Deposition of ultra-thin oxides on silicon: real-time film thickness and wafer temperature measurement

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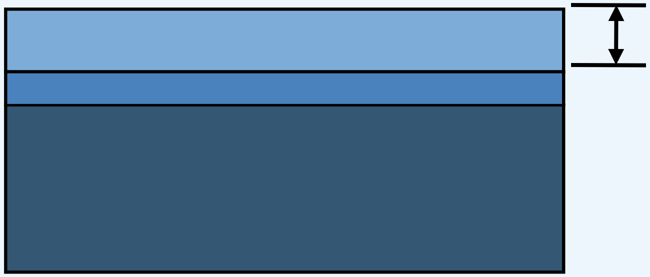
MBE and sputter deposition of metal oxides on Si/TiN substrates

purpose: screening of high k materials for next generation memory modules



metal oxide

TiN (~50 Å)

silicon

~100 Å

requirements: in-situ monitoring and control of thin oxide film deposition

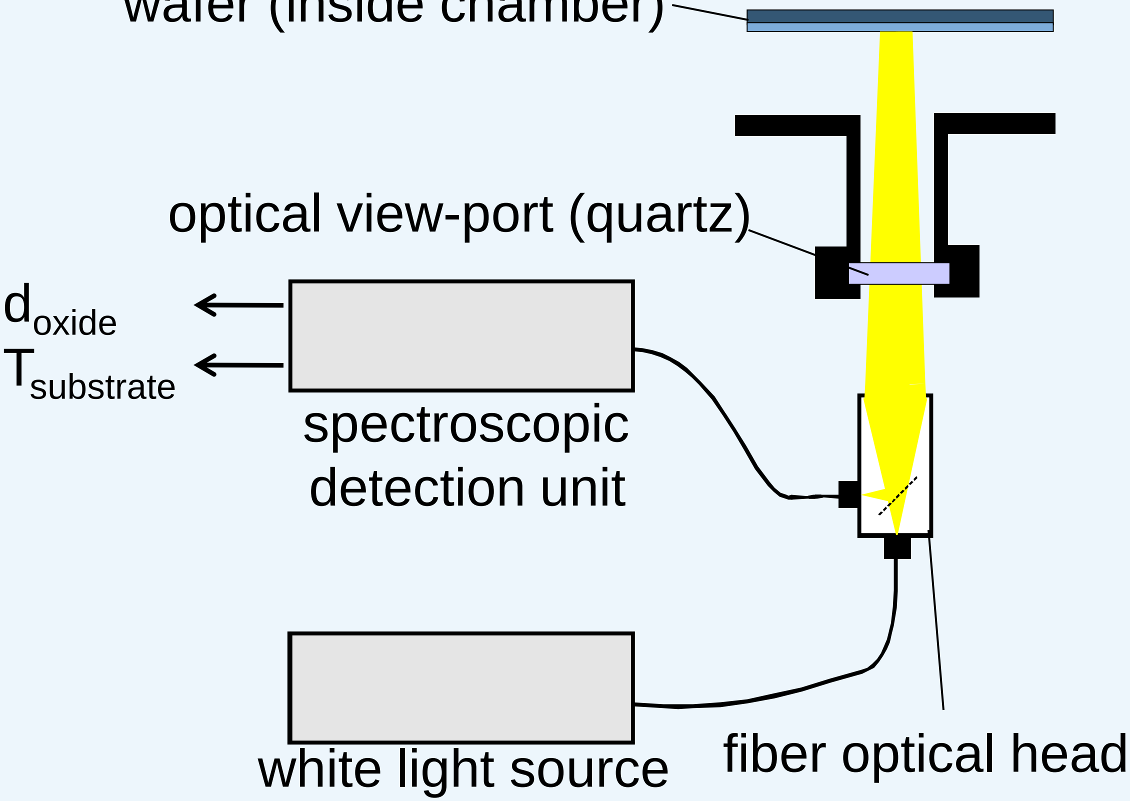
- total oxide layer thickness approx. 100 Å, accuracy ± 1 Å
- method applicable for wide range of oxide materials
- in-situ wafer temperature measurement

Outline

- experimental
- oxide thickness monitoring
- wafer temperature measurement
- summary and outlook

Set-up at MBE chamber

MBE: VG V80H



wafer (inside chamber)

optical view-port (quartz)

