FROM RESEARCH TO INDUSTRY

Real-time monitoring of thin-films using temperature-controlled ellipsometry for nanotechnology applications

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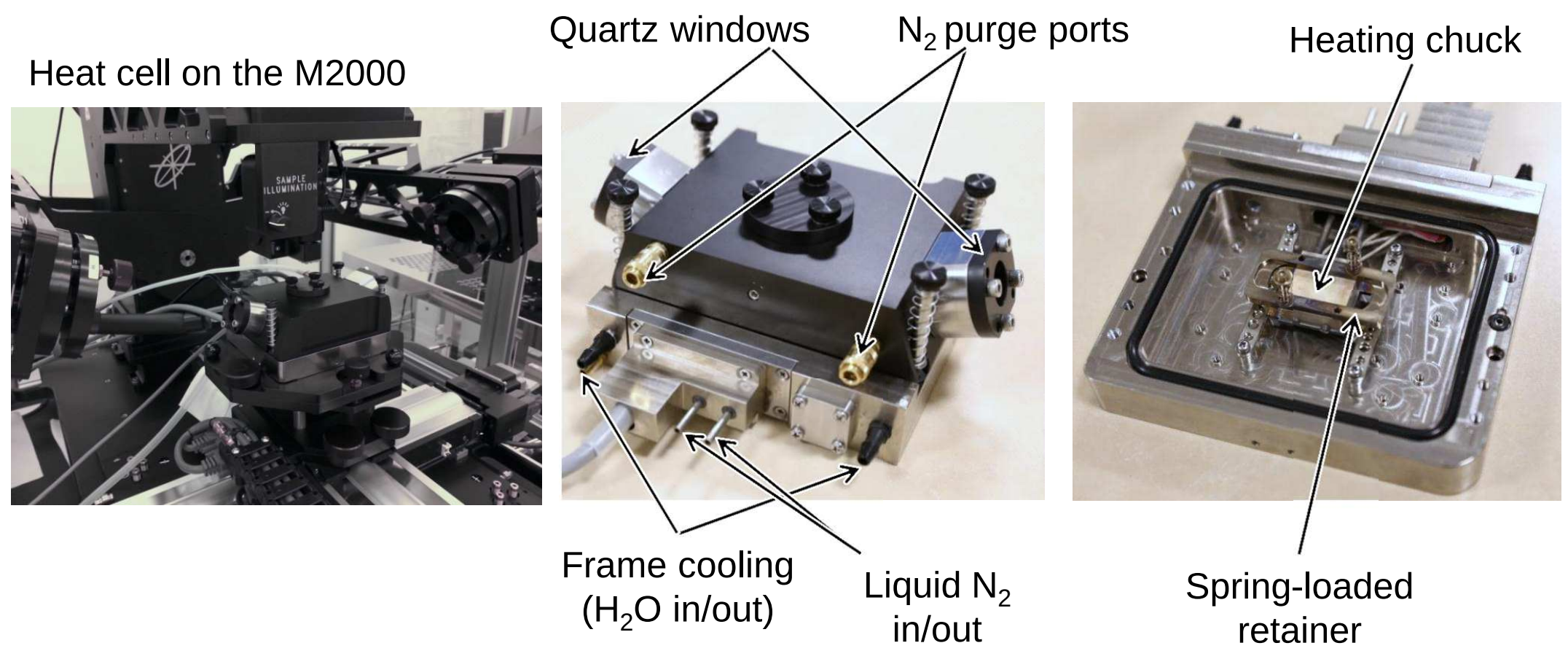
Introduction

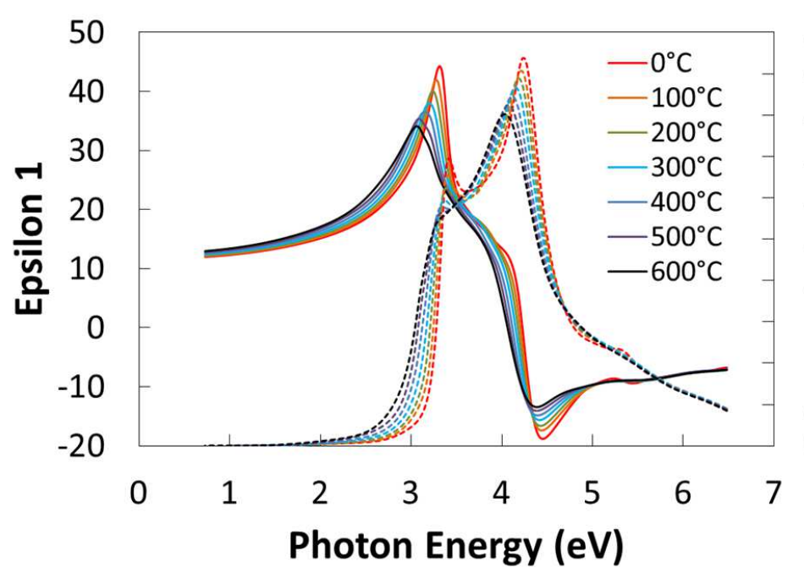
- Temperature is an important parameter for material integration:
  - Shift of the material properties
  - Degradation of the material properties
- Need of in situ characterization
- Ellipsometry: a relevant technique
  - Well-suited for real-time monitoring
  - Fast and non-destructive
  - Heat cells can be easily adapted on ellipsometers
  - Ellipsometers can be mounted on processing tools



