SENTECH Instruments GmbH

MIR Ellipsometry

- FROM FINGERPRINT TECHNOLOGY TO IN-DEPTH OPTICAL ANALYSIS -

Online Symposium
"Functional Coatings, Manufacturing, Metrology & Application“
TH Wildau - 9th March 2021

Dr. Robert Meyer
Application | Thin Film Metrology
SENTECH Instruments GmbH

SENTECH in brief

SENTECH

- Private company founded in 1990
- Located in Berlin (Germany)
- Extension building in 2020 with > 100 employees
- ISO 9001 certified

Business fields

- Thin Film Metrology
- Plasma Process Technology
- Photovoltaics
- Atomic Layer Deposition

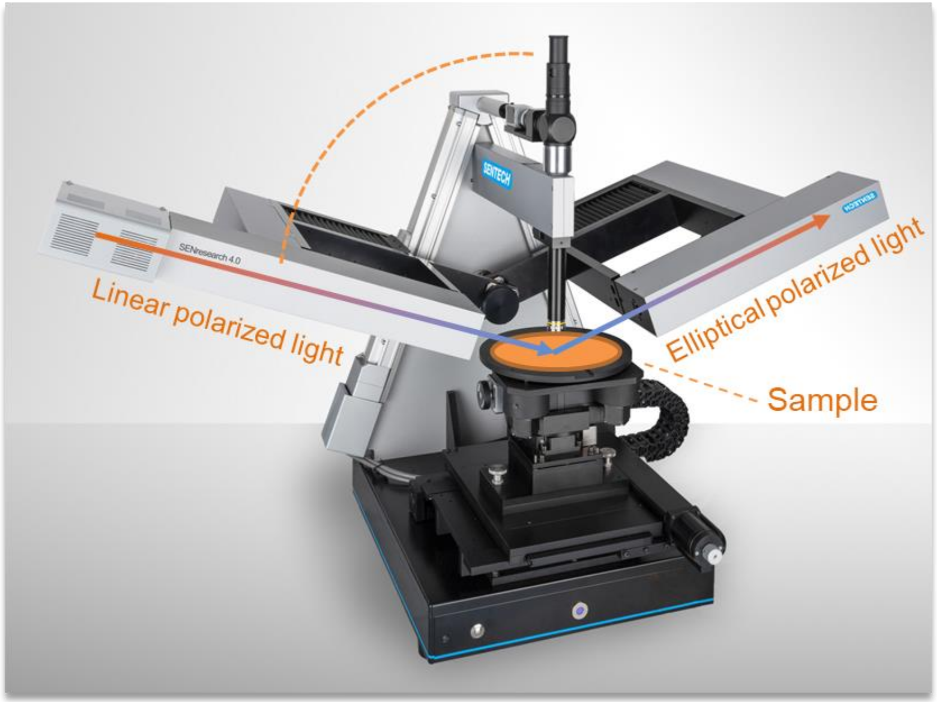
Strengths

- Innovation and Know-how
- High quality products
- Application Support
- Service
- Worldwide user & distributor network

Thin Film Metrology - What is Ellipsometry used for?

Ellipsometry

- Ellipsometry is an **indirect optical measurement technique** using
  - Reflection of polarized light
  - Oblique angles of incidence at the sample surface
- It measures the state of polarization after reflection at the sample
- The reflected light is elliptical polarized where '*Ellipsometry*' got its name from
- Non-destructive and non-invasive



Measurement

- Measurement results are the **ellipsometric angles Ψ, Δ**
  - Ψ = reflection ratio between p- and s-polarized components of the polarized light
  - Δ = phase shift between p- and s-polarized components of polarized light

Results

- Requires **building an optical model and a fitting procedure** to determine
  - Film thickness d
  - Optical constants n and k (and related parameters like compositions or semiconductor bandgaps)
  - Other parameters like surface roughness or interfaces

Thin Film Metrology - Applications

Industrial

- Semiconductor and Photovoltaic Industry
- Optical Industry
- Glass and Chemical Industry
- Automotive
- Steel Industry

Research

- Photovoltaics
- Physics, (Laser) Optics, Solid State Physics
- (Bio) Chemistry covering in-situ applications