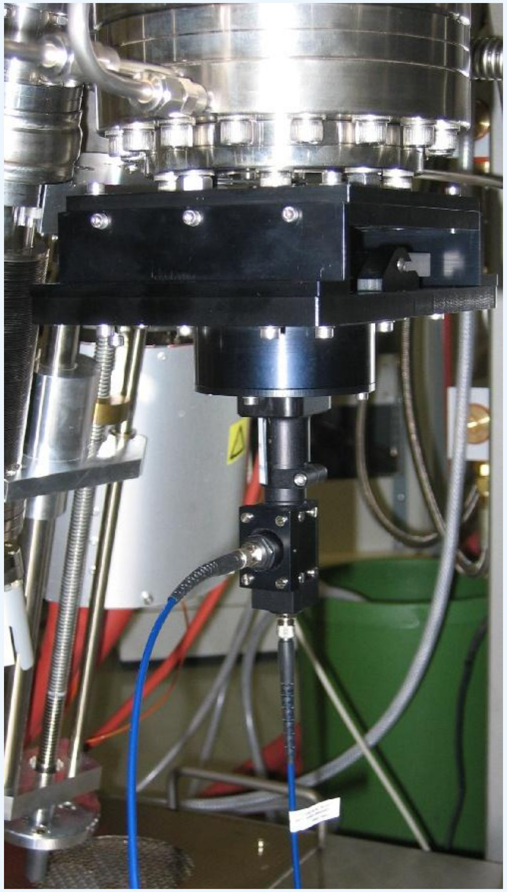
d_{oxide}

$T_{substrate}$

spectroscopic detection unit

white light source

fiber optical head



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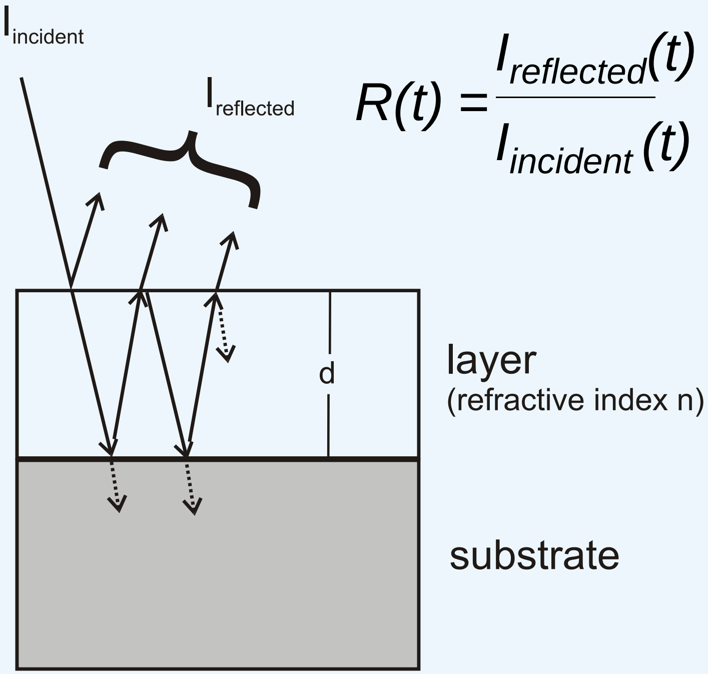
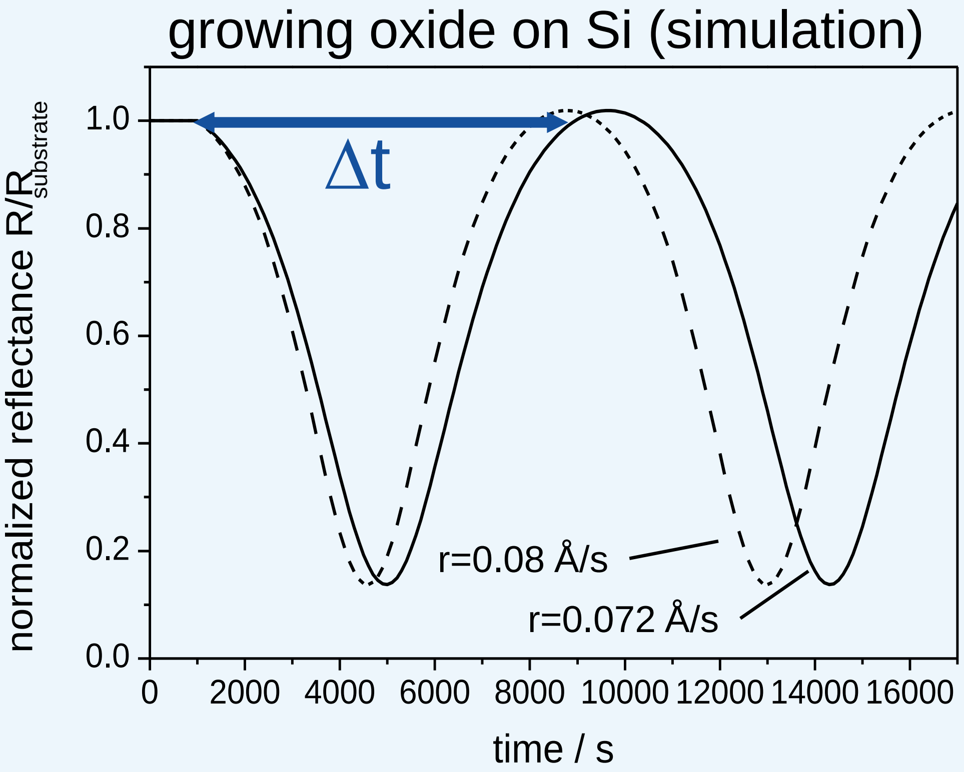
Oxide thickness monitoring: principles

$$R(t) = \frac{I_{reflected}(t)}{I_{incident}(t)}$$




growing oxide on Si (simulation)

longer oscillation period Δt

➔ smaller growth rate r

(and vice versa)

Δt = oscillation period

$$r = \frac{\lambda / n}{2 \cdot \Delta t}$$

Spectral detection enables to choose most adequate detection wavelength.

Oxide thickness monitoring: principles

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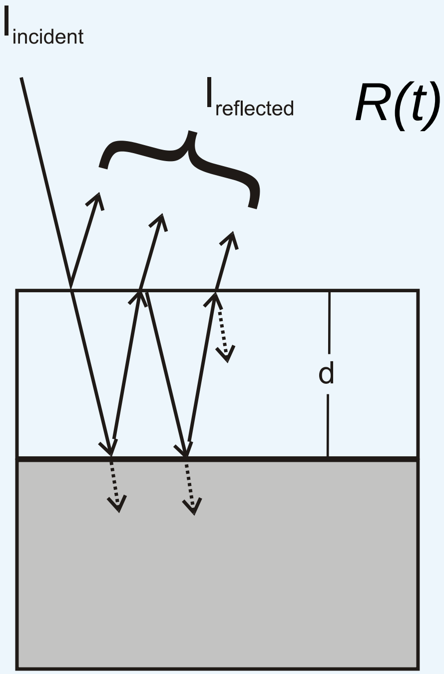

