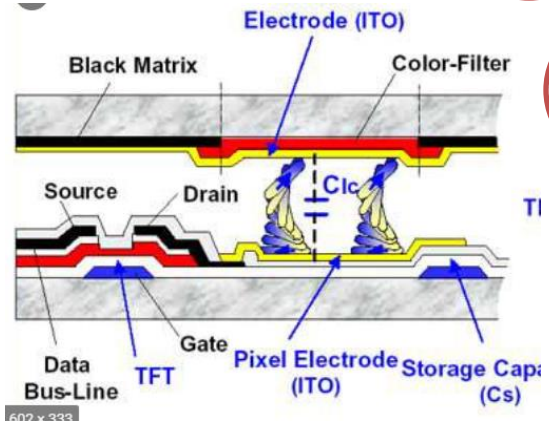


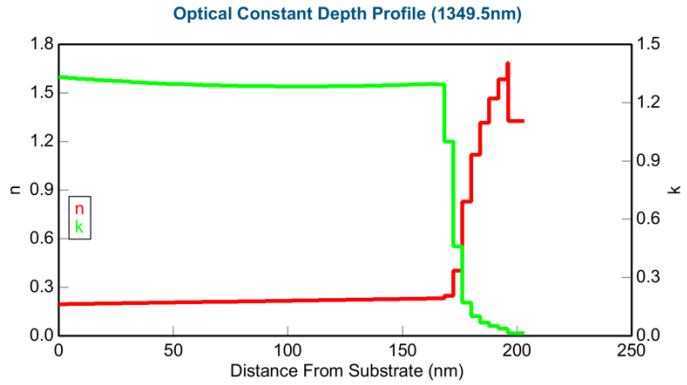
Refractive Index / Optical Constants

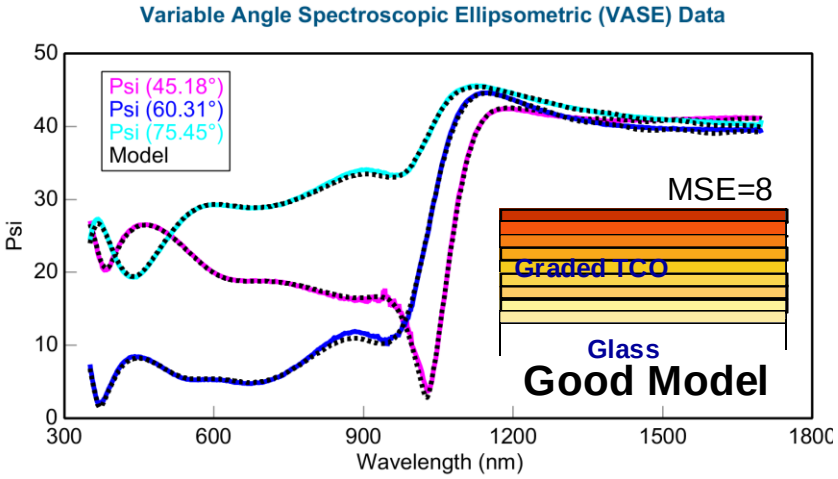


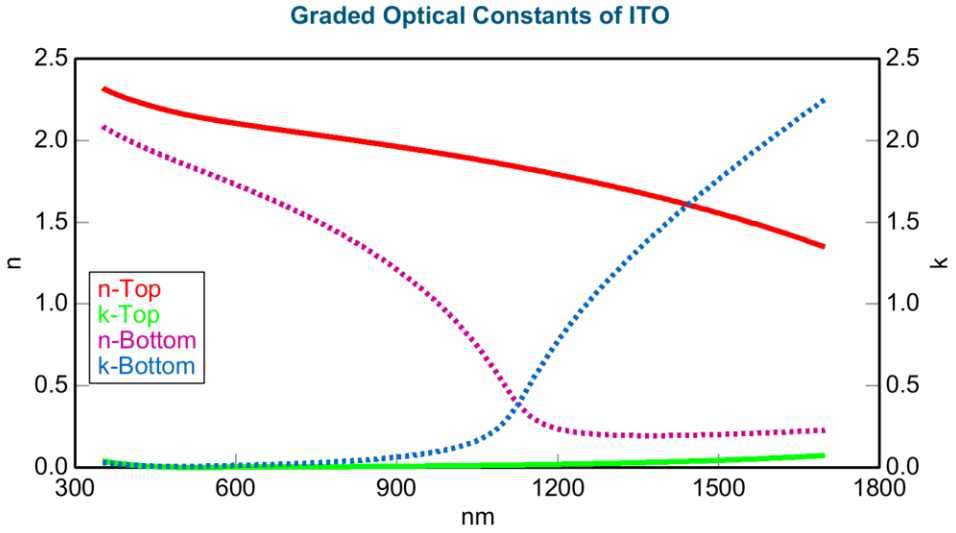
Grading and Roughness

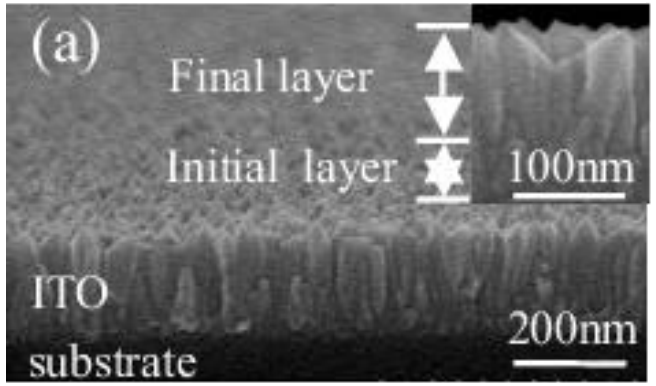








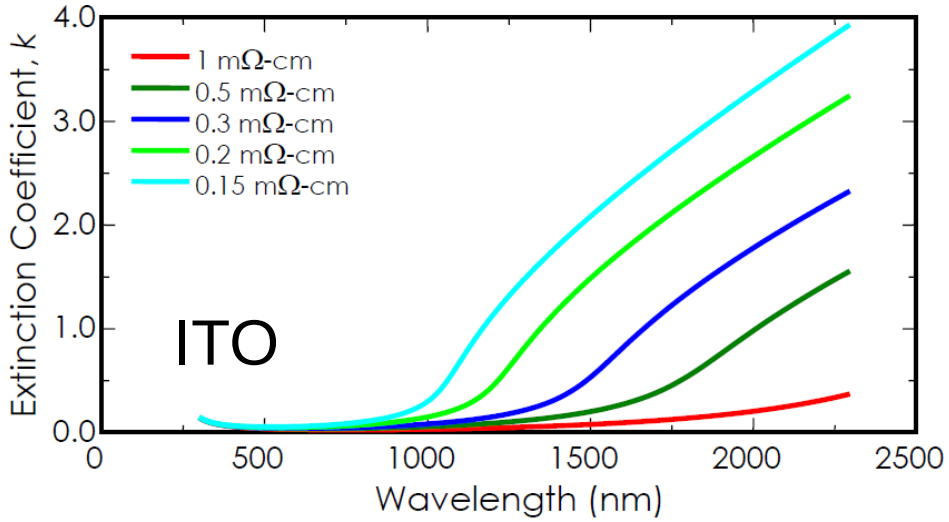