Sample Structures

- Substrates
- Single layer/substrate
- Multiple layer/substrate

Film Thickness Range

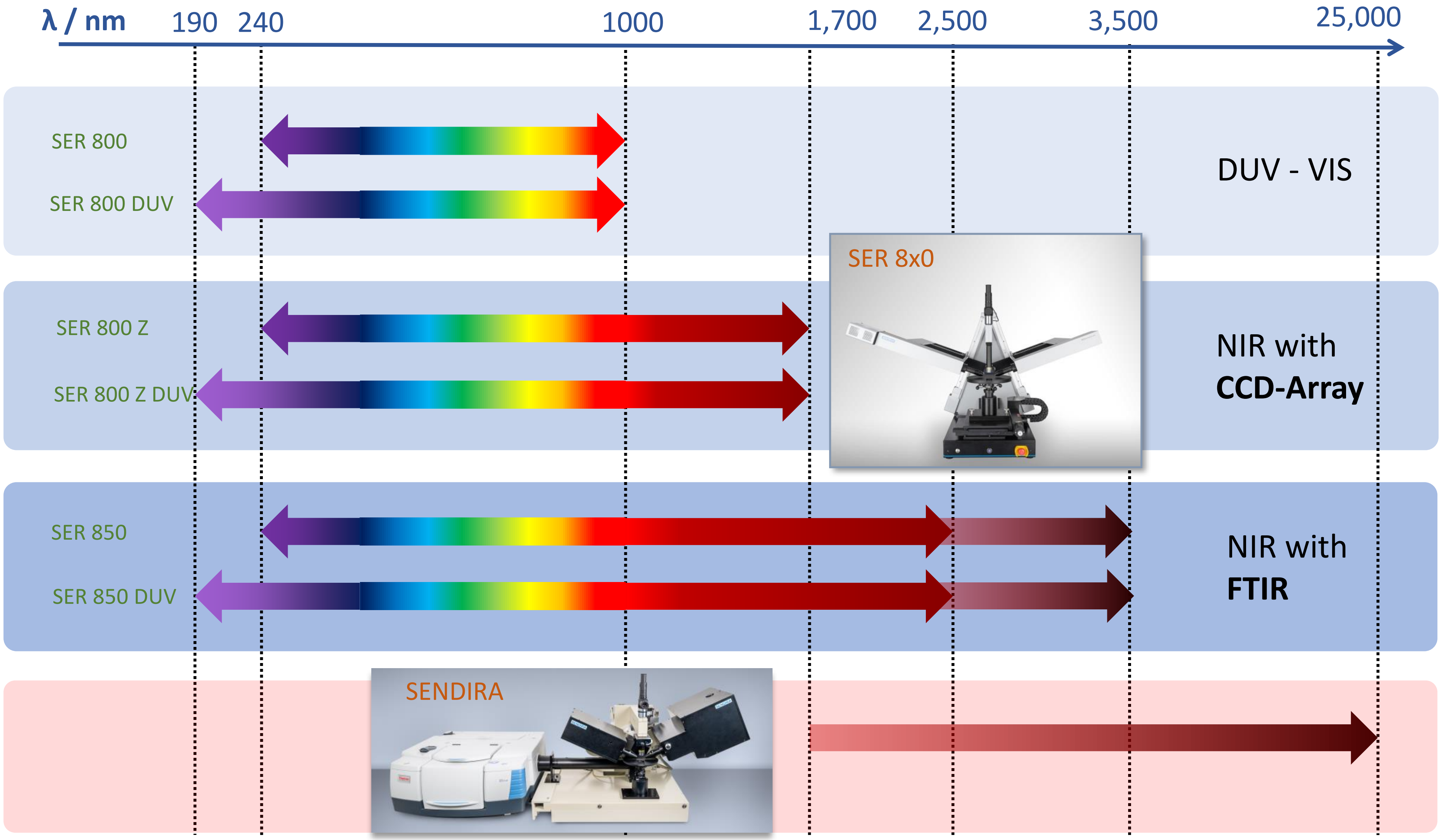
- ~ 0.3 nm (monolayers) … ~100 µm

Typical Materials

- Dielectrics (e.g.: SiO_2, Si_3N_4, TiO_2)
- Metals (e.g.: Cu, Au, Ag, Cr, alloys)
- Semiconductors (e.g.: IV, II-VI, III-V, organic)
- Photoresists (e.g.: SU-8, PMMA)
- Glass (e.g.: Quartz, BK7)

This variety requires different types of ellipsometers, especially different spectral ranges…
What has SENTECH to offer?

SENTECH Spectroscopic Ellipsometer Family



SENDIRA – Infrared Spectroscopic Ellipsometer

Spectral Range	1600 – 25000 nm
	6000 – 400 cm^{-1}
Spectral resolution	32 – 1 cm^{-1}
Light Source	Glow Bar
Detector	Peltier cooled DTGS
	(Deuterated Tri-Glycine Sulfate)
	MCT detector optional
AOI Range	40° – 90°
Sample stage	Height/Tilt adjustable 150 mm stage
Sample Alignment	ACT
Meas. Speed	typical 5 -10 min for full spectra
Goniometer	motorized, 40 - 90 deg / 0.01 deg steps
Beam diameter	typ. 5 mm
Software	SpectraRay/4

Benefits of SENDIRA MIR spectroscopic ellipsometer

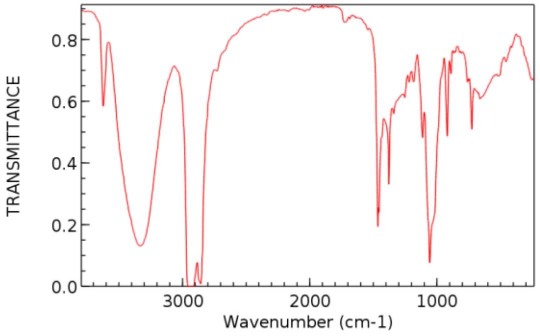
- Measurement of two parameters: amplitude ratio and phase difference
- Sensitive to mono layers and orientation of molecules
- Combines SE with R and T measurements

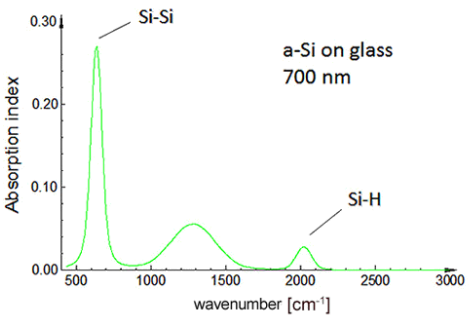
Applications in MIR Ellipsometry

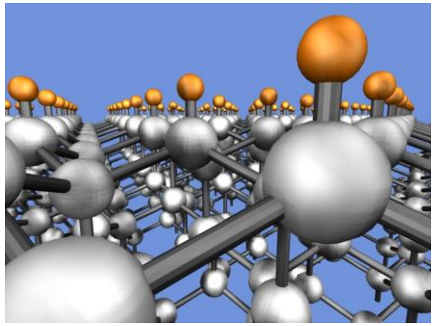
- IR region is very attractive for both ellipsometry and conventional spectroscopy
- Strong material activity in infrared due to:
  - Contributions of electronic transitions (NIR)
  - Free carriers, molecular rotation and vibration transitions (MIR)
  - Phonon modes (FIR)