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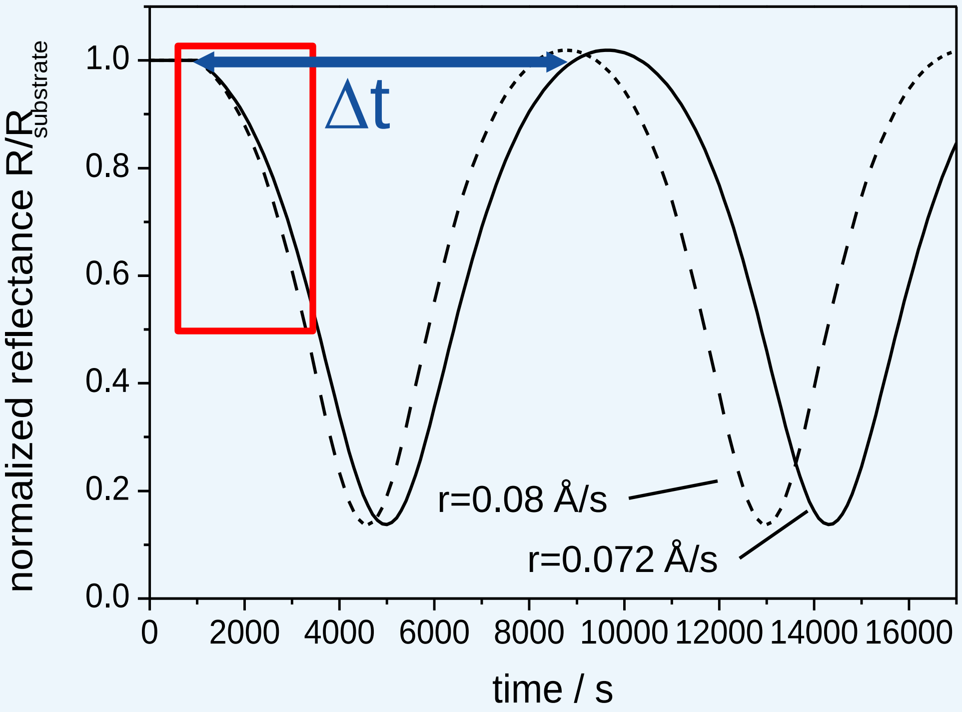

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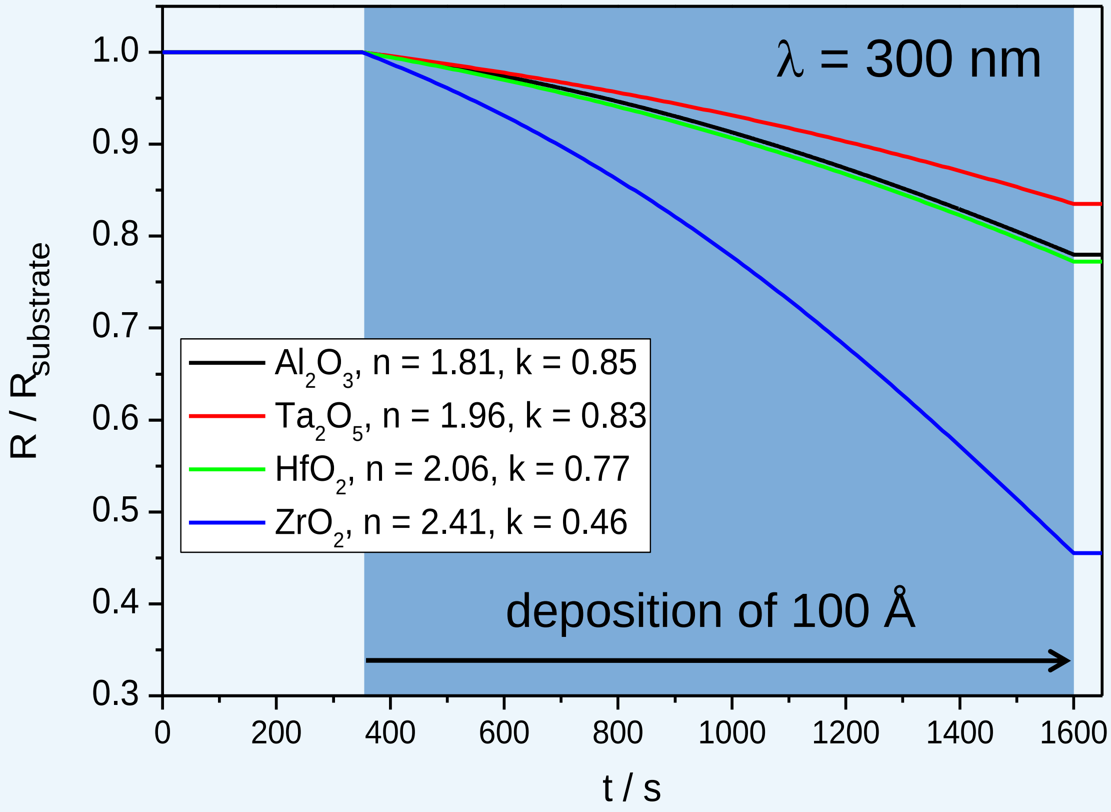
Oxide thickness monitoring: simulation

Simulated in-situ signals for typical oxides

- calculated for 0.08 Å/s, 100 Å total thickness
- n,k from literature

- thin layer growth can be monitored for many oxides
- sensitivity depends on refractive index n



Oxide thickness monitoring: requirements

Thickness determination for thin layers

Requirements for the measurement:

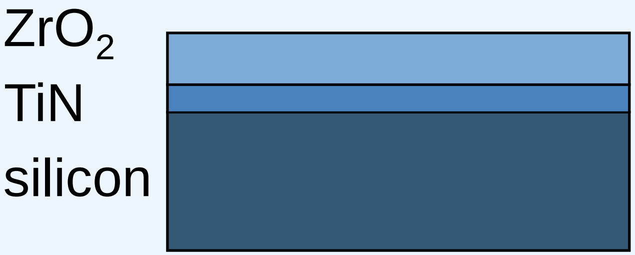
- UV wavelength of probe light
- sensor needs to be optimized for extremely low noise in reflectance ($\Delta R < 0.001$)
- UV n,k-dispersion of all materials must be known.
  ideal approach: one deposition of thicker calibration layer, showing at least one Fabry-Perot minimum