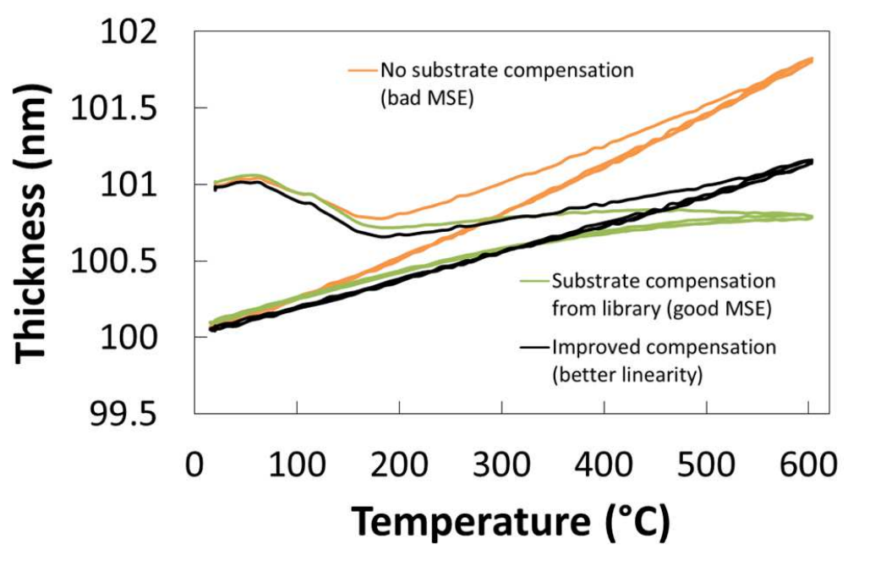
Experiments

- Ellipsometer: M2000 (Woollam)
- Heat cell (Instec)
  - Temperature range: -80°C to 600°C
  - Angle of incidence: 70° with cover
  - Measurement speed: ~2s
- Issues associated with heat cells
  - Sample and chuck temperature may be different
  - Sample oxidation (➔ use of N_2 purge)
  - Windows correction (birefringence)
  - Substrate optical constants need to be compensated

Silicon optical constants vs. temperature



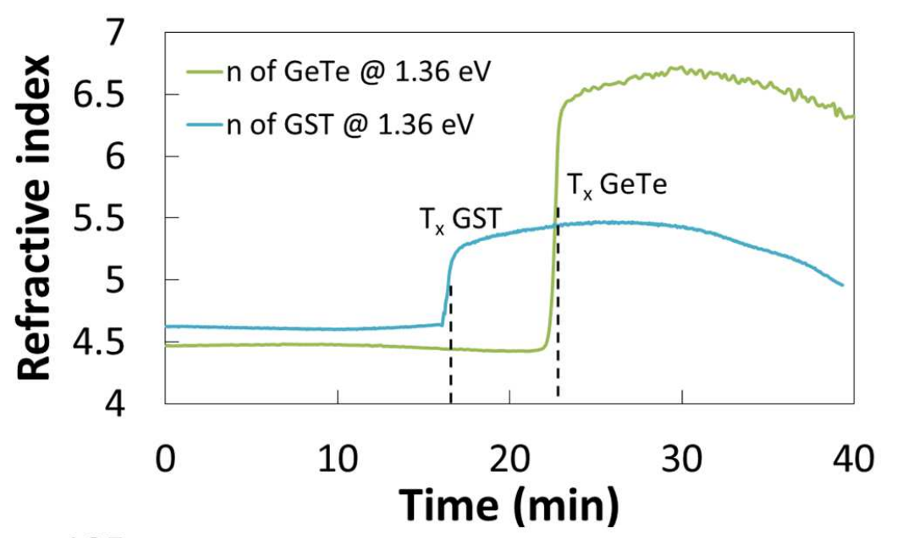
100 nm thermal oxide: two cycles at 600°C