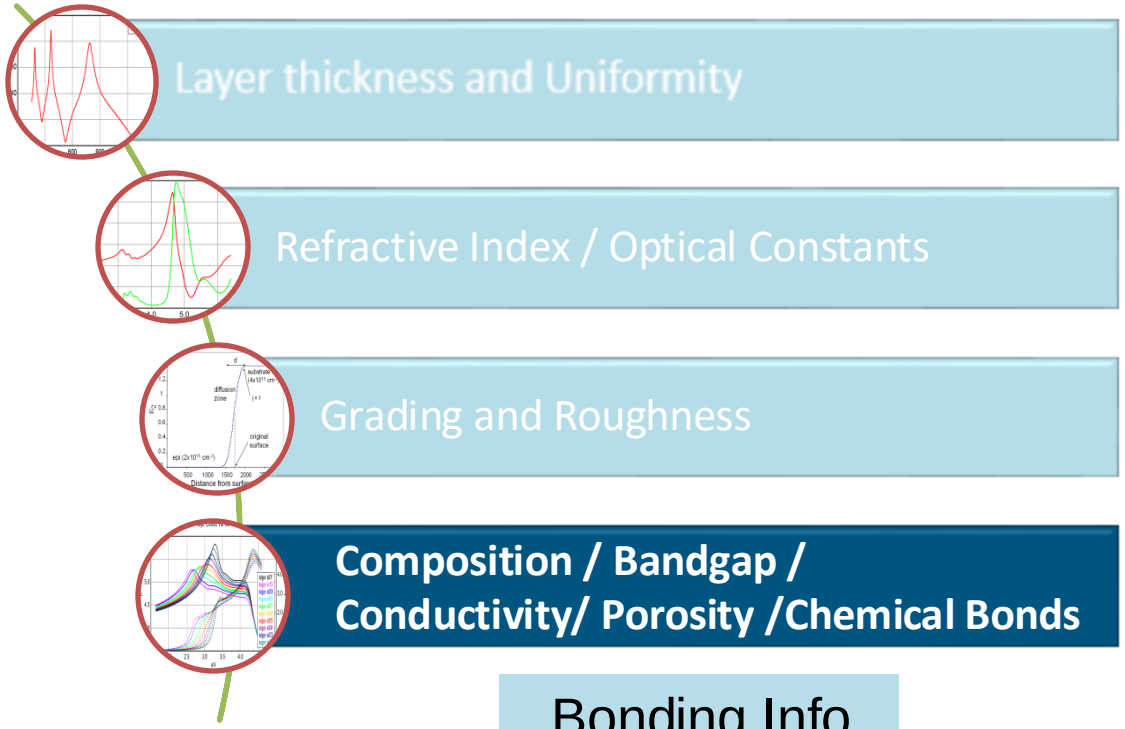


M. S. Huh et al., J. Elechem.Soc. 156, 1, J6-J11 (2009)

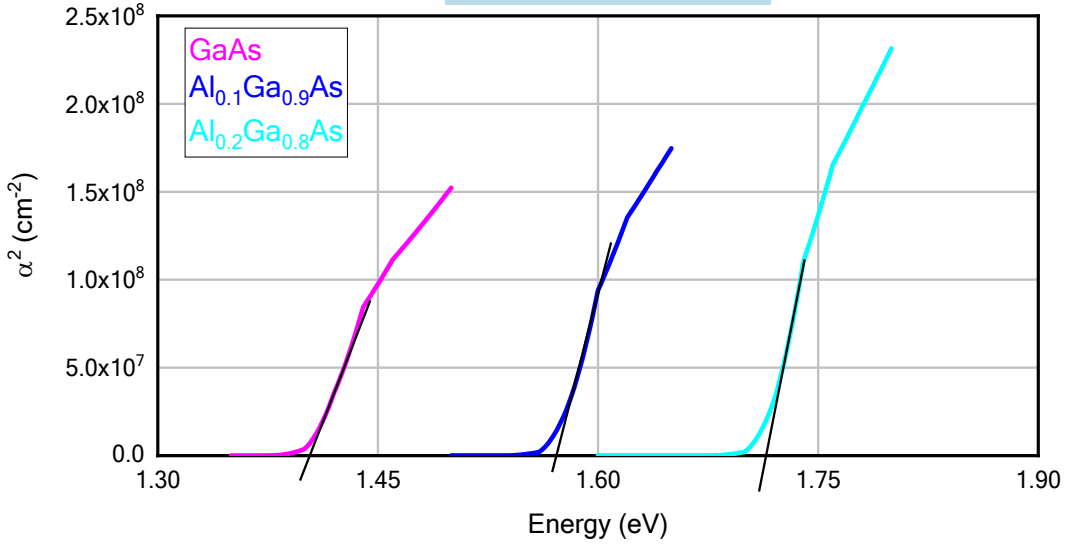


Conductivity

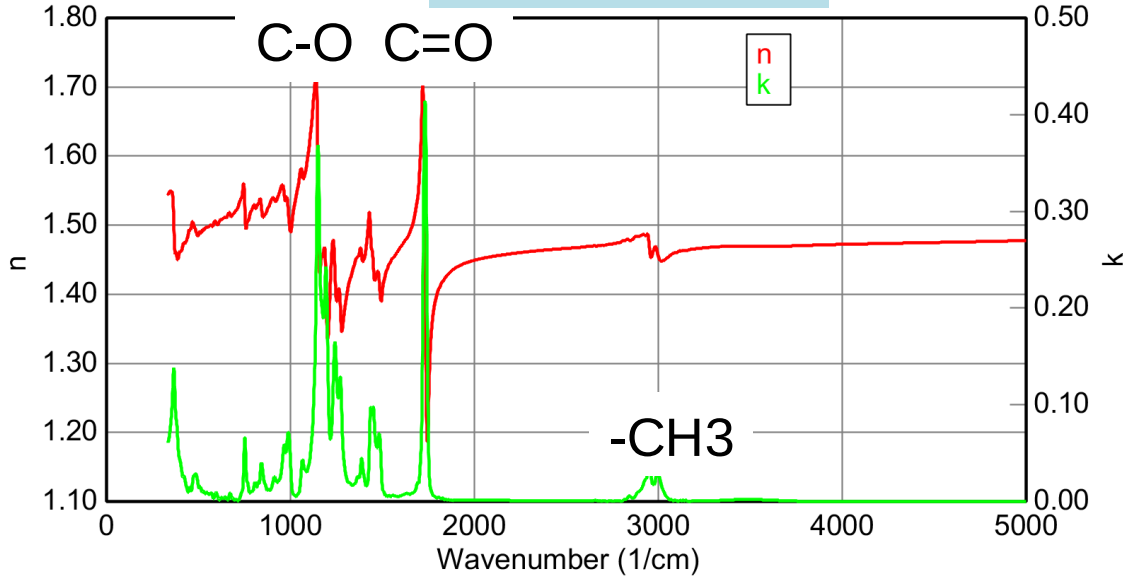




Band Gap

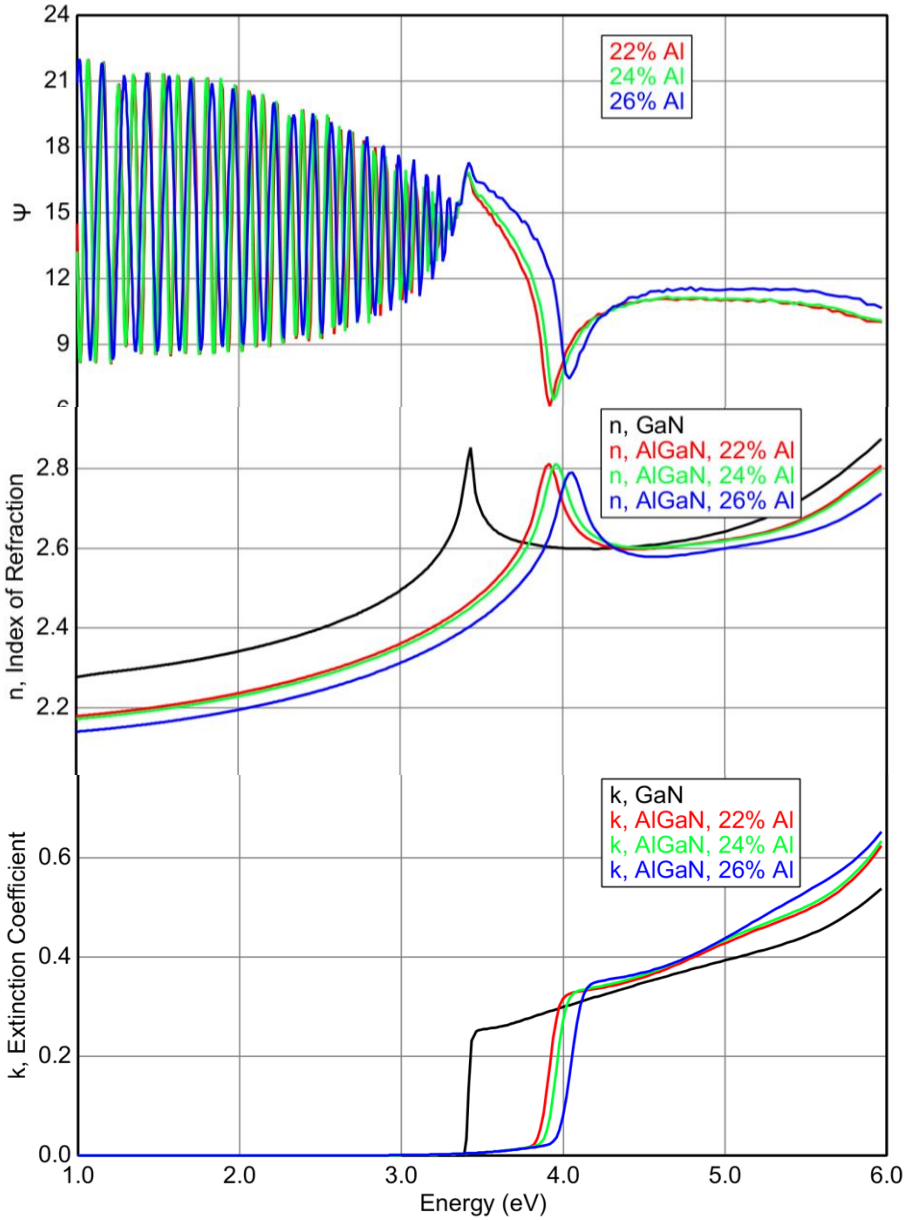


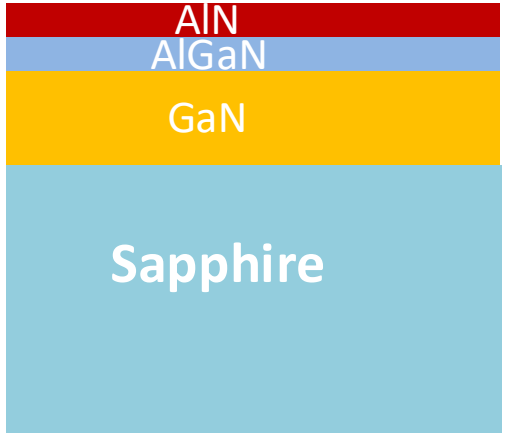
Bonding Info



© 2024 J.A. Woollam

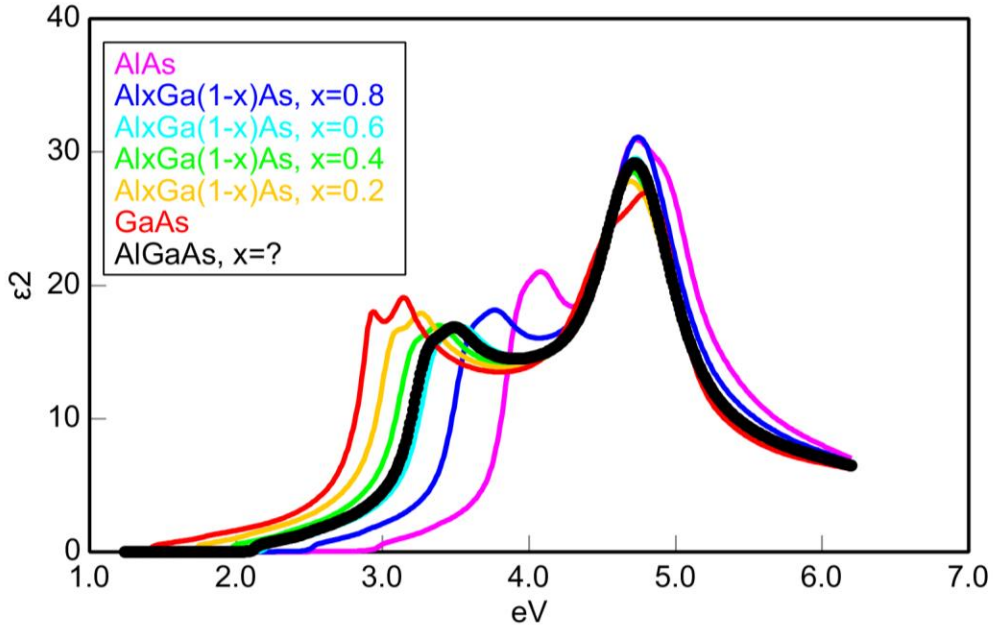