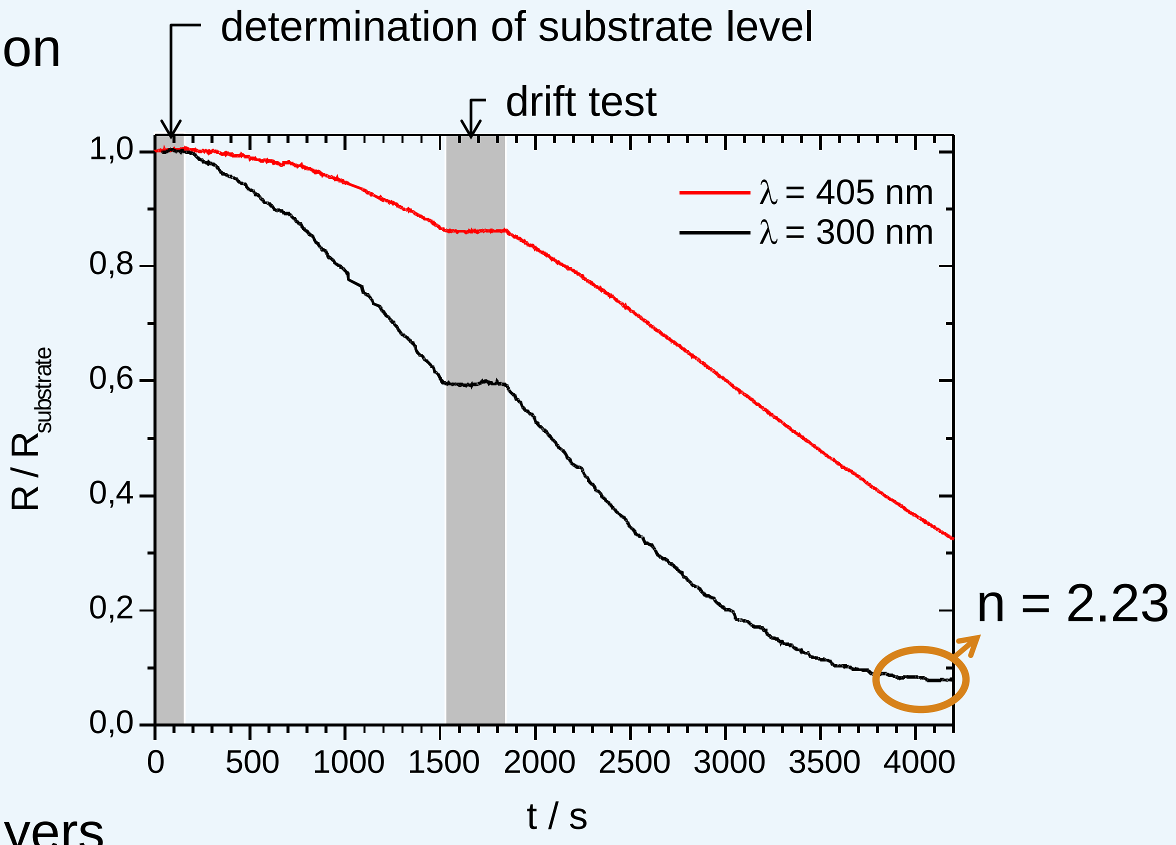
Requirements to the deposition system:

- optical view port (quartz)
- low wafer wobble during rotation
- wafer and sensor position stable

Calibration run for refractive index measurement

Deposition of ~300 Å ZrO_2 on Si/TiN





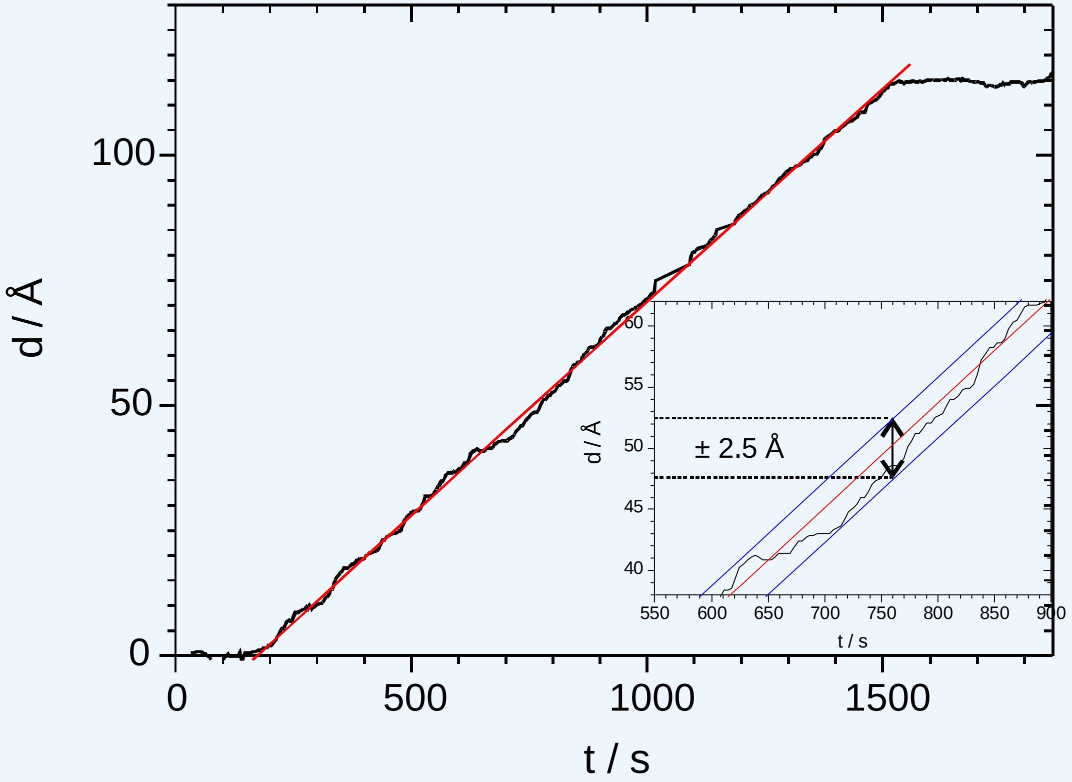
chosen wavelengths:

300 nm: ideal for very thin layers

405 nm: extends measurement range for thicker layers, still sensitive when reflectance at 300 nm passes minimum

Oxide thickness monitoring

Growth of ZrO_2 on Si/TiN



deposition rate (0.0852 ± 0.0001 Å/s) consistent with supplementary applied quartz monitor measurement based on single point noise of about ±2.5 Å

from deposition rate: layer thickness accuracy better than ± 1 Å at total thickness of ~100 Å