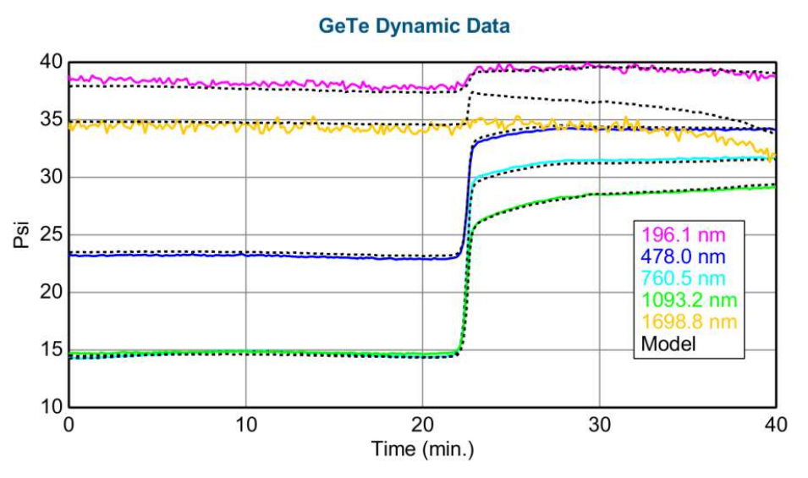


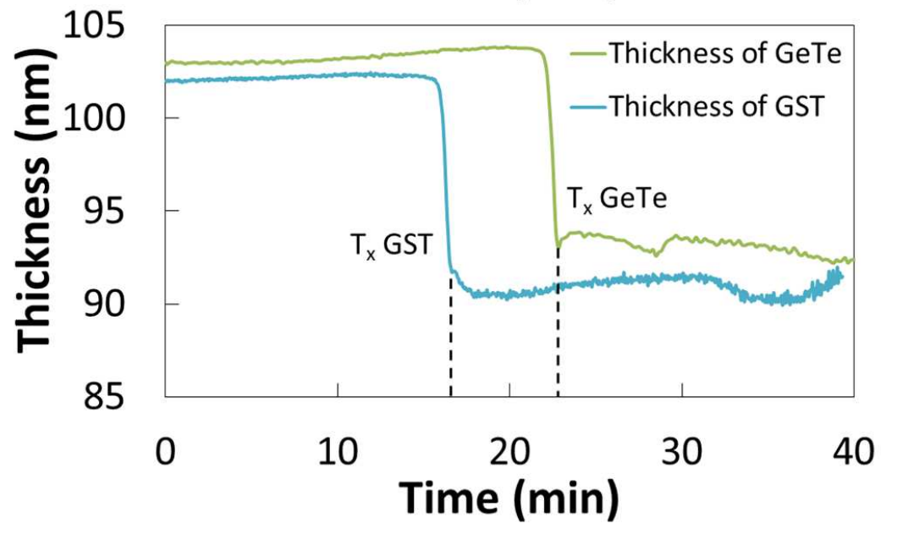
Phase change materials

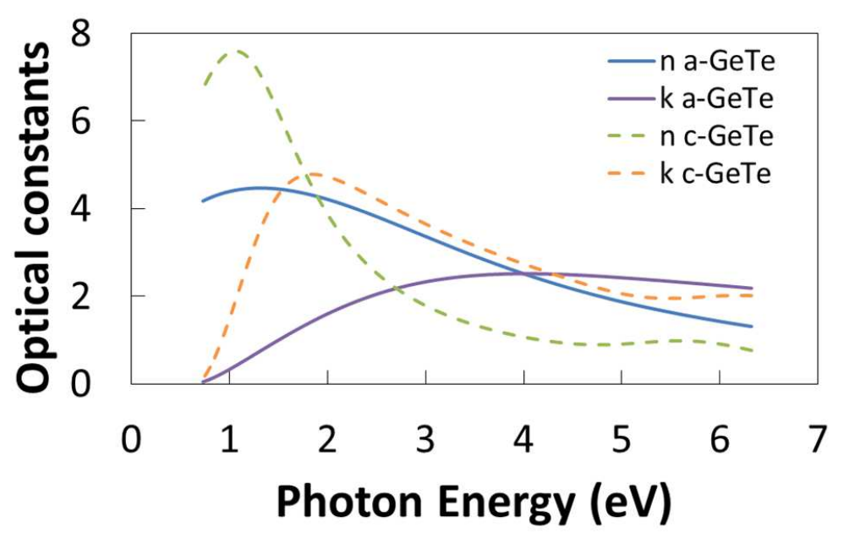
- PCM are used for memory applications
- Amorphous to crystalline phase change
- Real-time ellipsometry gives access to:
  - Crystallization temperature T_x
  - Thickness variation
  - Optical constants and bandgap variation
  - Drift of the material properties vs. time

Oxide: **Tauc-Lorentz**
PCM: **Tauc-Lorentz**
SiO_2 (optional)
Substrate: **Si temp**