Selected Applications

- **Vibrational spectroscopy (chemical analysis)**
- **Detection of impurities (e.g. -H, -OH or -CH)**
- **Optical constants in the MIR (MIR optical devices)**
- **Thin metallic layers (NiCr)**
- Doping and doping profiles in semiconductors (> 10^{17} cm^{-3})
- Detection of very thin films (hydrogen terminated Si, organic monolayers)
- Composition analysis of compound semiconductors (HgCdTe (MCT))





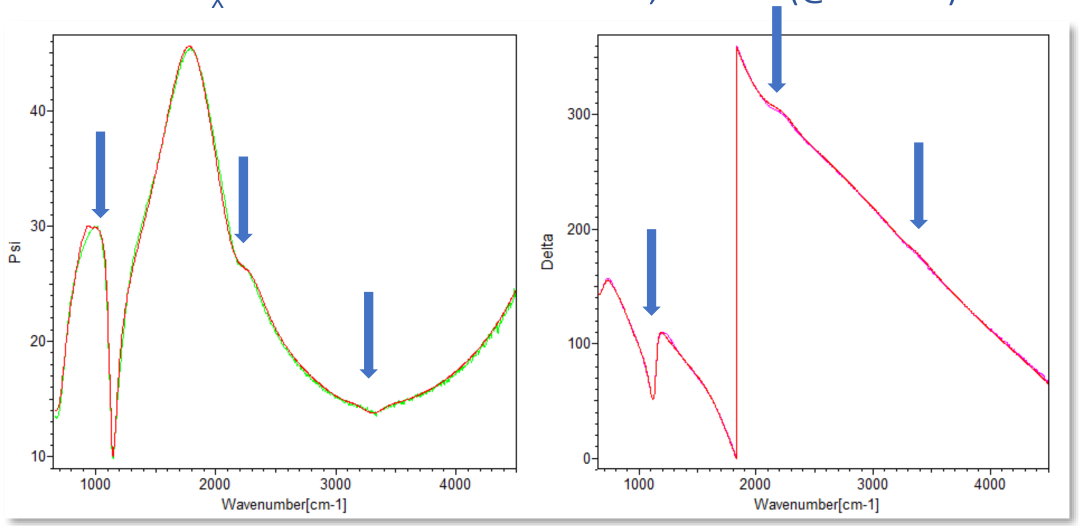


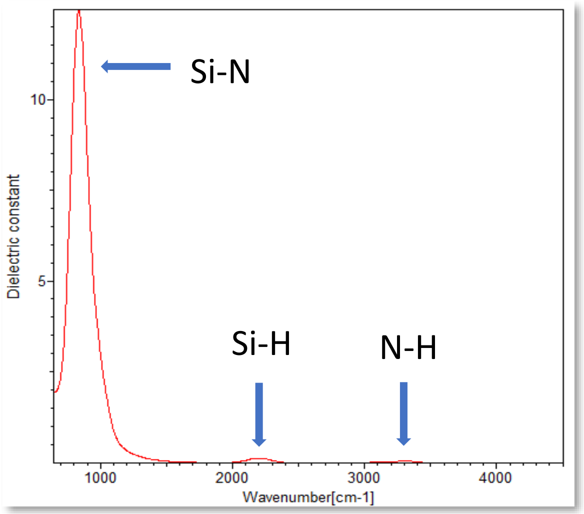
https://mclearwater.com/most-common-impurities-found-in-tap-water-mi
http://terpconnect.umd.edu/~bekane/SiOC/index_files/Page336.htm

Application – Vibrational Spectroscopy & Detection of Impurities

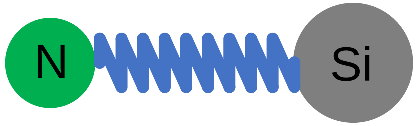
Applications in MIR Ellipsometry – Vibrational Spectroscopy

Example 1 SiN_x film on Si-wafer th= 850 nm, n= 1.99 (@633 nm)

