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Real-time, In-line and Integrated Metrology of SiGe/Si Structures

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Outline of Presentation

- Introduction
- Optical and epitaxy facilities
- Ex-situ characterisation of strained SiGe structures
  - ➜ *in-line SE for SiGe process development*
- Real-time in-situ monitoring/control of SiGe
  - ➜ *data analysis methods*
- Development of integrated metrology
  - ➜ *advantages and future work*

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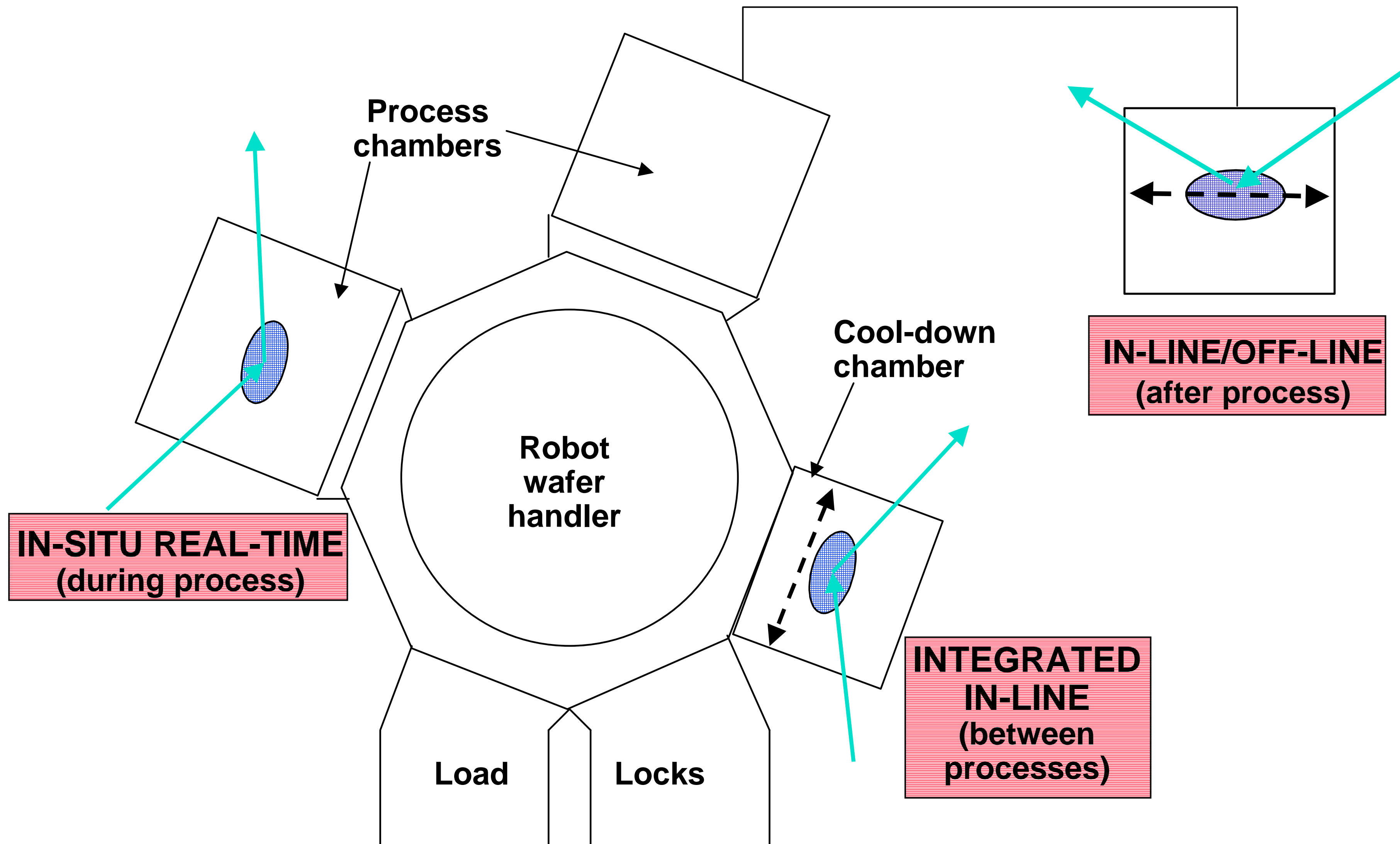
INTEGRATED METROLOGY USING SPECTROSCOPIC ELLIPSOMETRY