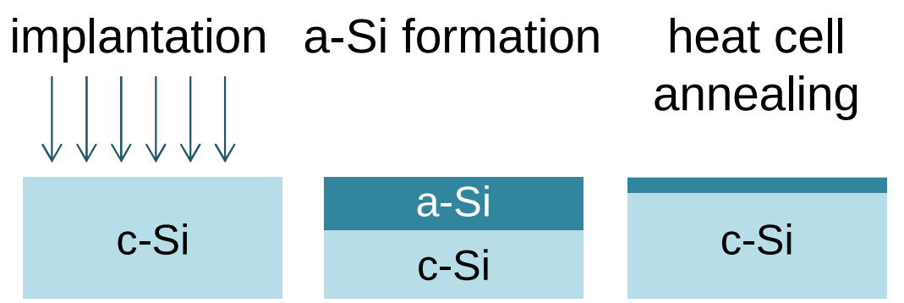






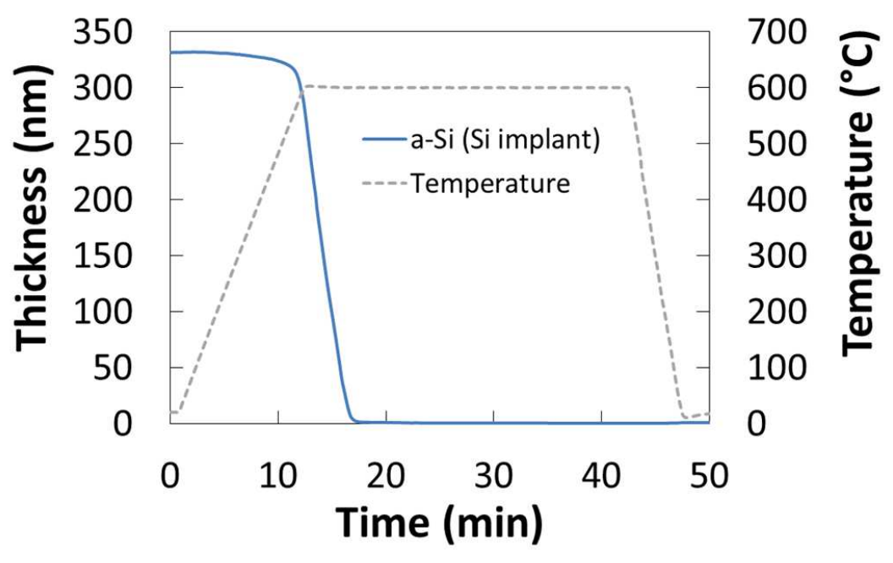
Solid Phase Epitaxial Regrowth

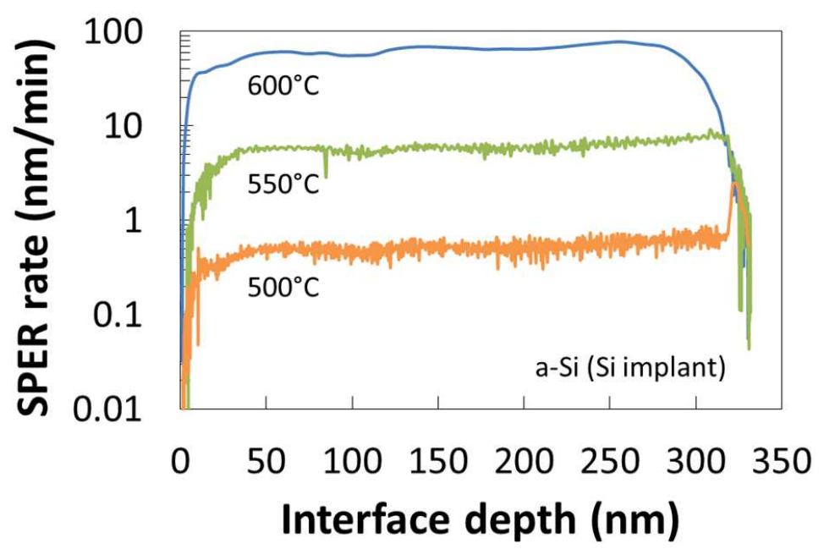
- In CMOS 3D sequential integration scheme, SPER is used for dopant activation at low temperature
- Real-time ellipsometry gives access to:
  - Thickness vs. time
  - Regrowth rate vs. depth
- SPER rate depends on:
  - Temperature: Arrhenius-type equation $v(T)=v_0 e^{(-E_a/kT)}$
  - Dopant concentration
  - Presence of impurities: metal induced crystallization
  - Surface preparation



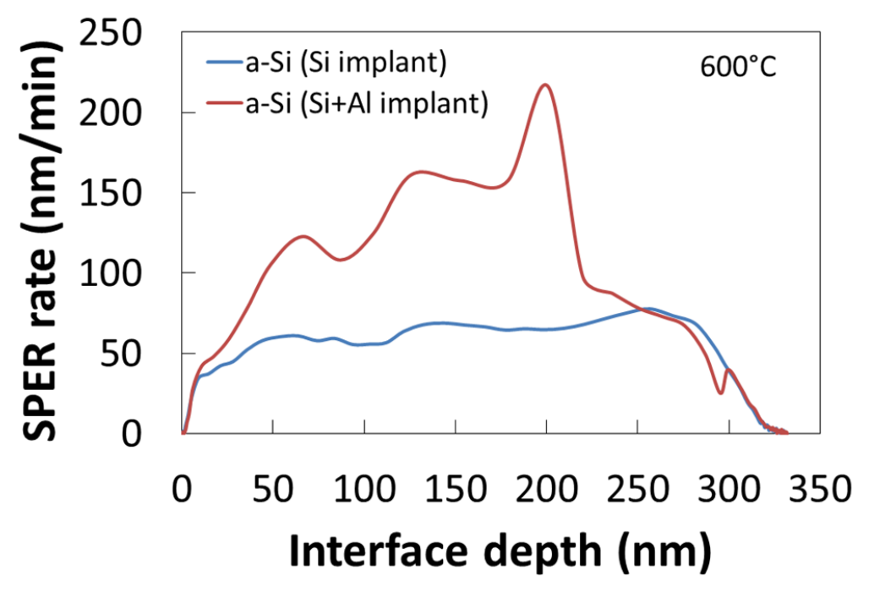
Effect of temperature, intrinsic silicon
$v_0=7x10^{17}$ nm/min, E_a=2.75 eV