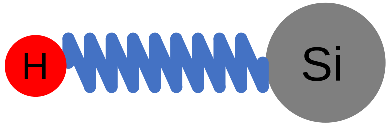




Si-N stretching vibration at 839 cm^{-1}



Si-H stretching vibration at 2200 cm^{-1}



N-H stretching vibration at 3300 cm^{-1}

Effective mass $\mu = \dfrac{m_1 m_2}{m_1 + m_2}$

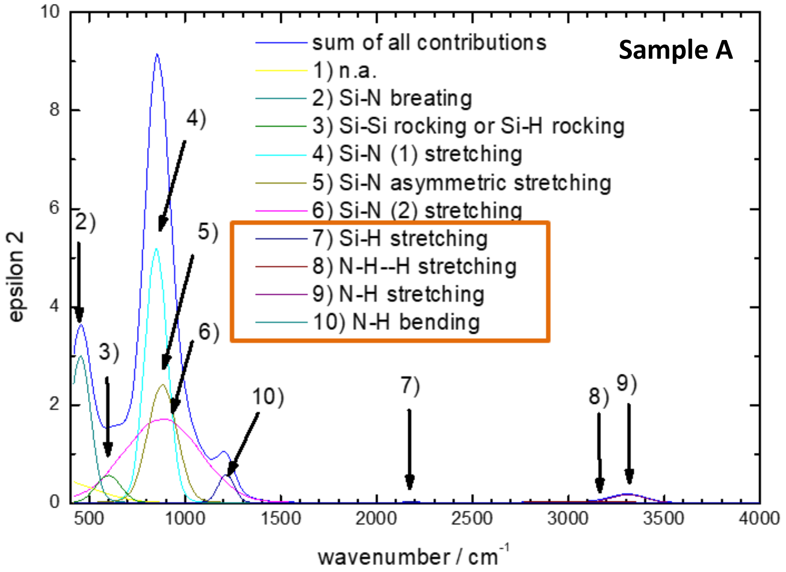
Wavenumber of Absorption maximum $\bar{\nu} = \dfrac{h}{2\pi c}\sqrt{\dfrac{k}{\mu}}$

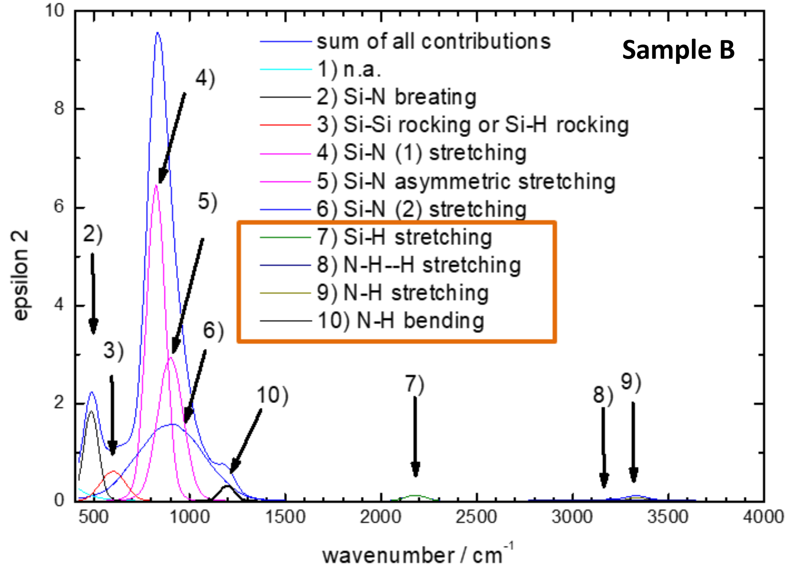
Spring constant k

Applications in MIR Ellipsometry – Detection of Impurities

Example 3

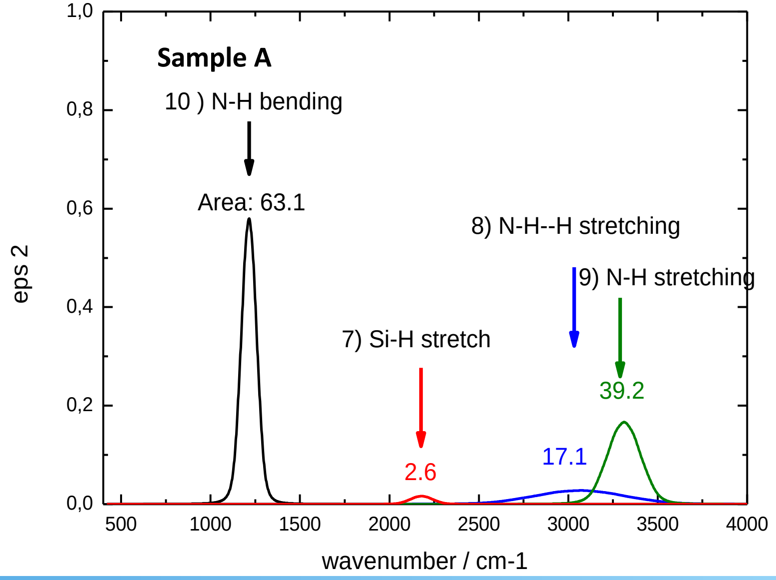
Sample Measurement	ΨΔ-Spectra Modelling	Analysis of ε_2

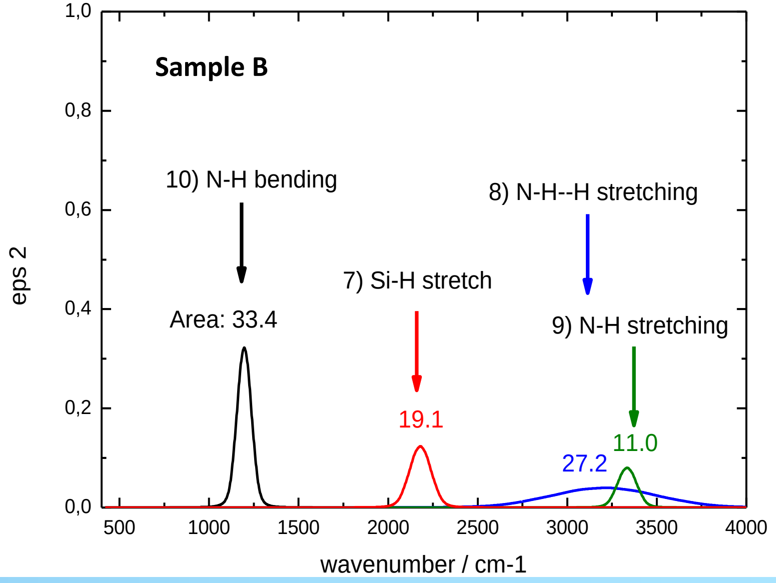




Result

- SiN_x dispersion is superposition of all individual absorption band contributions
- Determination of H-content: Analyzing area below hydrogen related absorption bands (Oscillators 7, 8, 9, 10)