LED Backlighting



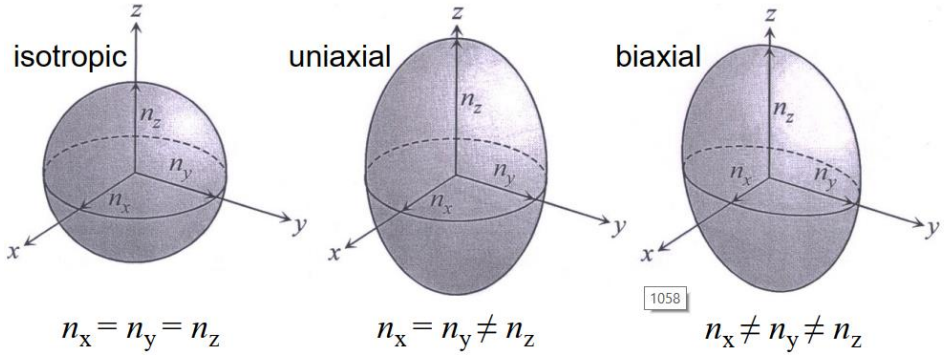


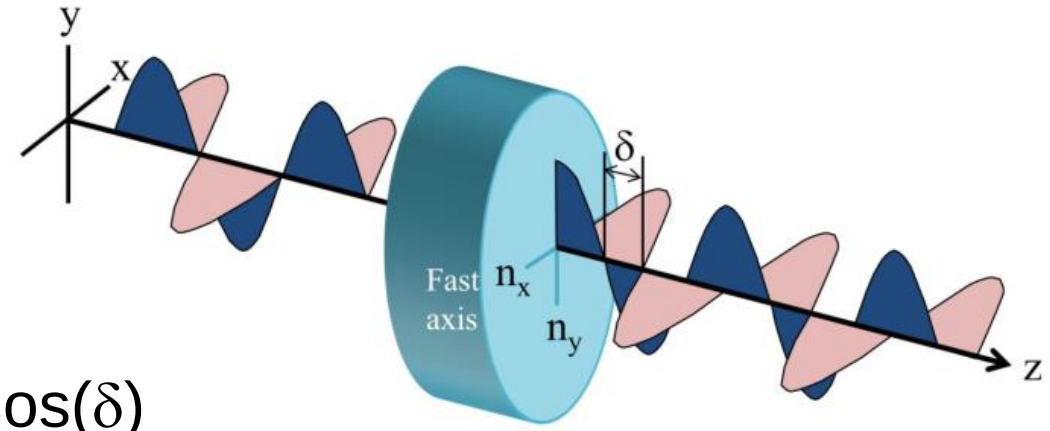


Composition

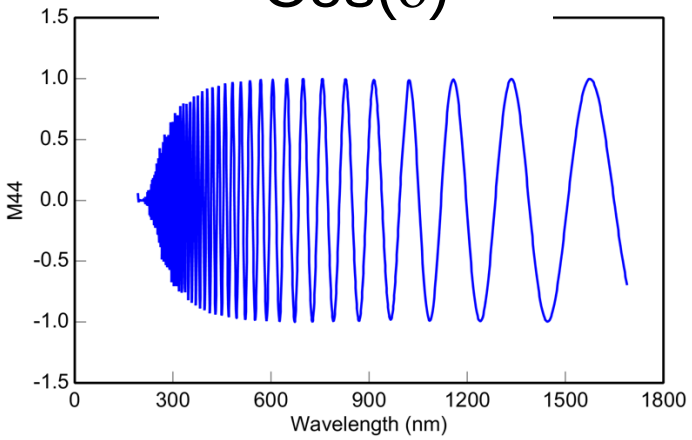


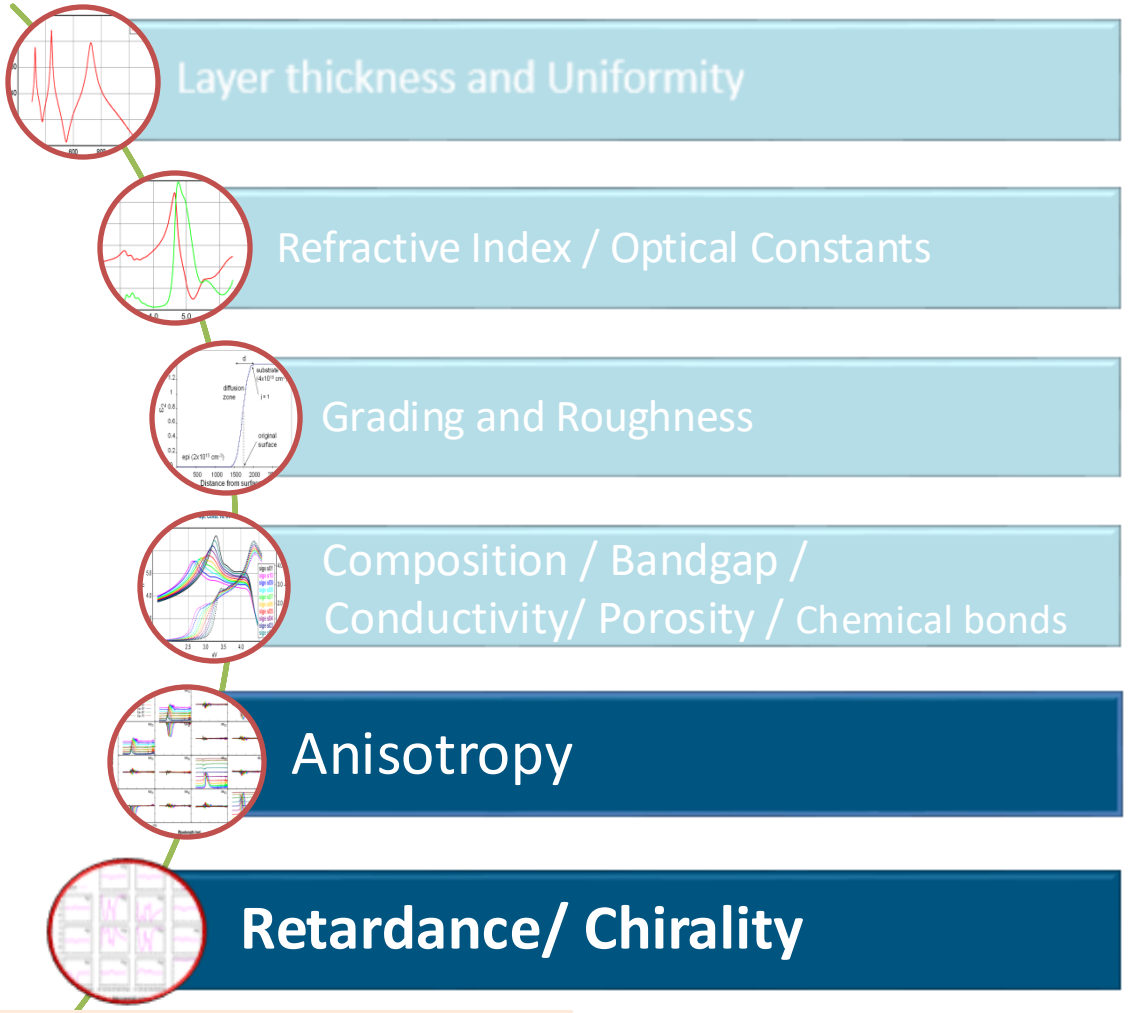






Cos(δ)



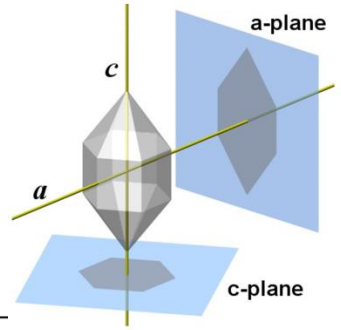


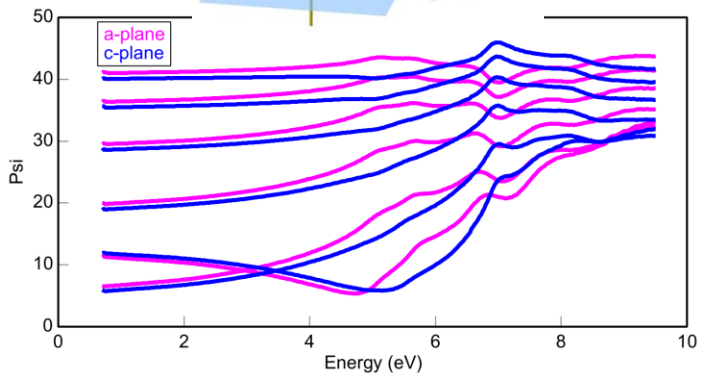
$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos^2 2\theta + \cos\delta \sin^2 2\theta & (1-\cos\delta)\cos 2\theta \sin 2\theta & -\sin\delta \sin 2\theta \\ 0 & (1-\cos\delta)\cos 2\theta \sin 2\theta & \sin^2 2\theta + \cos\delta \cos^2 2\theta & \sin\delta \cos 2\theta \\ 0 & \sin\delta \sin 2\theta & -\sin\delta \cos 2\theta & \cos\delta \end{bmatrix}$$