Native oxide
a-Si (330 nm): **Tauc-Lorentz**
Substrate: **Si temp**



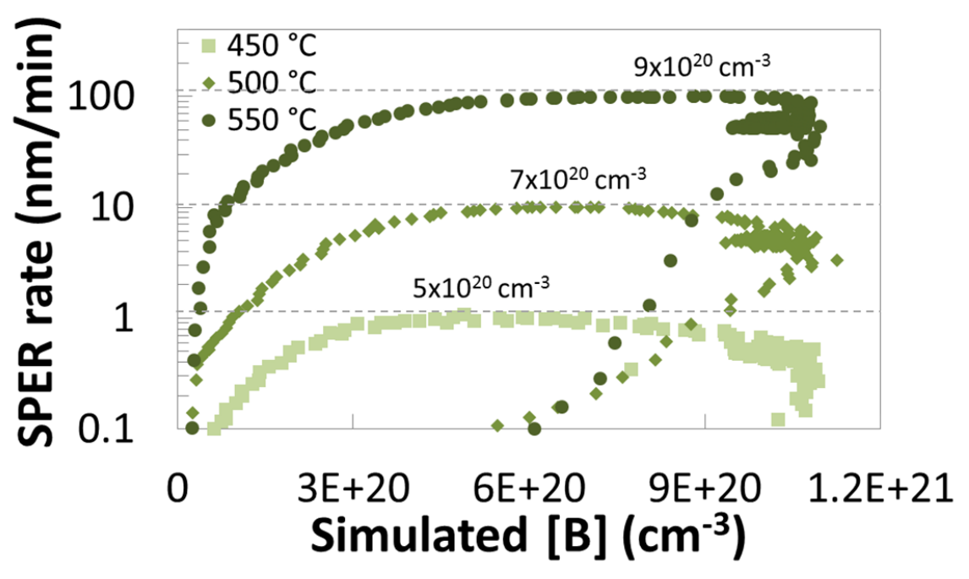


Effect of metal incorporation, Al-implanted silicon
Si (pre-amorphisation step) + Al 100 keV, 1E15 /cm^2



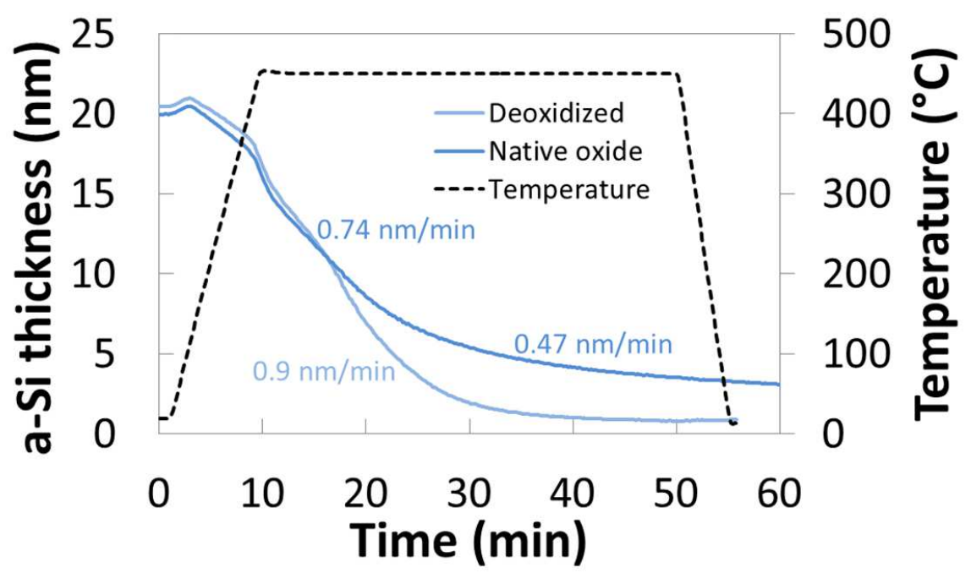
Native oxide
a-Si (330 nm): **Tauc-Lorentz**
Substrate: **Si temp**

Effect of dopant concentration + temperature
Si (pre-amorphisation step) + [B] = $1x10^{21}$ at/cm^3



Native oxide
a-Si (180 nm): **Tauc-Lorentz**
Substrate: **Si temp**

Effect of pre-implantation surface preparation on SOI wafers
Ge (pre-amorphisation step) + [B] = $5\text{-}6x10^{20}$ at/cm^3