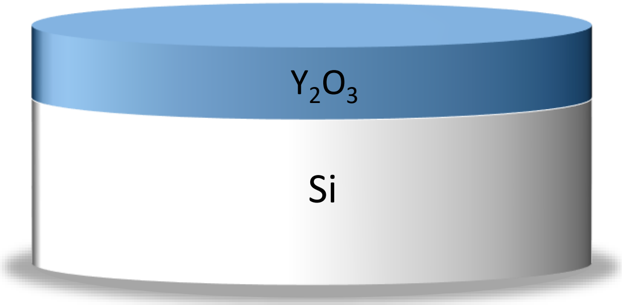


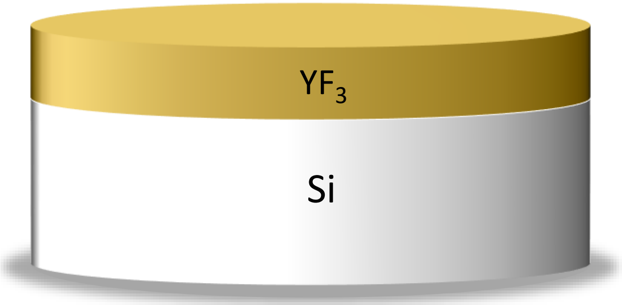
Application – Determination of optical constants in MIR

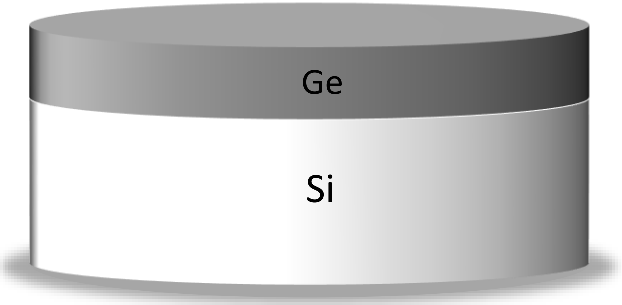
Applications in MIR Ellipsometry – Optical Constants in MIR

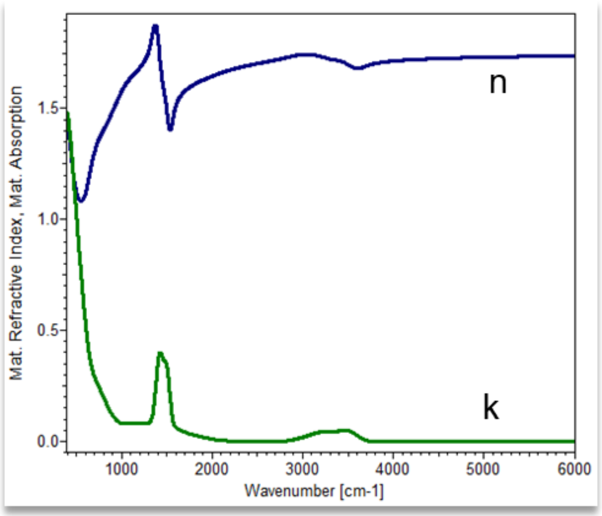
Example

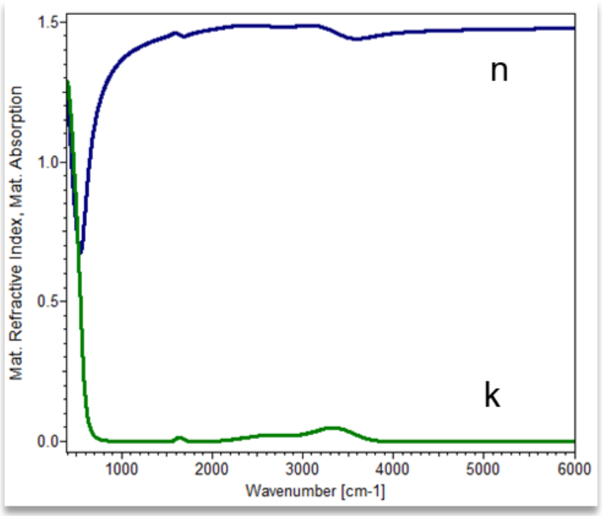
- MIR optical devices like Quantum Cascade lasers (QCLs) operate in the MIR spectral range (> 3.5 µm)
- QCL require the exact knowledge of optical constants for the semiconductor layers and dielectric coatings
- Literature optical constants in the MIR can be whether unavailable or inaccurate
- Due to the QCL design wavelength in MIR, SENDIRA measurements enable accurate determination of n,k