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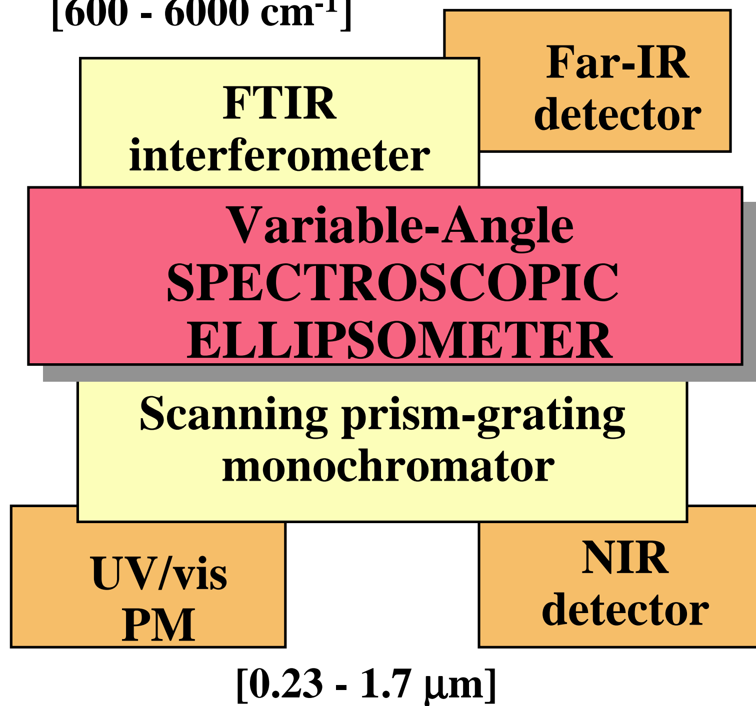
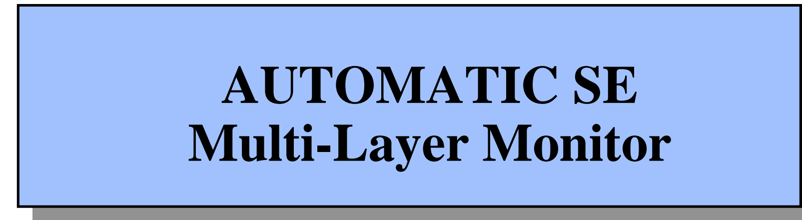
SPECTROSCOPIC ELLIPSOMETRY



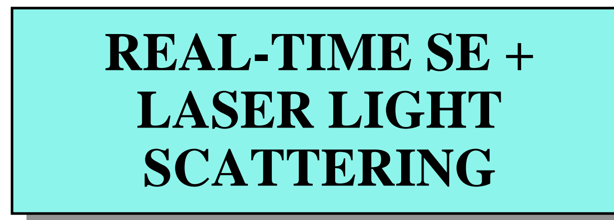
In-line: Si Cleanroom

Robot wafer-handling
Pattern recognition
Scribe line measurements
Multilayer mapping
High throughput



[0.21 - 0.85 μm
Up to 1 spectrum per sec]

In-situ: SiGe reactor



[0.25 - 0.82 μm
512 wavelengths
5 spectra per sec]