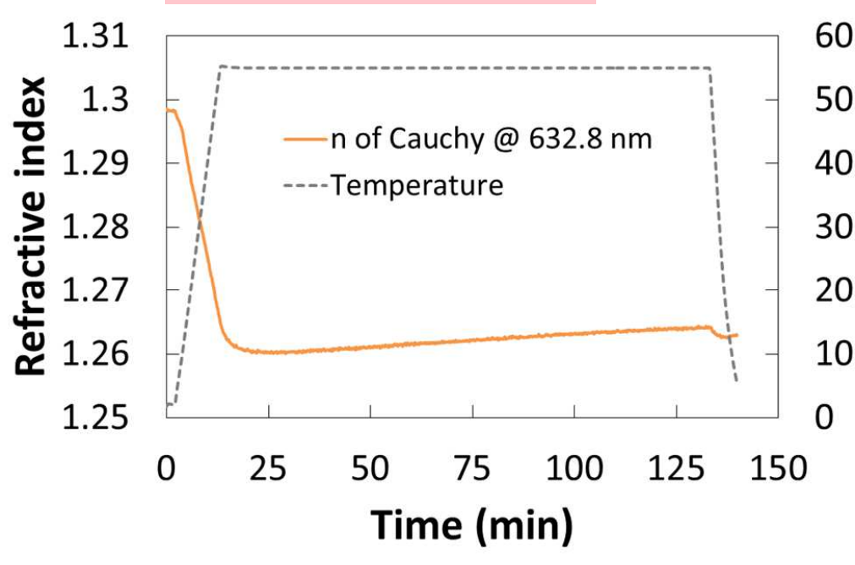


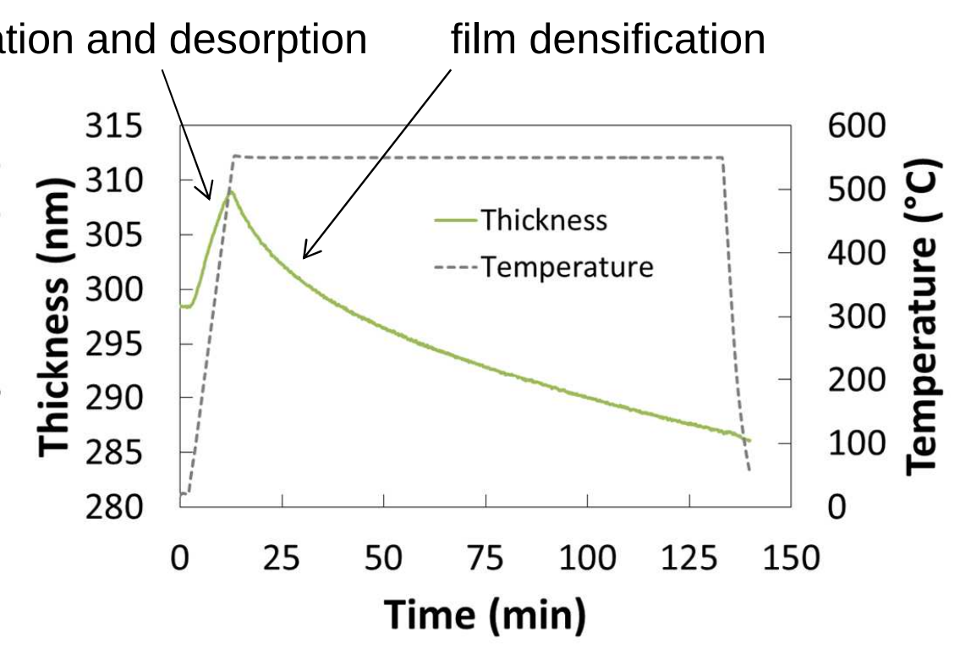
a-Si (20 nm): **Tauc-Lorentz**
c-Si (2nm): **Si temp**
BOX (144 nm): **SiO2**
Substrate: **Si temp**

Porous materials

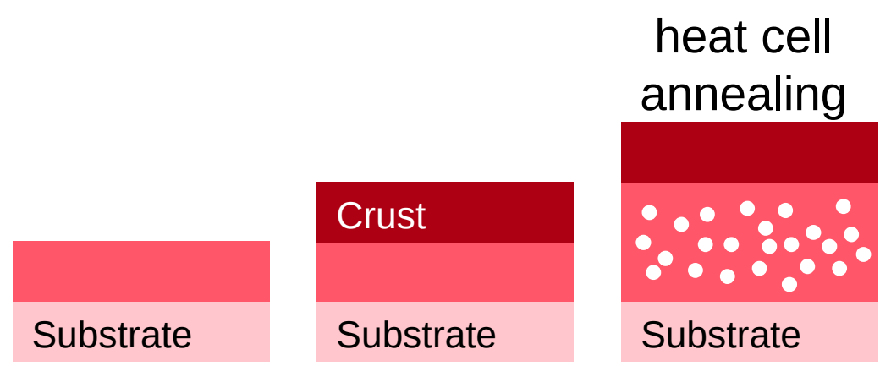
- Porous materials are used in CMOS interconnect, gaz and moisture sensors
- Film modifications at high temperature:
  - Desorption of water and hydrocarbon contamination
  - Skeleton shrinkage (densification)

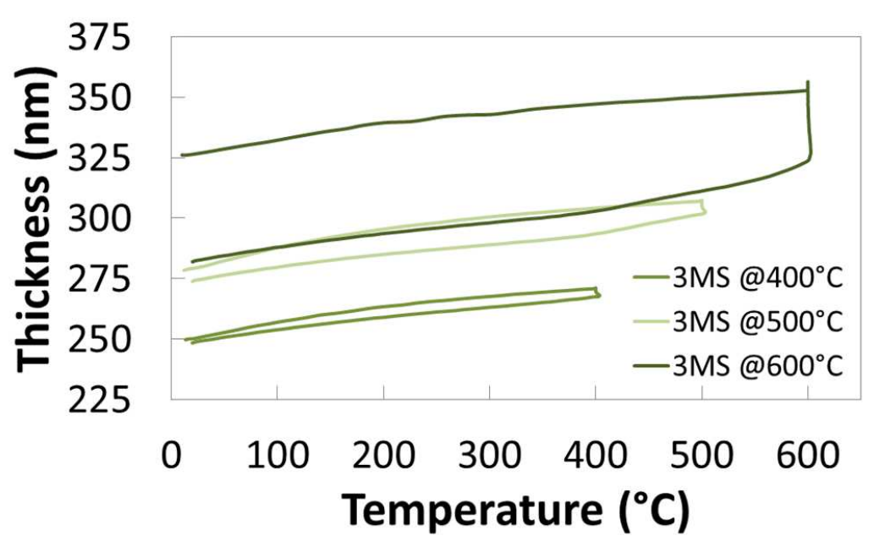
SiCOH: **Cauchy**
Substrate: **Si temp**