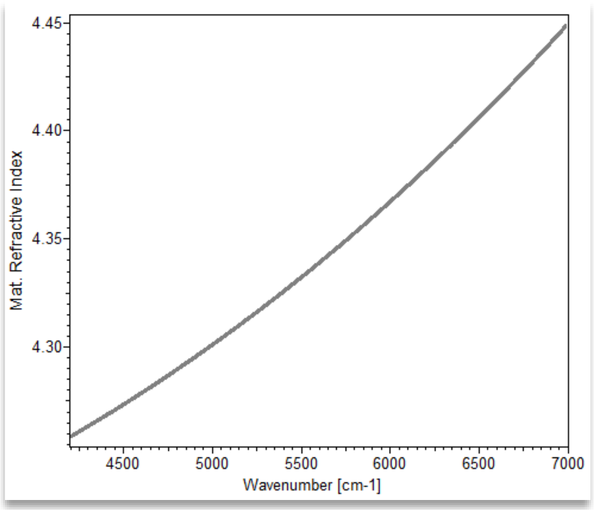












Application – Percolation

Applications in MIR Ellipsometry – Percolation

Initial Situation

- The NiCr films starts growing in small isolated islands
- The NiCr islands optically behave like a dielectric material
- No or extremely low free carrier concentration is observed

- The islands grow and connect to each other
- Free electron gas is created and carrier concentration increases

- Finally a dense film is established

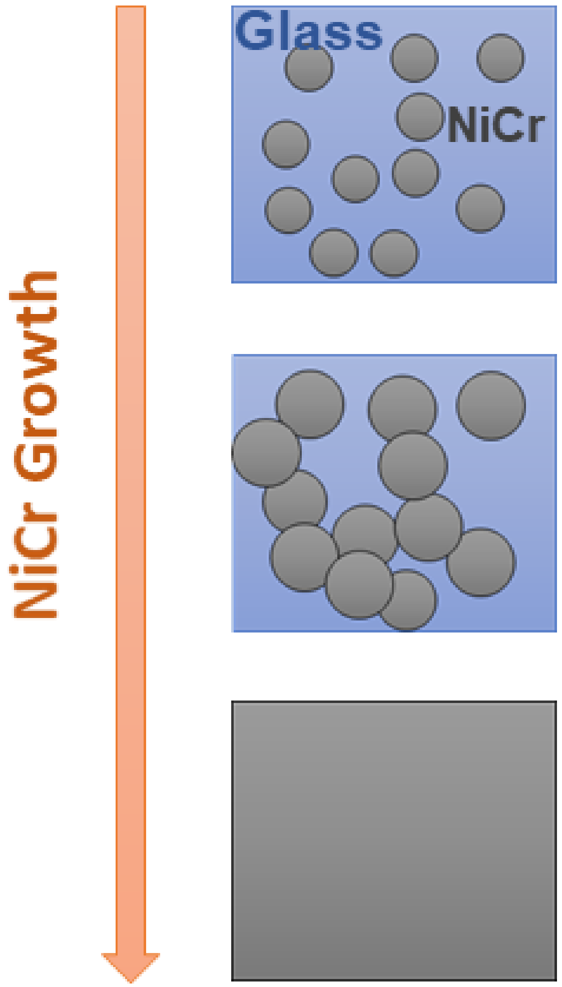
Measurements

- NiCr / float glass with different film thickness were prepared by magnetron sputtering
- Thickness range 1.1 – 10.0 nm
- 4 point probe (4pp) (Jandel)
- Spectroscopic ellipsometry:

  DUV – NIR (190 nm – 2500 nm)

  MIR (1600 nm - 25000 nm)

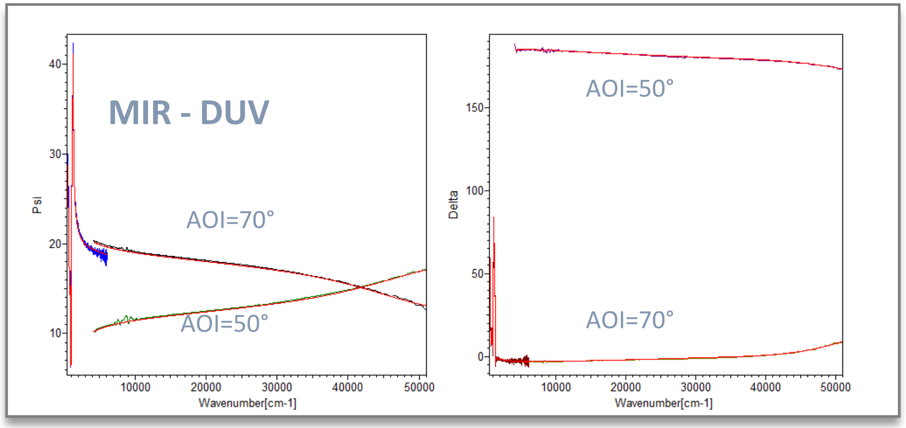
- The samples were roughened on the backside