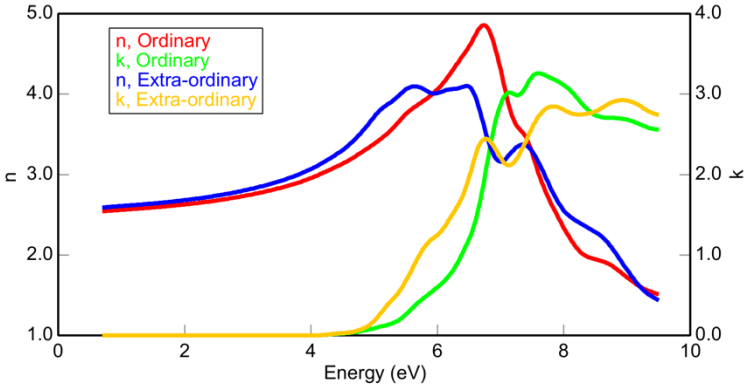
Birefringence and Liquid Crystals



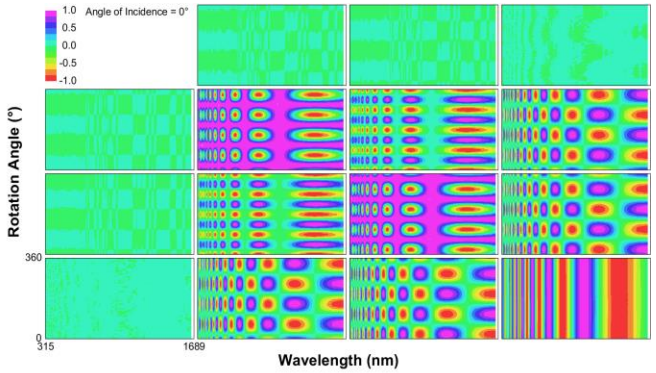
Uniaxial

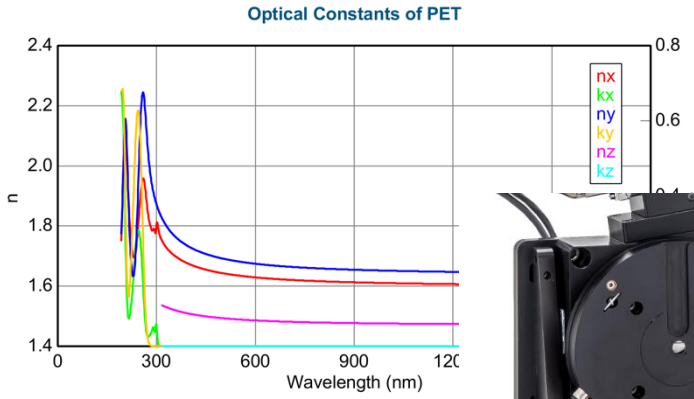






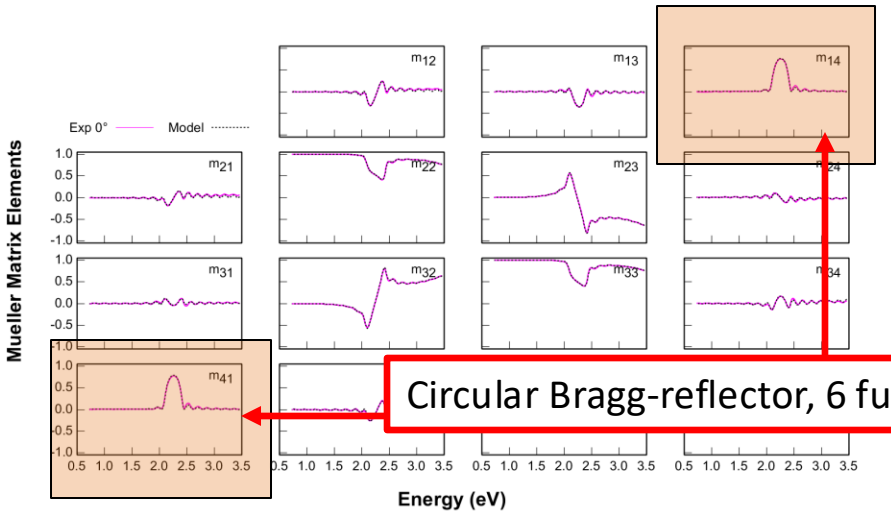
Biaxial

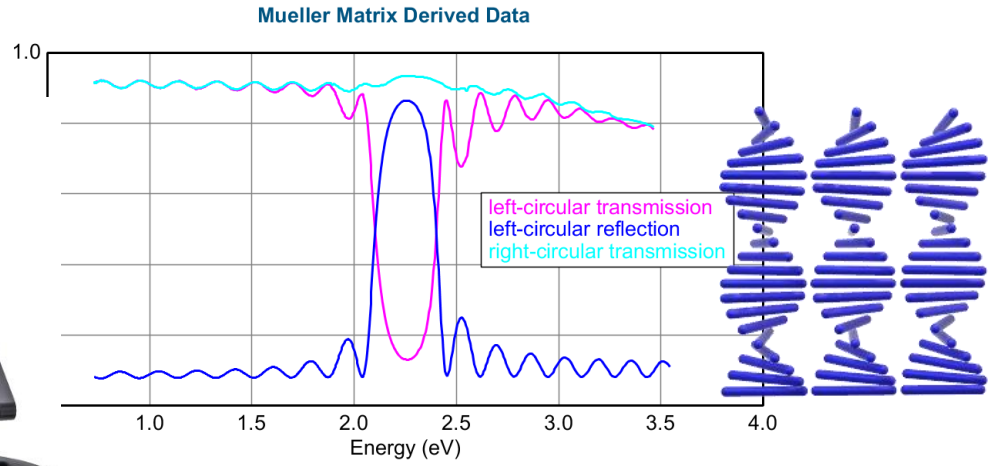


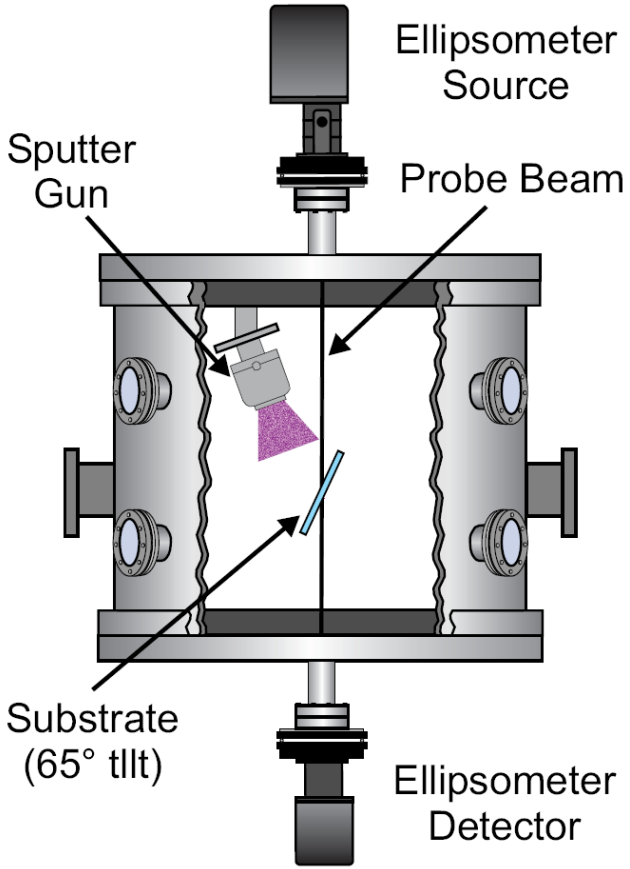




Cholesteric LC







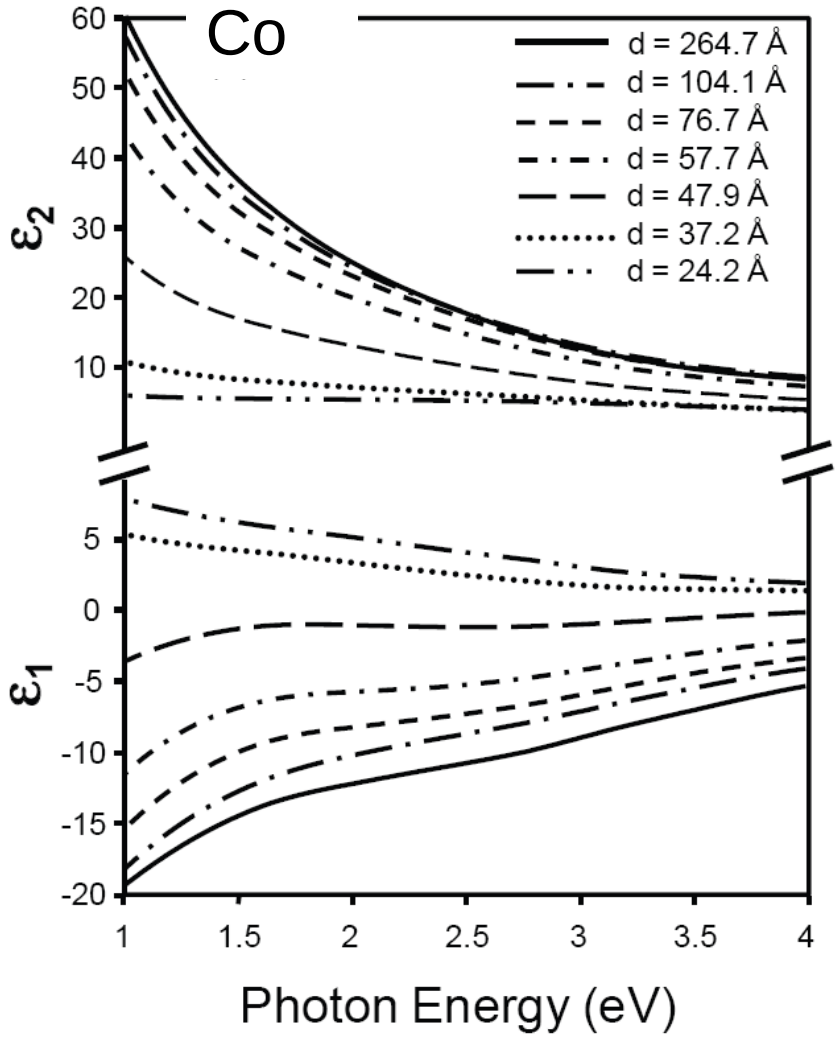




- Layer thickness and Uniformity
- Refractive Index / Optical Constants
- Grading and Roughness
- Composition / Bandgap / Conductivity/ Porosity / Chemical bonds
- Anisotropy
- Retardance/ Chirality
- **In-situ Monitoring / Dynamic Properties**