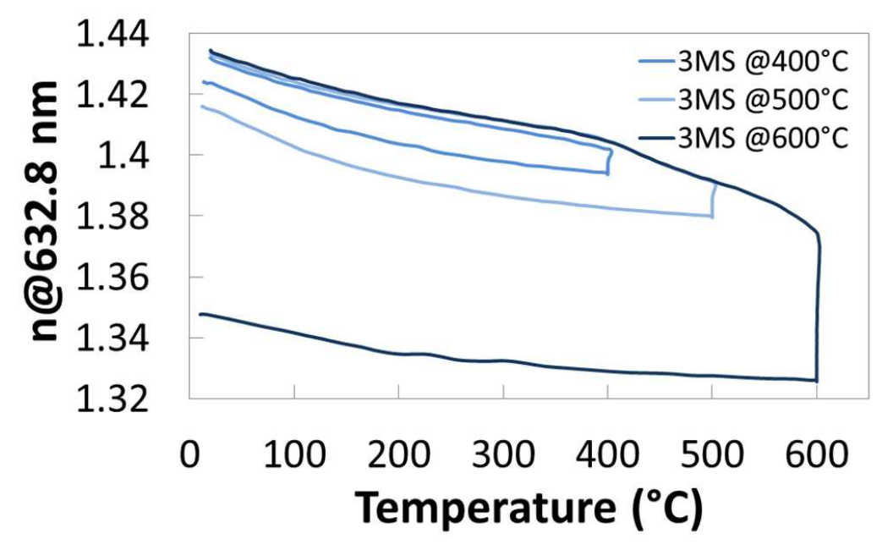




- Original foaming process to increase the porosity
  - PECVD deposition
  - Trimethylsilane (3MS)



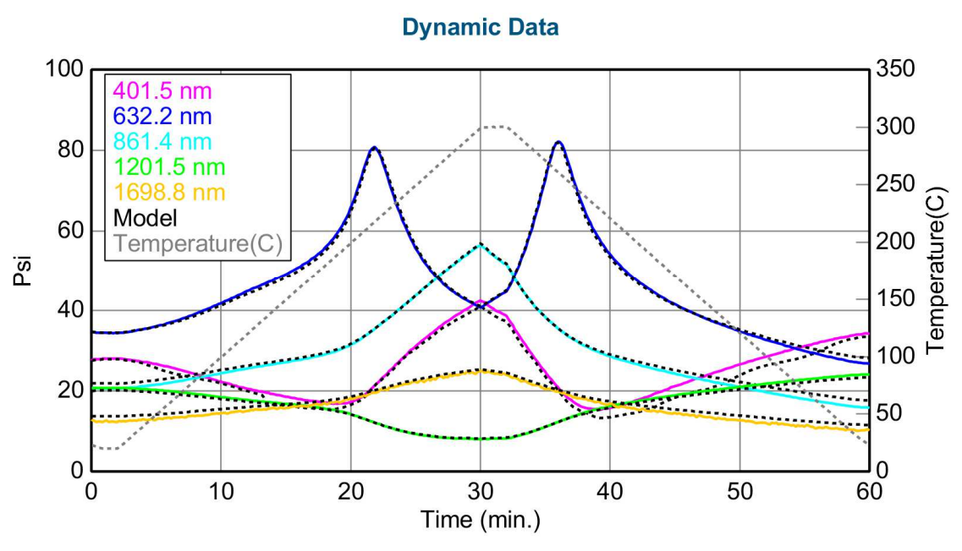




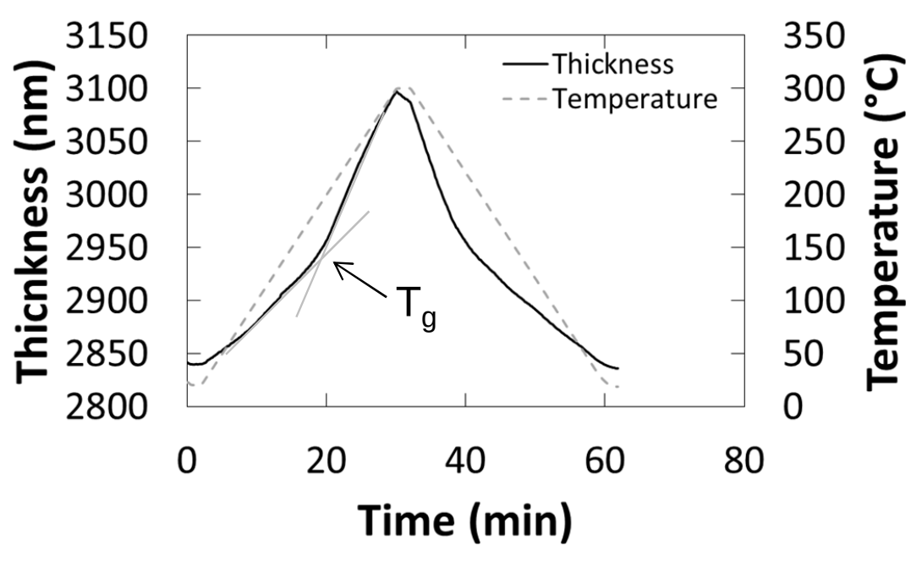
Polymers

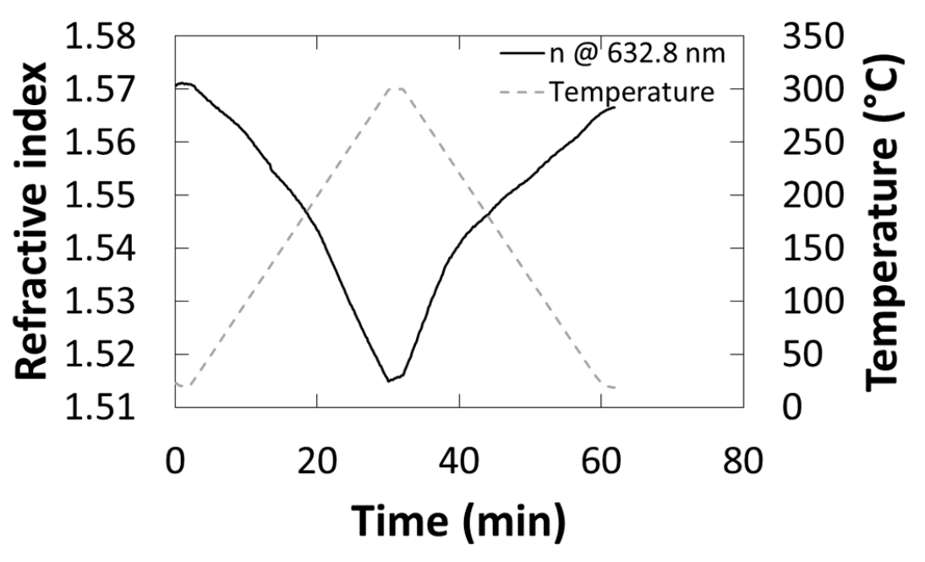
- Polymers are used in wafer level packaging, as dielectric layer for integrated passive devices, as bumping material for MEMS and as buffer layers
- Stress can appear with thermal budget
- Real-time ellipsometry gives access to:
  - Glass transition T_g
  - Thickness variations
  - Cross-linking checking