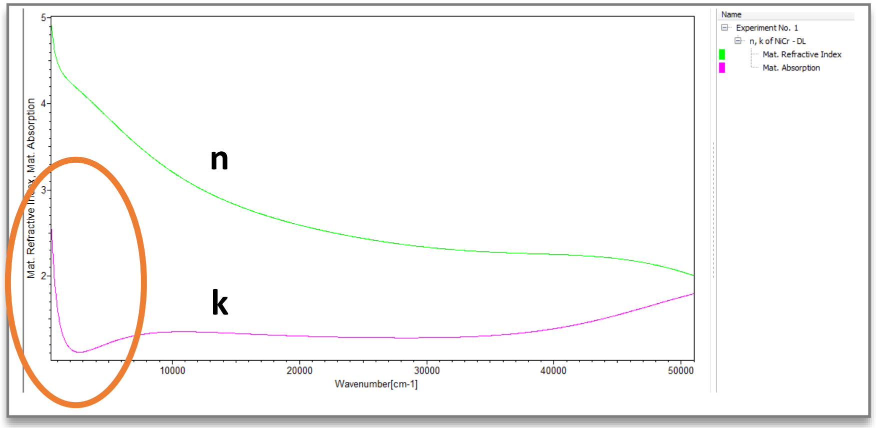


Applications in MIR Ellipsometry – Percolation

Thin Sample

Nominal Thickness ~1.1 nm



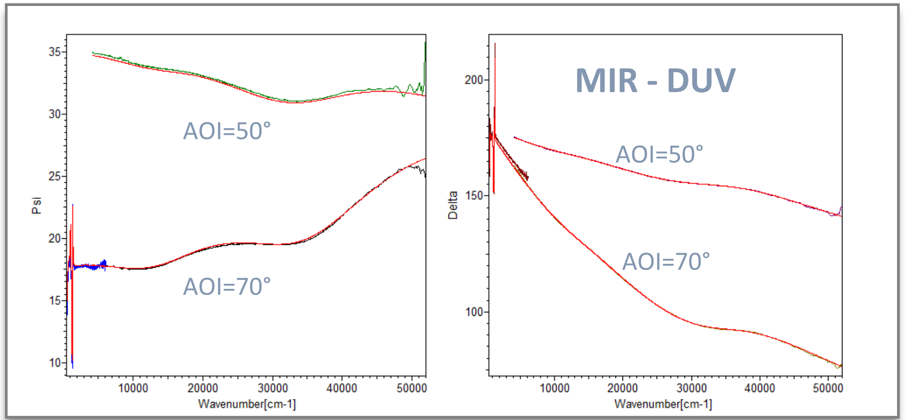


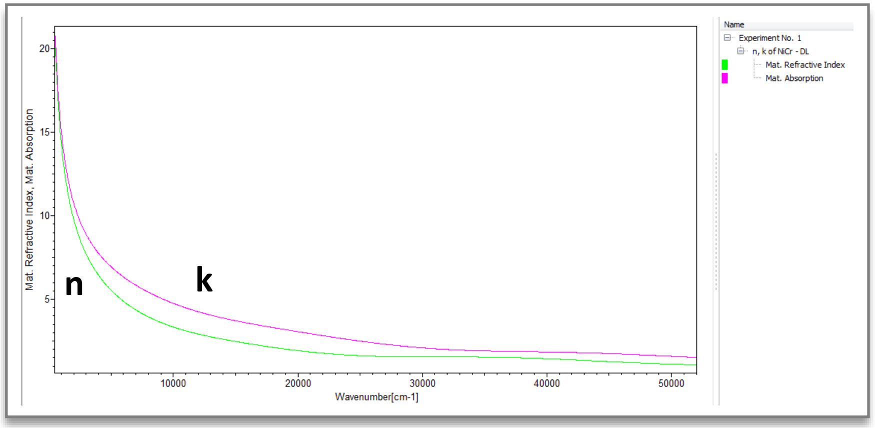
- Film shows low k value in the MIR due to weak Drude absorption

→ Film has low conductivity

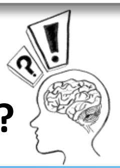
Thick Sample

Nominal Thickness ~10 nm





→ Drude Free Carrier Absorption?



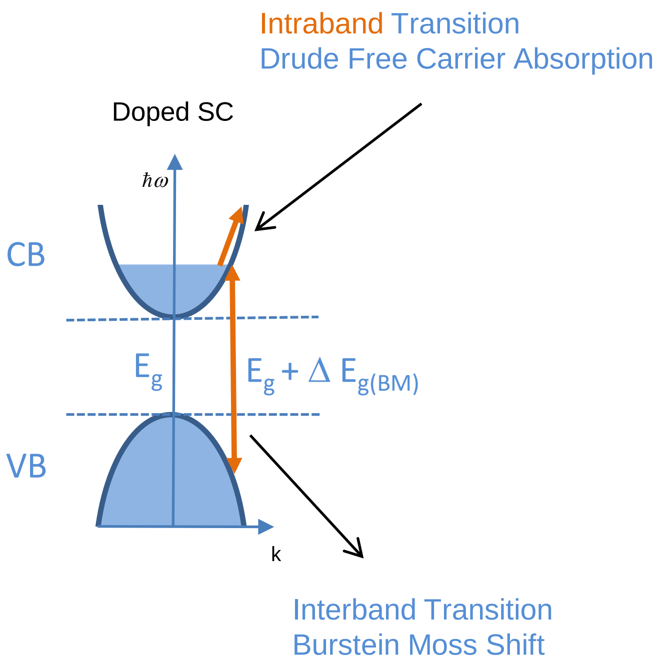
- Films shows a strong k value especially in the MIR due to Drude free carrier absorption

→ Film has strong conductivity

Applications in MIR Ellipsometry – Percolation

Drude Free Carrier Absorption

- The Drude formalism allows a connection between electrical and optical behavior of a conductive film
- It describes the absorption of free carriers which typically takes place in the MIR – NIR spectral range



Drude – Lorentz Oszillator Model: $\epsilon(\nu) = \epsilon_\infty - \frac{\omega_p^2}{\nu^2 + i\omega_\tau \nu} + \frac{\Omega_p^2}{\Omega_0^2 - \nu^2 - i\Omega_\tau \nu}$