AMAT Epi Centura Cluster Tool

Combination of MLM and RTSE Cool-down chamber measurements

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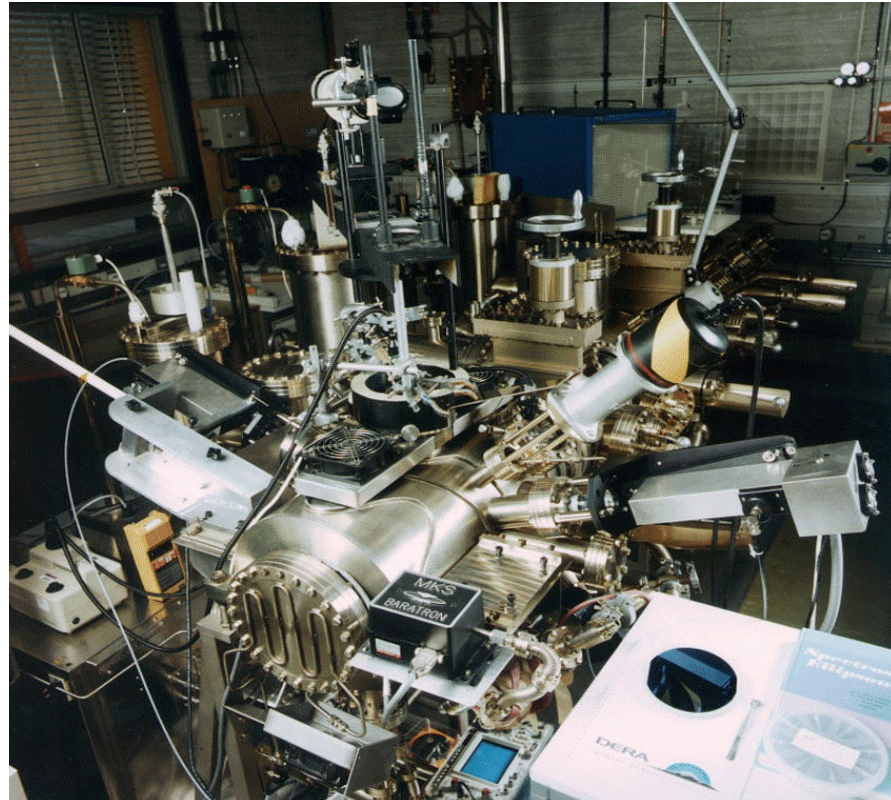
Advanced Low-Temperature Epitaxy at DERA

Applied Materials Epi Centura ®

- single wafer cluster tool wafer sizes: 100mm, 150mm, 200mm
- standard reduced pressure processes
- new low pressure process
- n- and p-type Si and SiGe multi-layers
- selective and non-selective epitaxy
- strain-relaxed SiGe virtual substrates
- integrated metrology under development



Custom low-pressure cold-wall reactor

- UHV background pressure
- 100mm, single wafer
- *in-situ* diagnostics for process control
- n- and p-type Si and SiGe multi-layers
- SiGe virtual substrates
- high mobility 2D electron gases in strained-Si layers
- SiGe/Si multi-quantum well structures