In-situ Deposition

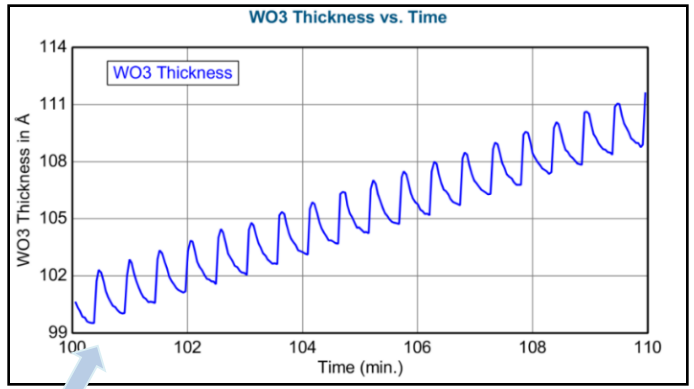
Metal Sputter Deposition

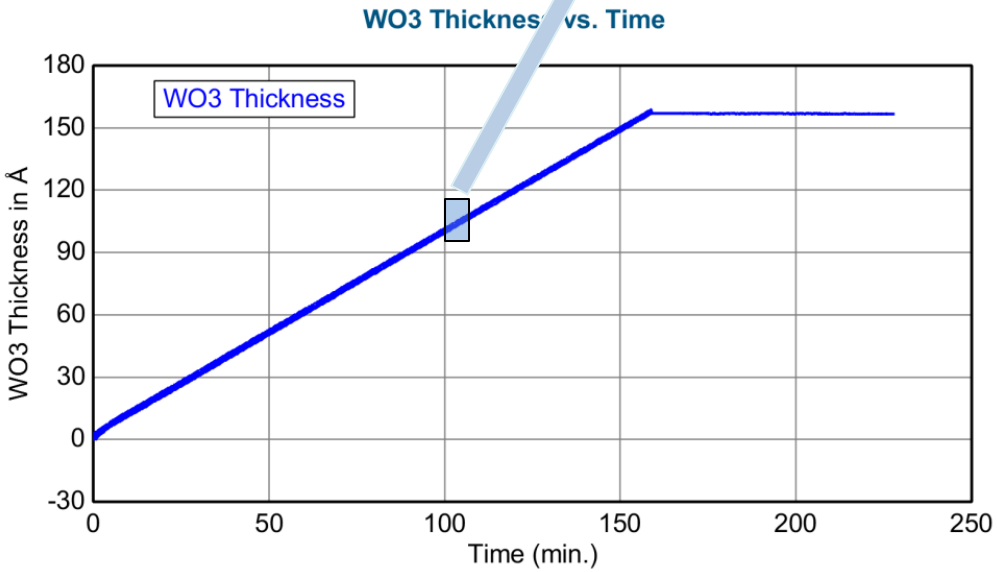


G.K. Pribil, et al., *Thin Solid Films* **455-456** (2004) 443.