Carrier Concentration: $N_e = \frac{\epsilon_0 m^* \omega_p^2}{e^2}$

Resistivity: $\rho = \frac{\omega_\tau}{\epsilon_0 \omega_p^2}$

Mobility: $\mu = \frac{e}{\omega_\tau m^*}$

Sheet Resistance: $Rs = 6 \cdot 10^8 \frac{\omega_\tau}{\omega_p^2\, d}$

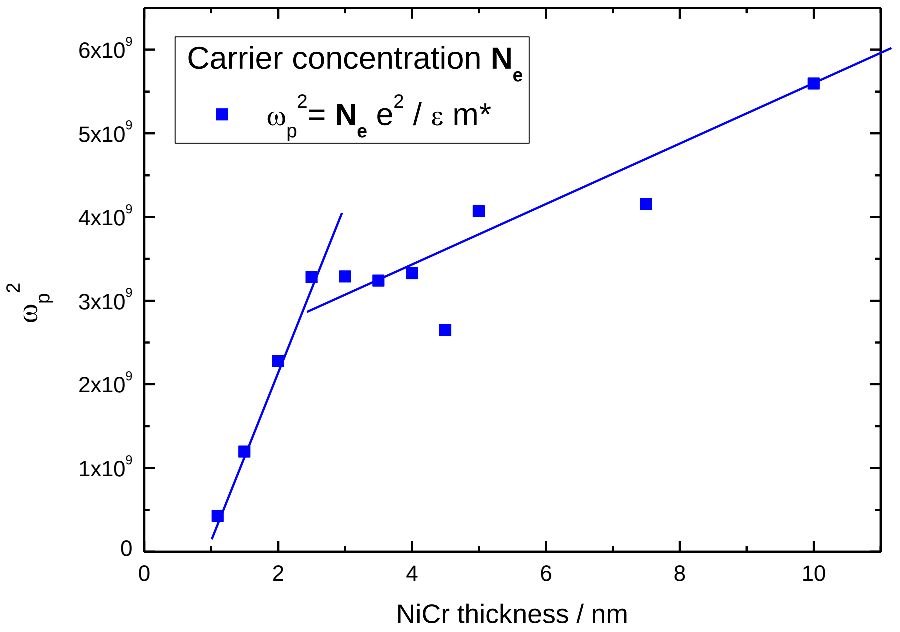
The sheet resistance is calculated using the film thickness d and the Drude parameters ω_p^2 and ω_τ

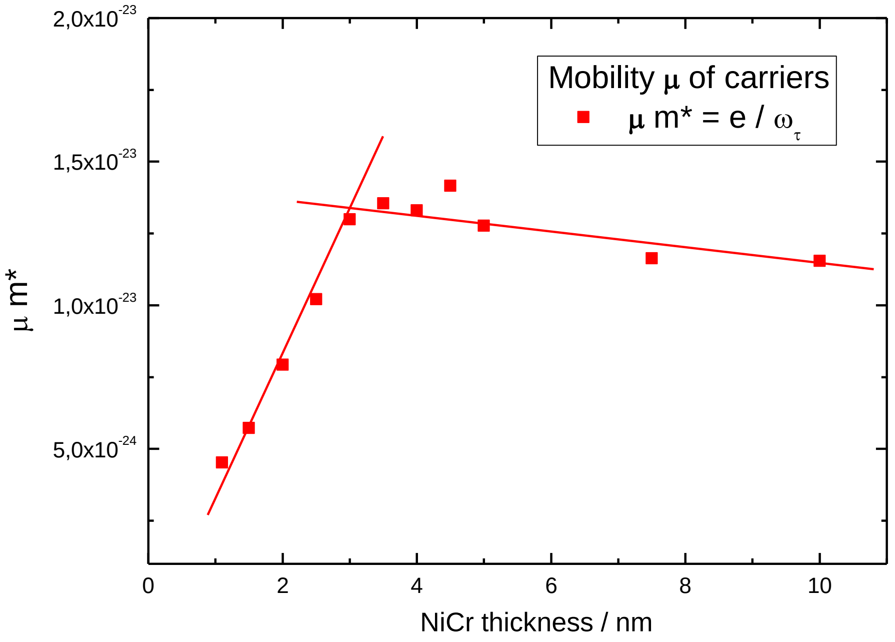
Applications in MIR Ellipsometry – Percolation

Carrier Concentration & Mobility

Carrier concentration: $$N_e = \frac{\epsilon_0 m^* \omega_p^2}{e^2}$$

Carrier mobility: $$\mu = \frac{e}{\omega_\tau m^*}$$





- The carrier concentration is rising strongly up to 3 nm NiCr film thickness
- For film thickness > 3 nm the carrier concentration shows a weaker slope

- The carrier mobility is strongly rising up to 3 nm
  - This indicates a growth of metallic islands up to 3 nm NiCr film thickness
  - The growth of these islands seems to stop at 3 nm NiCr film thickness

Conclusion

- The SENTECH infrared spectroscopic ellipsometer SENDIRA is an ideal tool for IR spectroscopic analysis of bulk materials, films, layer stacks and sample surfaces
- The high spectral resolution of the FTIR allows access to high film thickness of up to 20 µm
- Applications from research and industry were presented benefiting from the FTIR advantages
  - Detection of hydrogen content in SiNx films
  - Ternary III/V semiconductor composition
  - Percolation of extremely thin NiCr films
  - Detection of thin organic materials
  - Anisotropic substrates
  - Thick Si films for SOI

Thank you for your attention!

SENTECH Instruments GmbH (Berlin)

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