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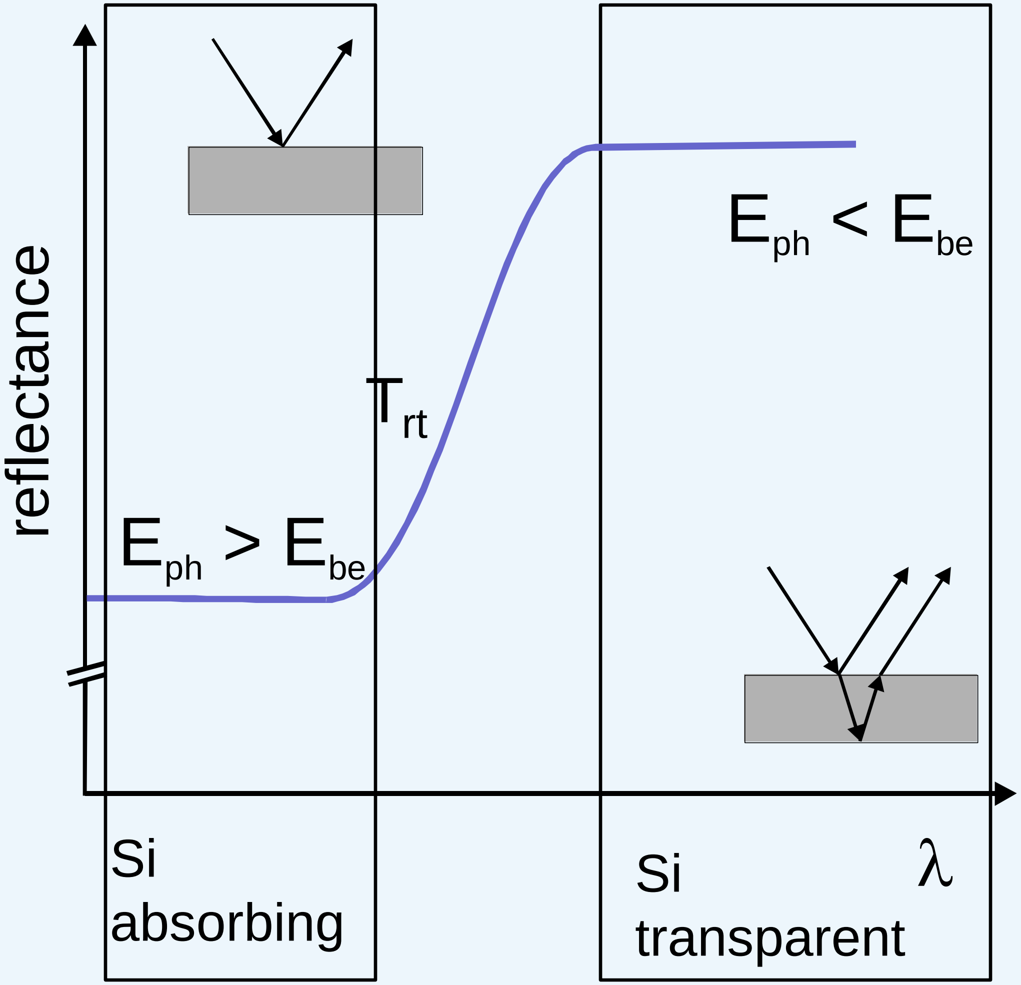
Back-side reflectance of double side polished wafer

$E_{ph} = hc/\lambda$

E_{be} = band-edge energy (material property of wafer)



Temperature Measurement: principles

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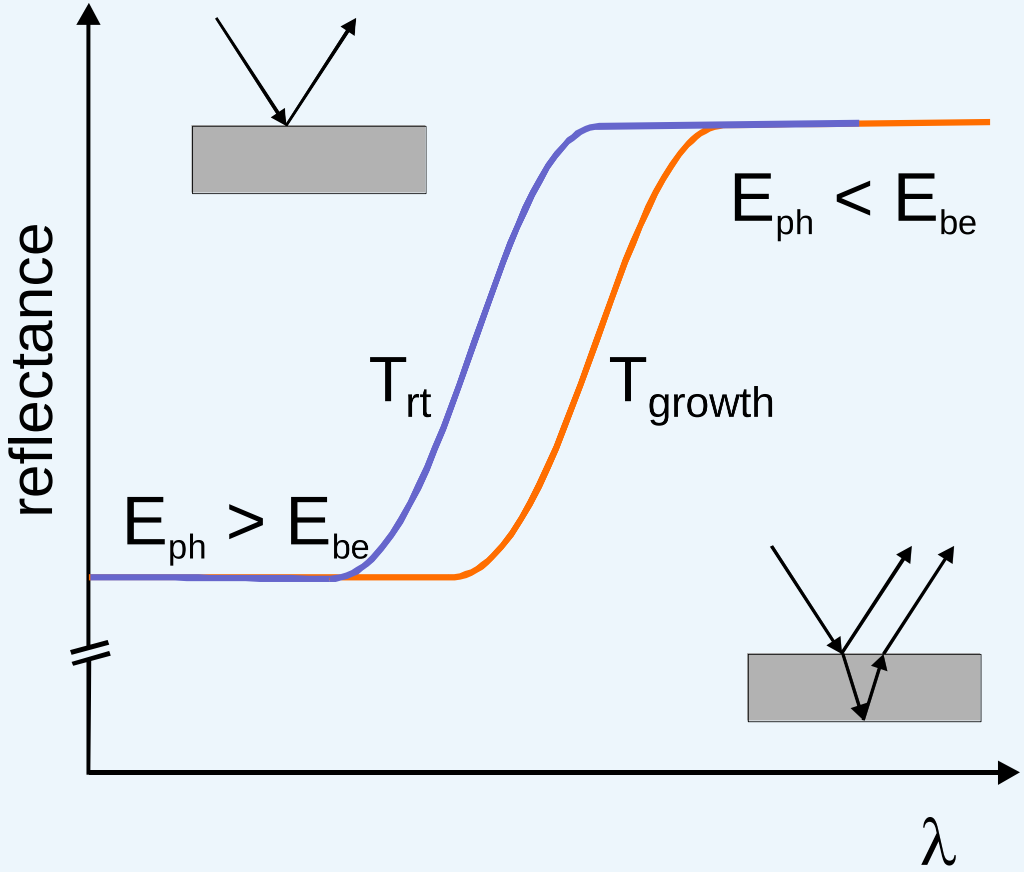
(material property of wafer)