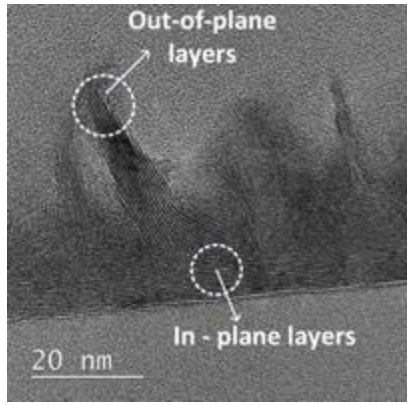
Atomic Layer Process

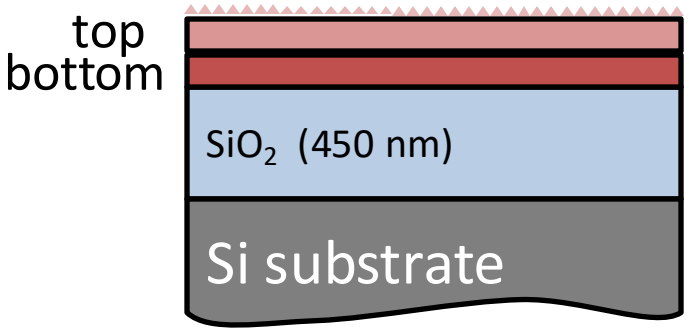


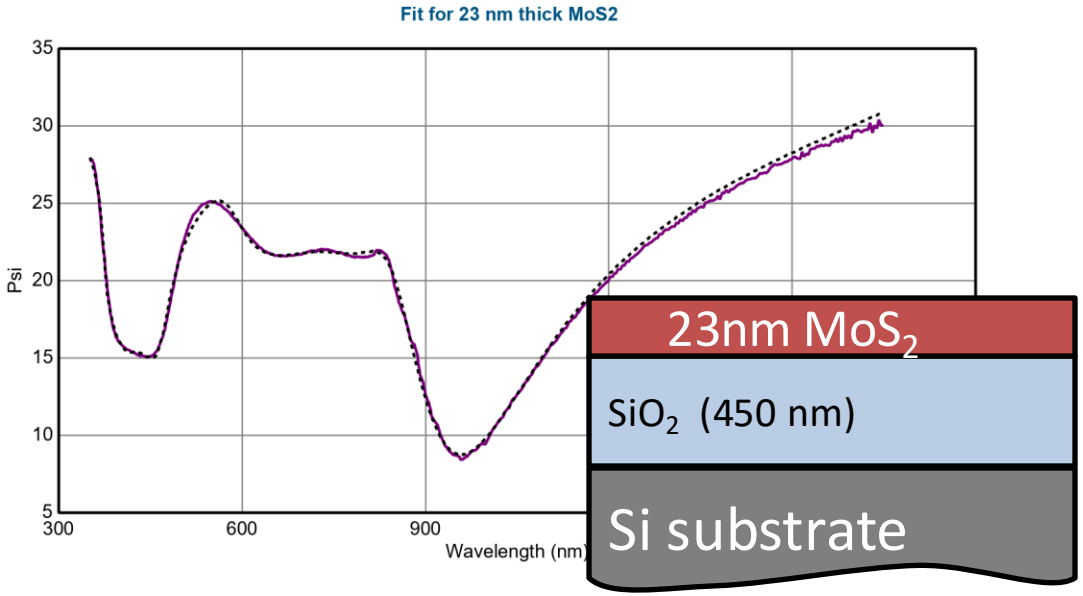


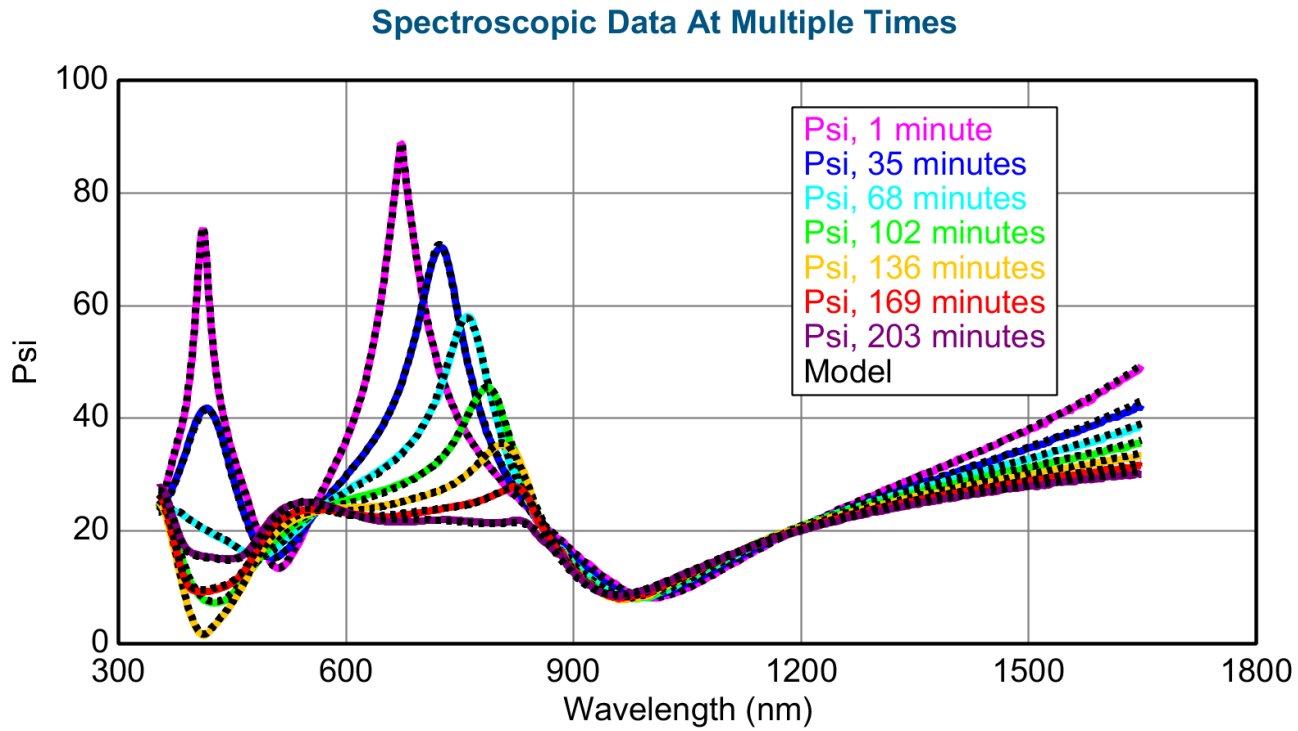


ALD of MoS_2

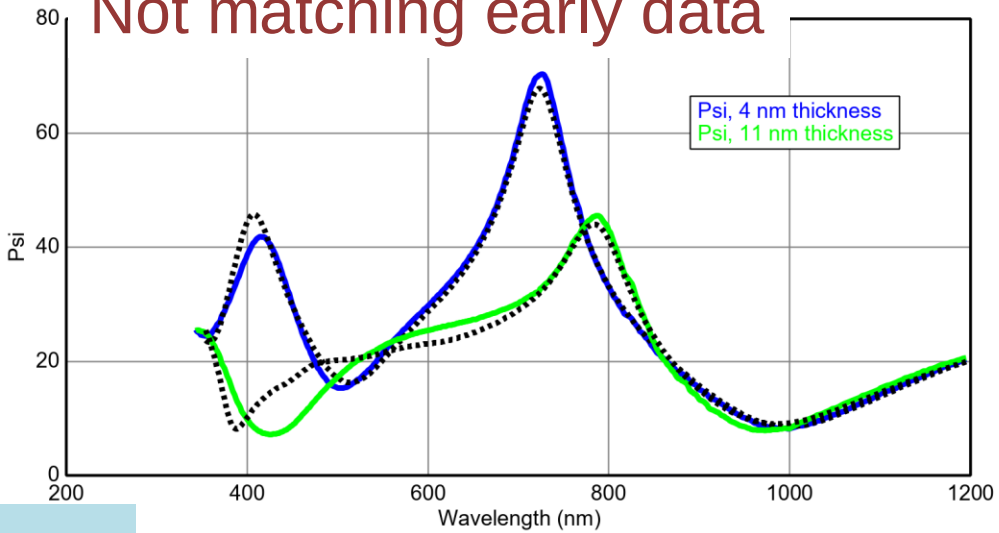








Not matching early data

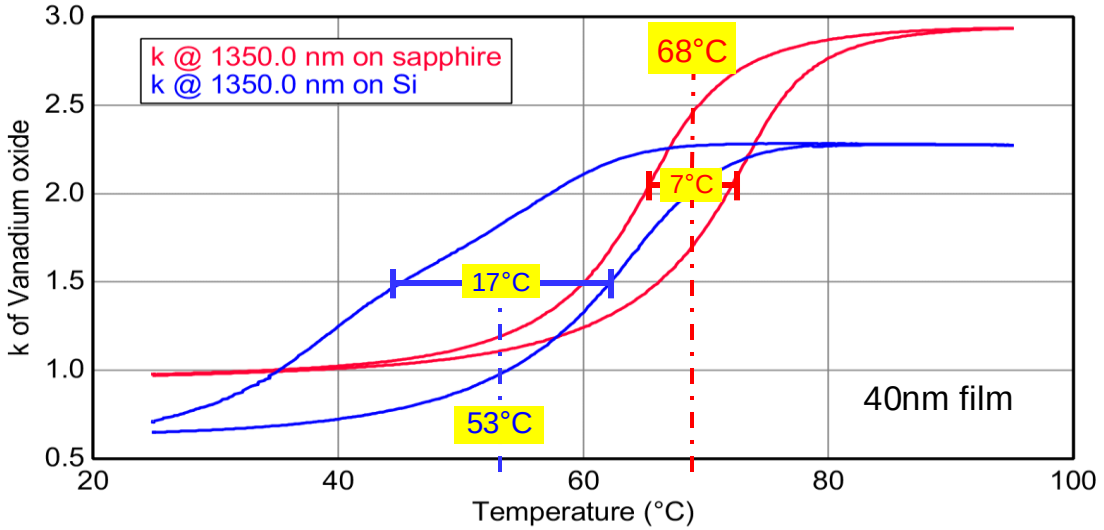


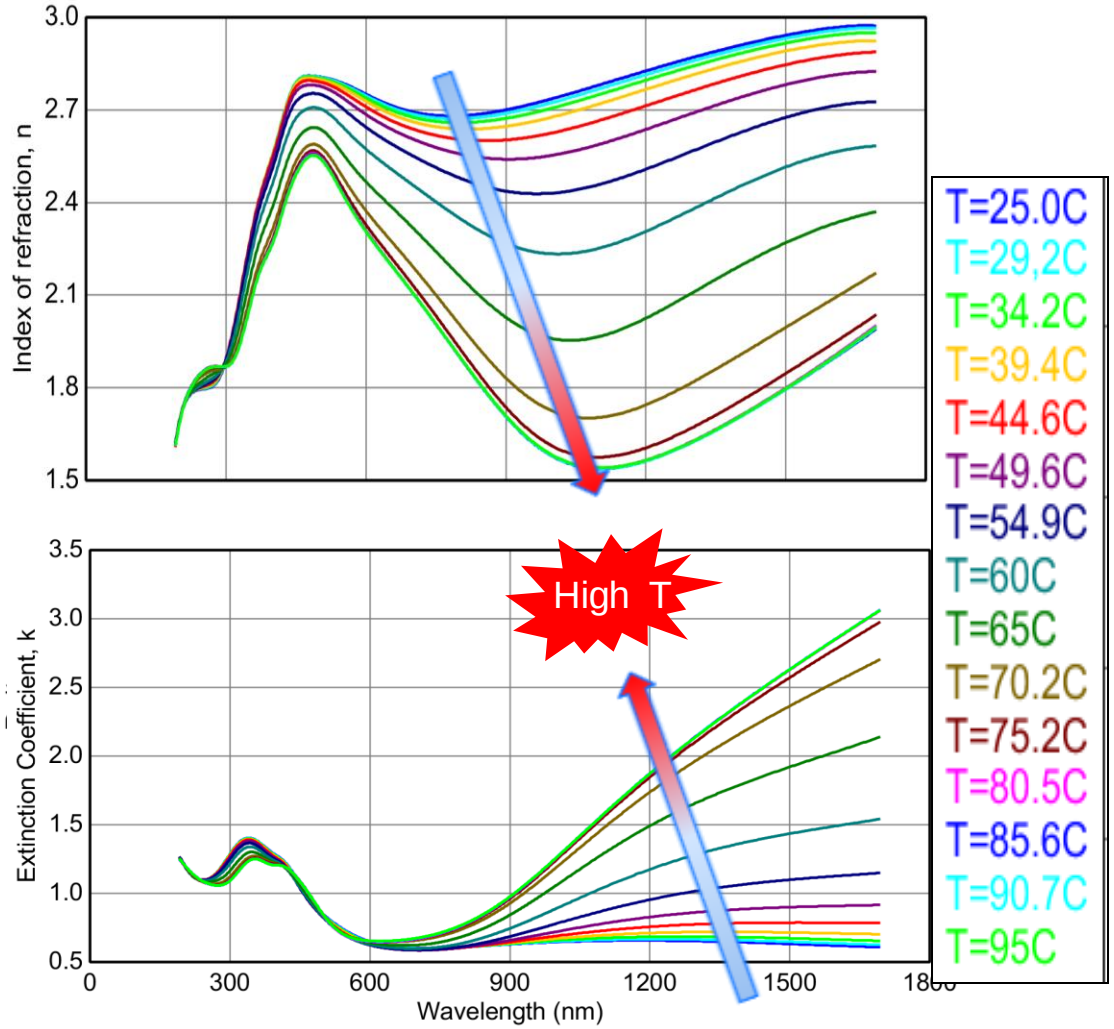
Data courtesy of TU Eindhoven

© 2024 J.A. Woollam

VO_2 IMT Phase Transition

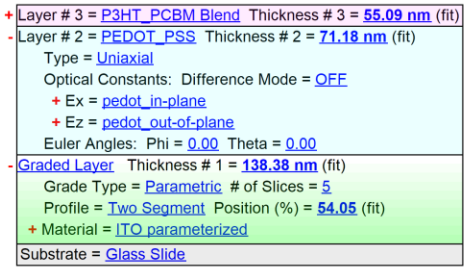


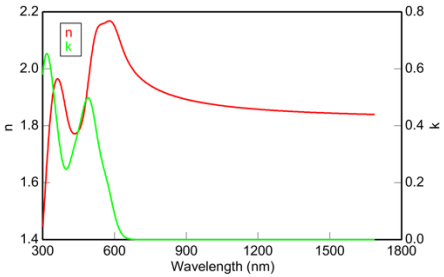


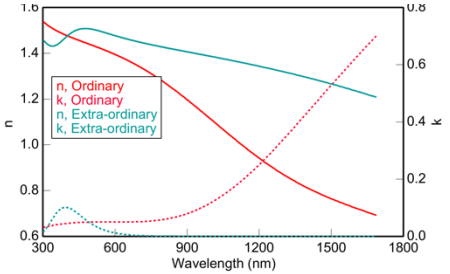


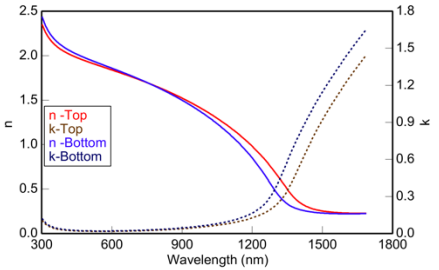
© 2024 J.A. Woollam

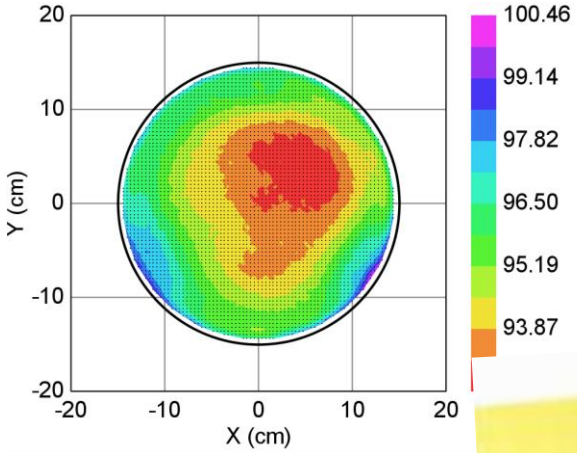
Summary – Optical, Non-destructive

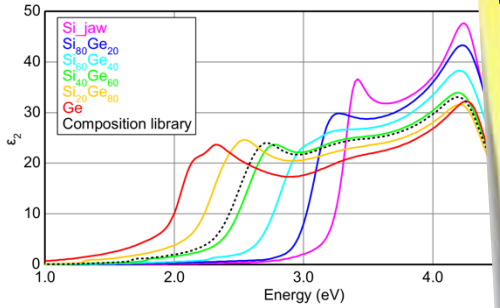


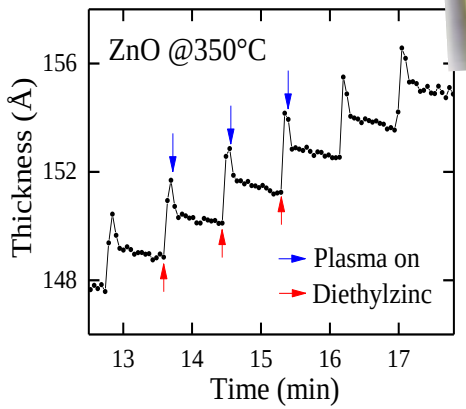




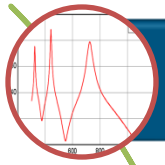


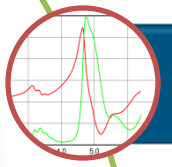


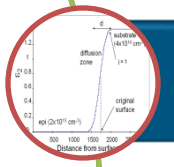


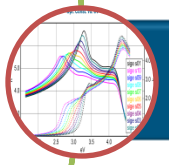


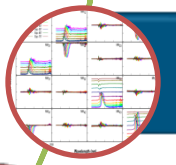
"If you can't measure it, you can't make it."


Layer thickness and Uniformity


Refractive Index / Optical Constants


Grading and Roughness


Composition / Bandgap / Conductivity/ Porosity / Chemical bonds


Anisotropy


Retardance/ Chirality