Polymer: **Tauc-Lorentz**
Substrate: **Si temp**



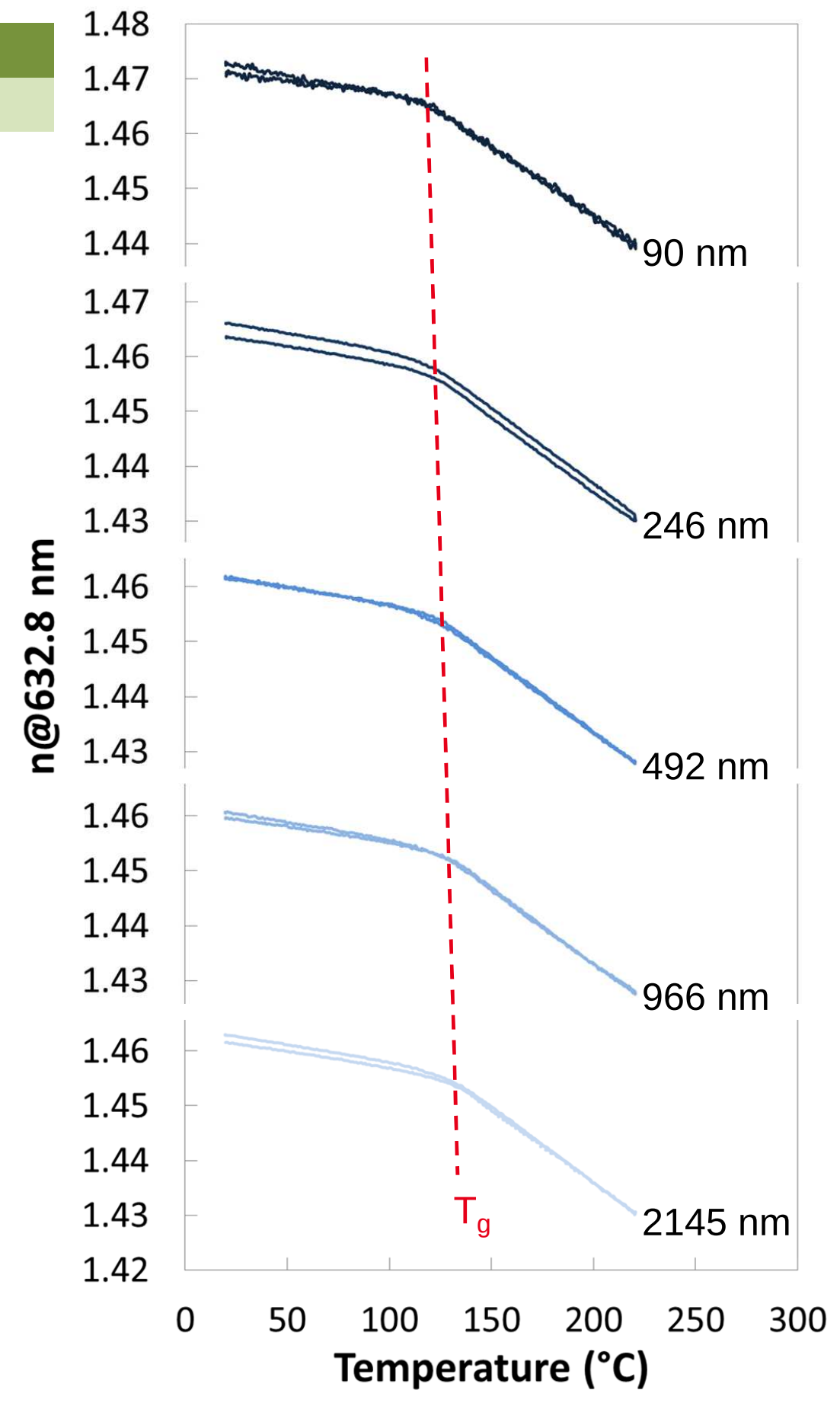
ALX (Asahi Glass Co.) fluorinated aromatic polymer





Polymer: Cauchy
Substrate : **Si temp**

Polymethacrylate films



Conclusion

- Temperature-controlled ellipsometry is a very powerful tool for many applications
- Relatively easy to implement on an existing ellipsometer
- Need of careful calibration
- It allows the characterization of many properties:
  - Optical constants
  - Thickness
  - Phase transition
  - Glass transition
  - Crystallization rate
  - Film damage
  - Coefficient of thermal expansion
  - And many more…

Commissariat à l'énergie atomique et aux énergies alternatives
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