$T_{growth} > T_{rt}$



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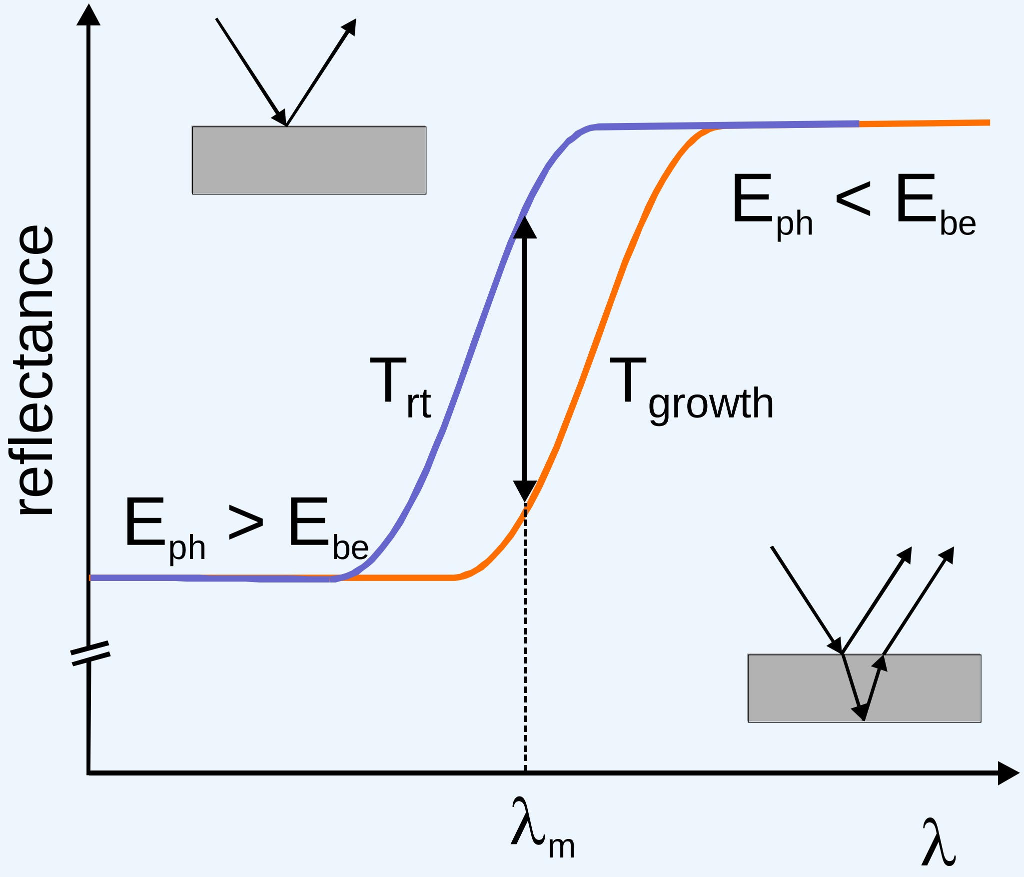
$R(\lambda_m)$ reveals T



Temperature Measurement: principles

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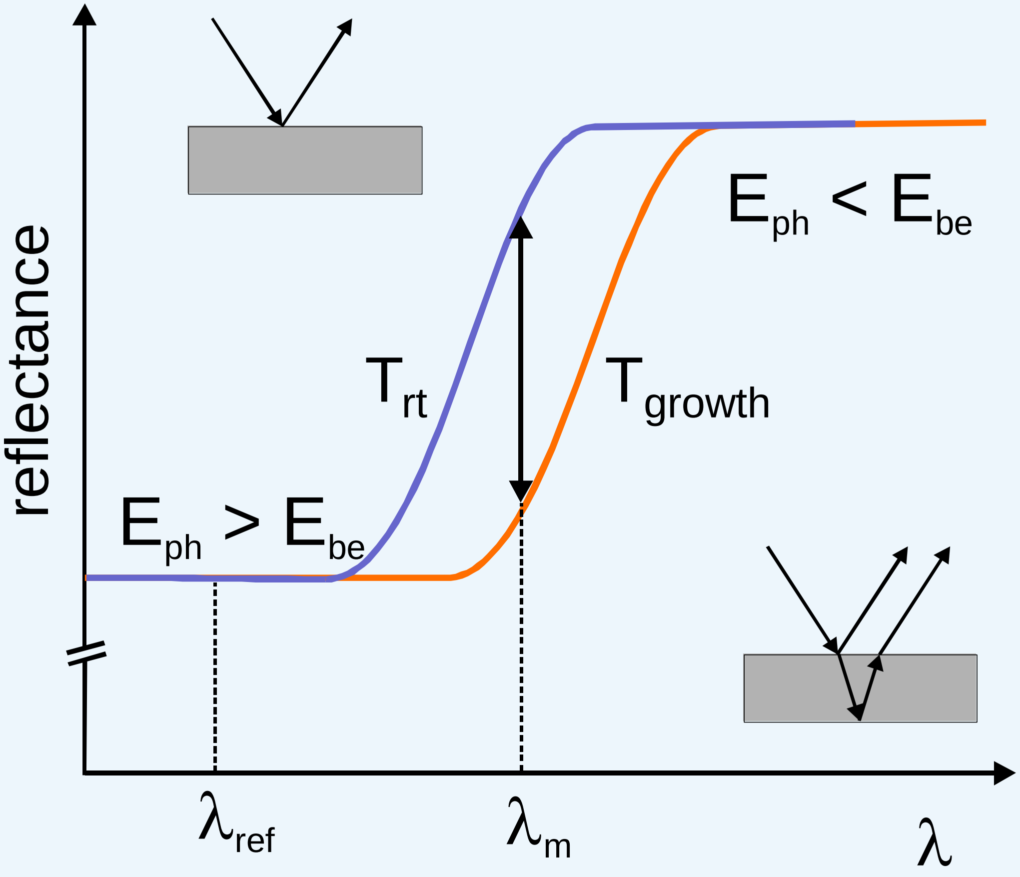
$R(\lambda_m)$ reveals T