In-situ Monitoring / Dynamic Properties

© 2024 J.A. Woollam


Thank You
Suksama
Maake
Asante
Shukria
Dhanyavadagalu
Vinaka
köszönöm
Kiitos
Manana
Dankon
Suksama
Dank Je
Dankscheen
спасибо
Maururu
Biyan
நன்றி
Dziekuje
Chokrane
Diolch i Chi
Gratias Tibi
Terima Kasih
Juspaxar
Arigato
Grazie
Taiku
Najis Tuke
감사합니다
Bedankt
धन्यवाद
Gracias
Paldies
Matur Nuwun
Ua Tsaug Rau Koj
Ďakujem
Grazas
cảm ơn bạn
Khap
Tack
Obrigado
Nirringrazzjak
Děkuji
Di Ou Mèsi
Kop Khun
ありがとう
Rahmat
谢
Hvala
Eskerrik Asko
хвала
Danke
Merci
Go Raibh Maith Agat
Salamat
谢
ขอขอบคุณคุณ
Tingki

CONTACT INFO

Dr. Jianing Sun
JSun@jawoollam.com
Sales@jawoollam.com



J.A. Woollam

Quick Survey + Sign-up for Free Discovery Consultations

COVALENT METROLOGY

Want to learn more about Covalent's
Ellipsometry Services?

Talk with a Covalent Expert!

Schedule your Appointment now
with the link in the chat.

View On-Demand Recordings in the Covalent Academy

COVALENT METROLOGY

Search resource topics

SEARCH

From Select

To Select

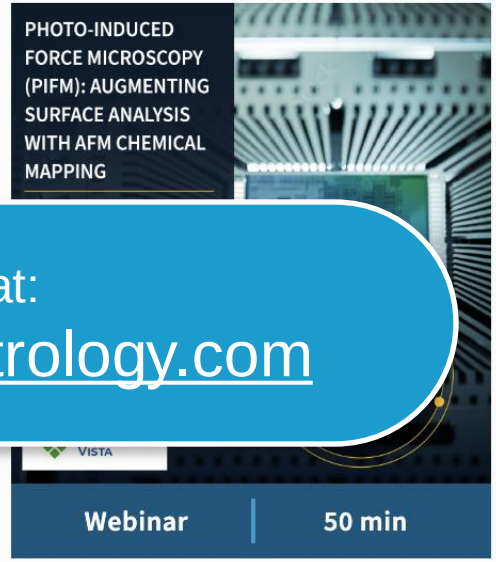
Type Select

Duration Select

Learning Center

- Browse All Topics

Register and start exploring at:
academy.covalentmetrology.com













COVALENT METROLOGY



Q & A Session

COVALENT METROLOGY

Thank you.