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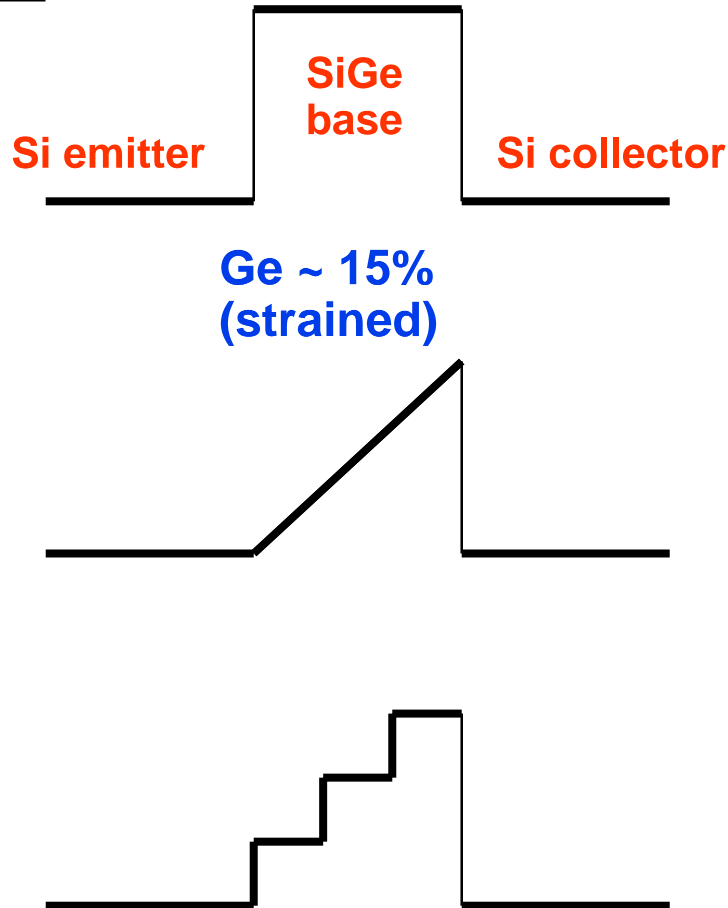
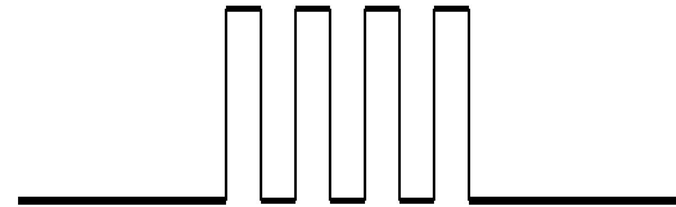
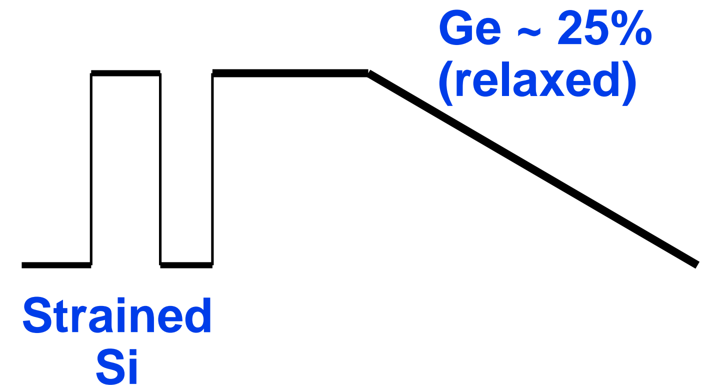
Representative Device Structures