for drift compensation:
$R(\lambda_m)/R(\lambda_{ref})$ is monitored

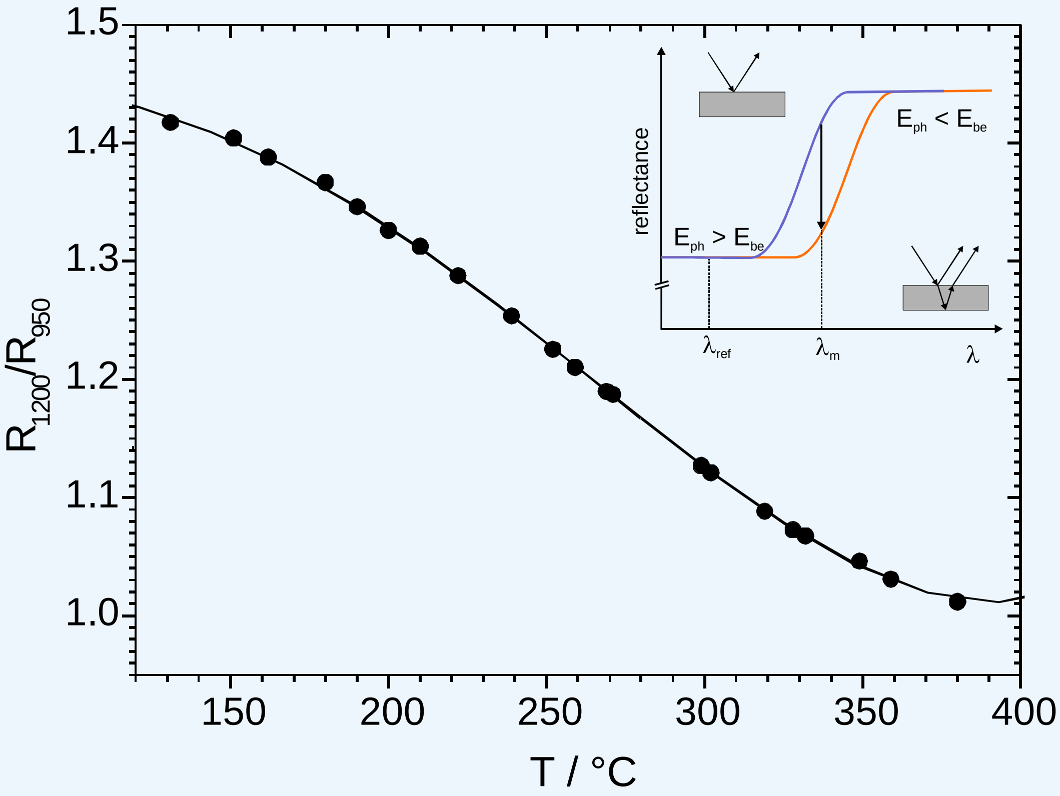


Temperature Measurement: calibration

T-Calibration for highly resistive silicon wafers

λ_m =1200 nm
λ_{ref} = 950 nm

Selected wavelength 1200 nm is suitable for Si wafer temperatures between 120 °C and 350 °C (typical range of oxide growth in MBE)



Application: T-step run

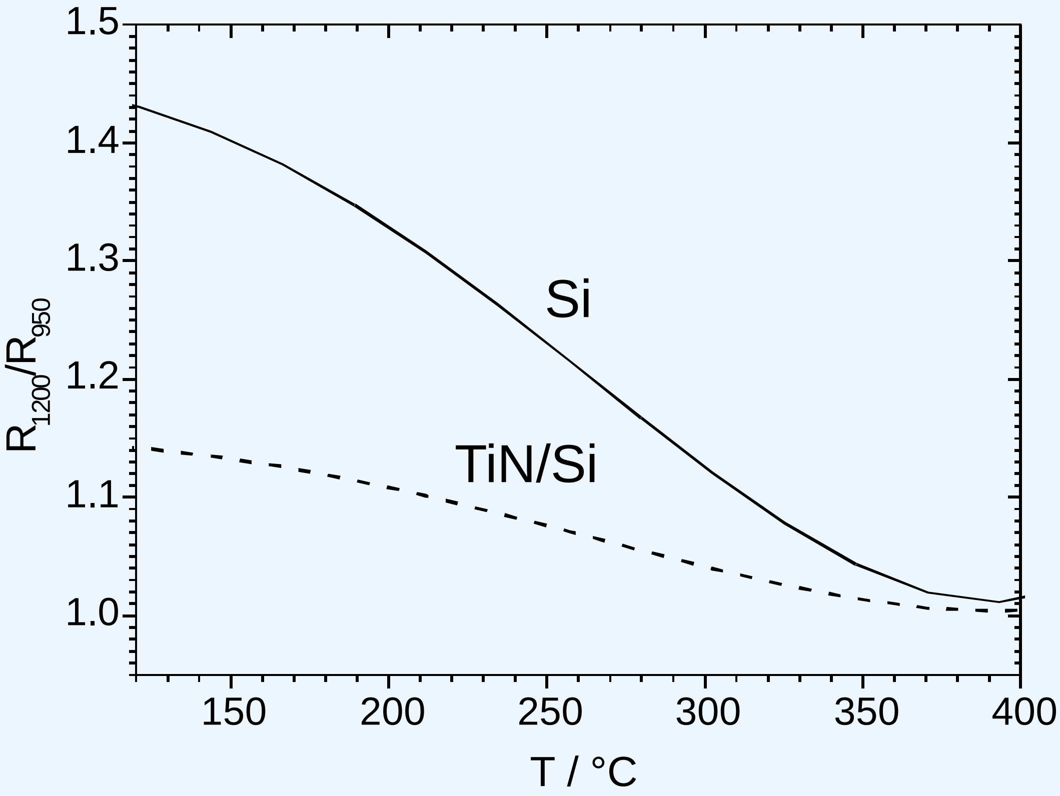
T-measurement on highly resistive silicon: ideal means for temperature calibration

T-accuracy: ± 1 K

Temperature Measurement: TiN coated Si

Calibration for TiN/Si

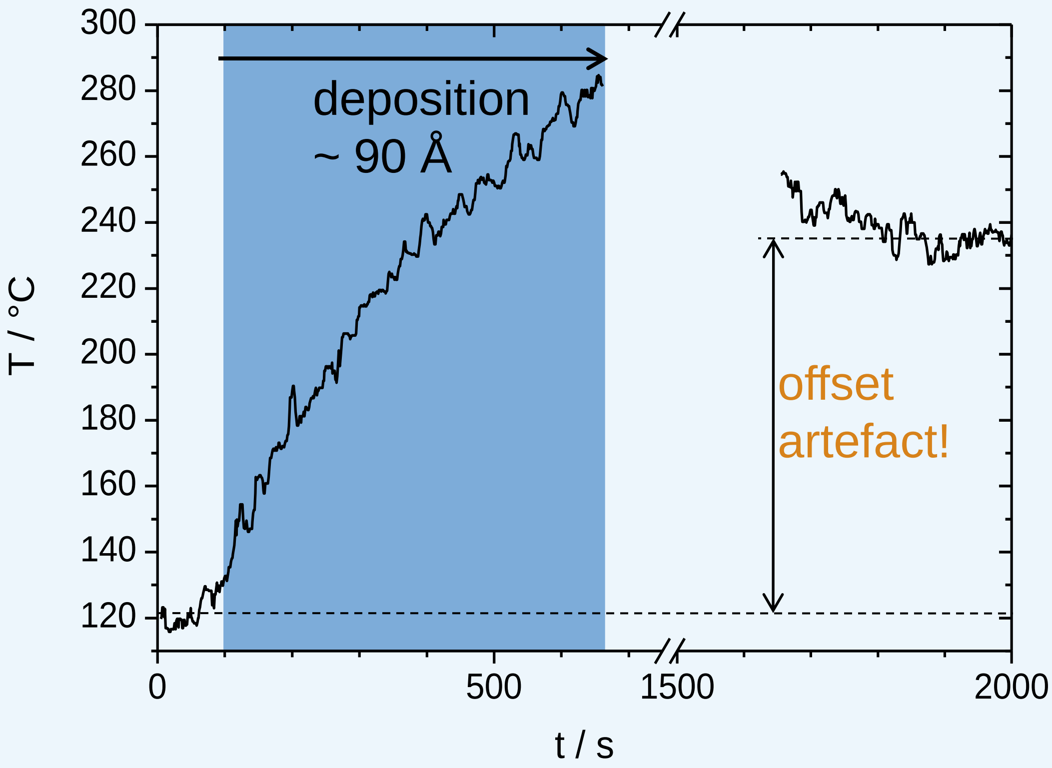
Absorption in TiN layer reduces sensitivity to T changes.
TiN layer thickness influences the T-signal!



Simultaneous deposition of Al_2O_3 and ZrO_2 on Si/TiN

At constant heating: Temperature apparently increases during deposition but does not decrease after deposition.

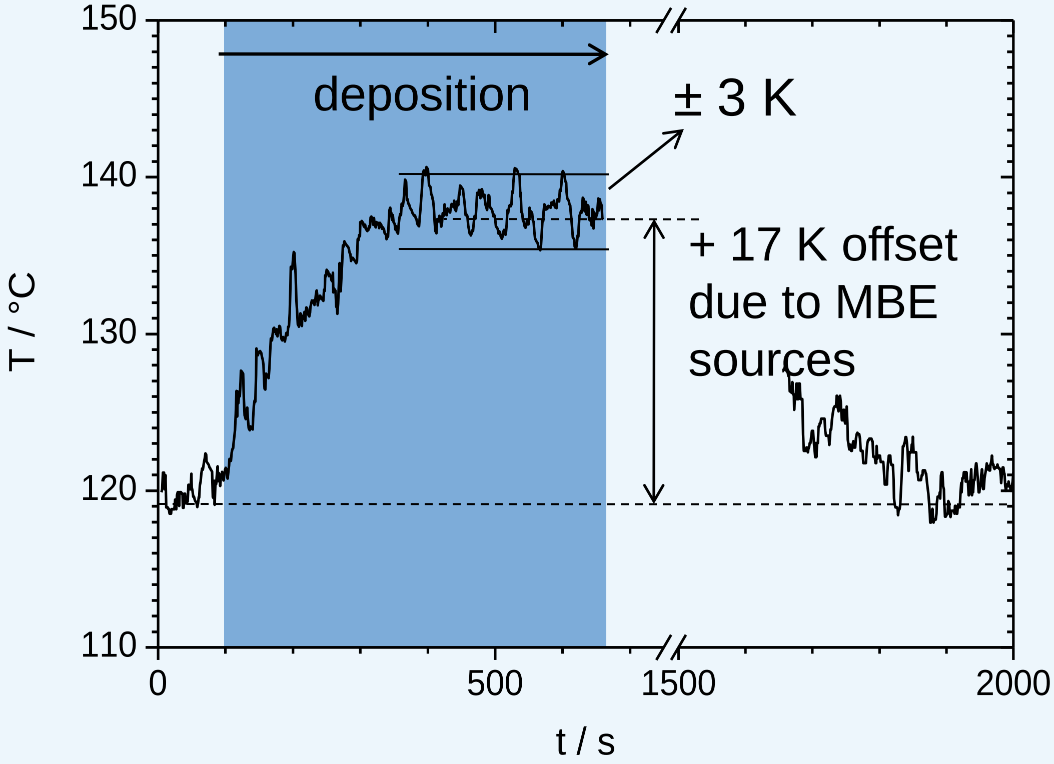
-> artefact due to oxide induced change of reflectance



Oxide growth corrected wafer temperature

After correction for reflectivity changes caused by growing oxide layer:

- Substrate temperature is raised by approx. 17 K due to MBE source radiation
- stable T after approx. 250 s of deposition



Summary and outlook

Results

Optimized UV reflectance measurements:

- Layer thickness of Al_2O_3 and ZrO_2 layers were determined in situ with an accuracy of better than ± 1 Å even for less than 100 Å absolute thickness

From IR-reflectance measurement:

- wafer temperature of bare Si: accuracy of ± 1 K
- wafer temperature of bare TiN covered Si: accuracy of ± 3 K
- T-increase by MBE-source radiation: approx. +17 K

Outlook:

- transfer sensor from MBE to sputter system

Some gems

need a little

extra help to

sparkle

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