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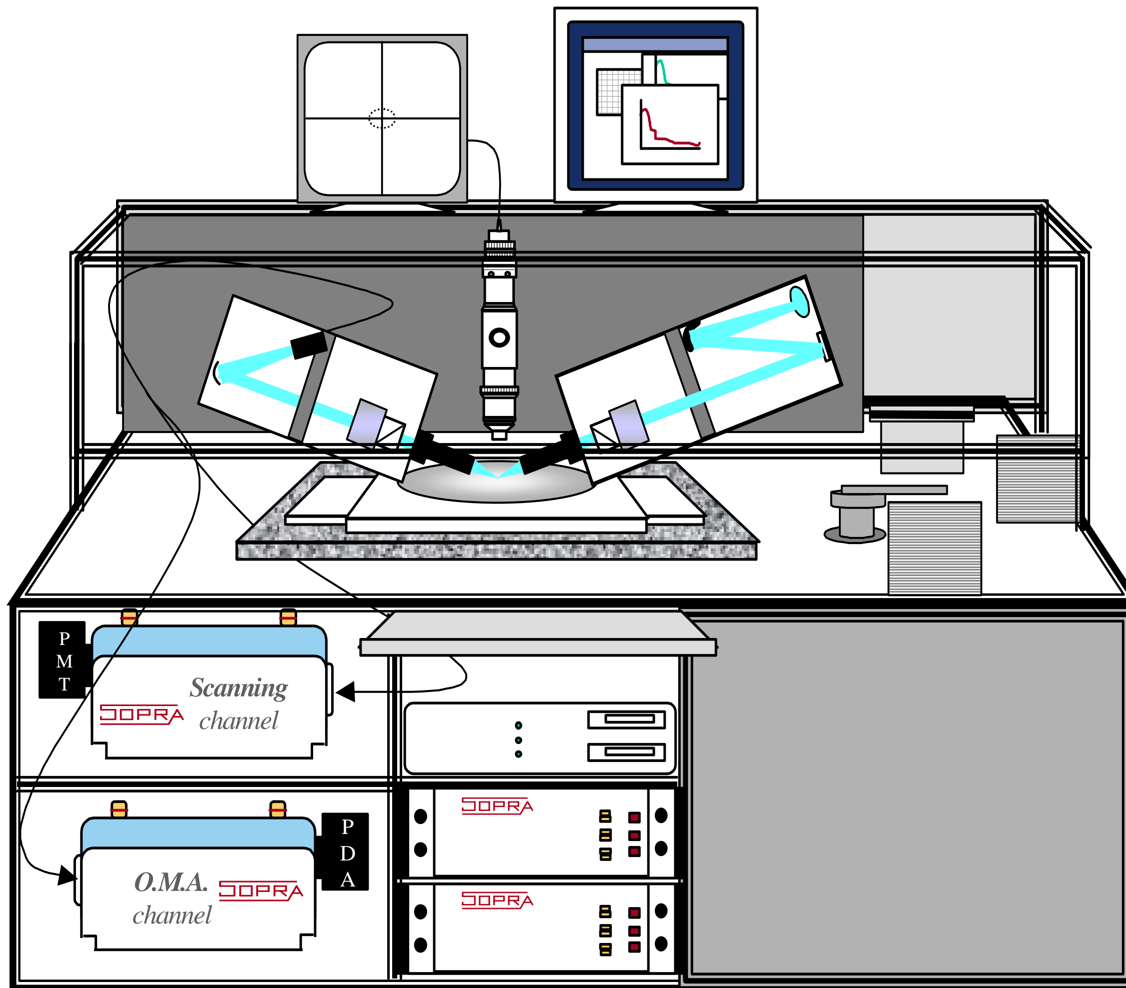
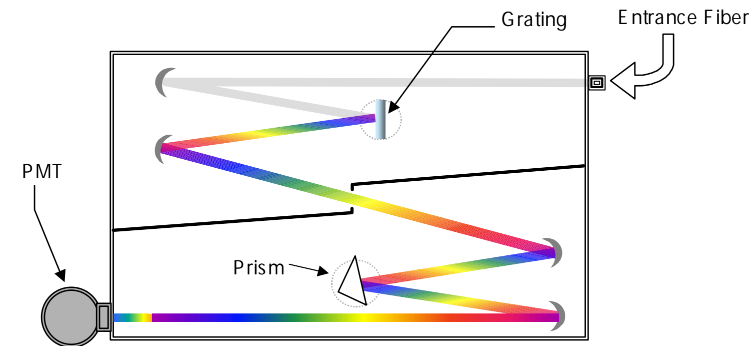
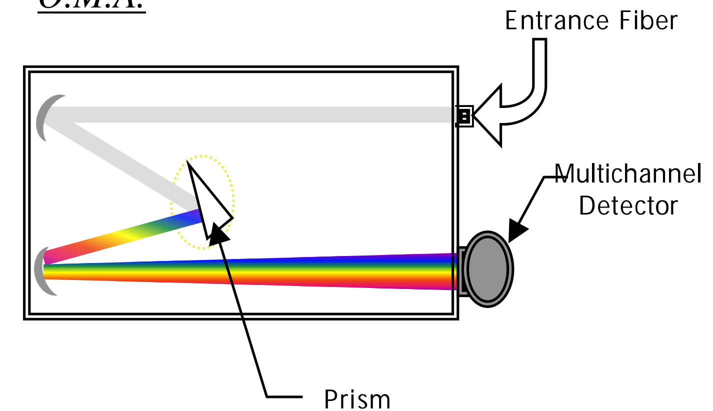
SOPRA Multi-Layer Monitor







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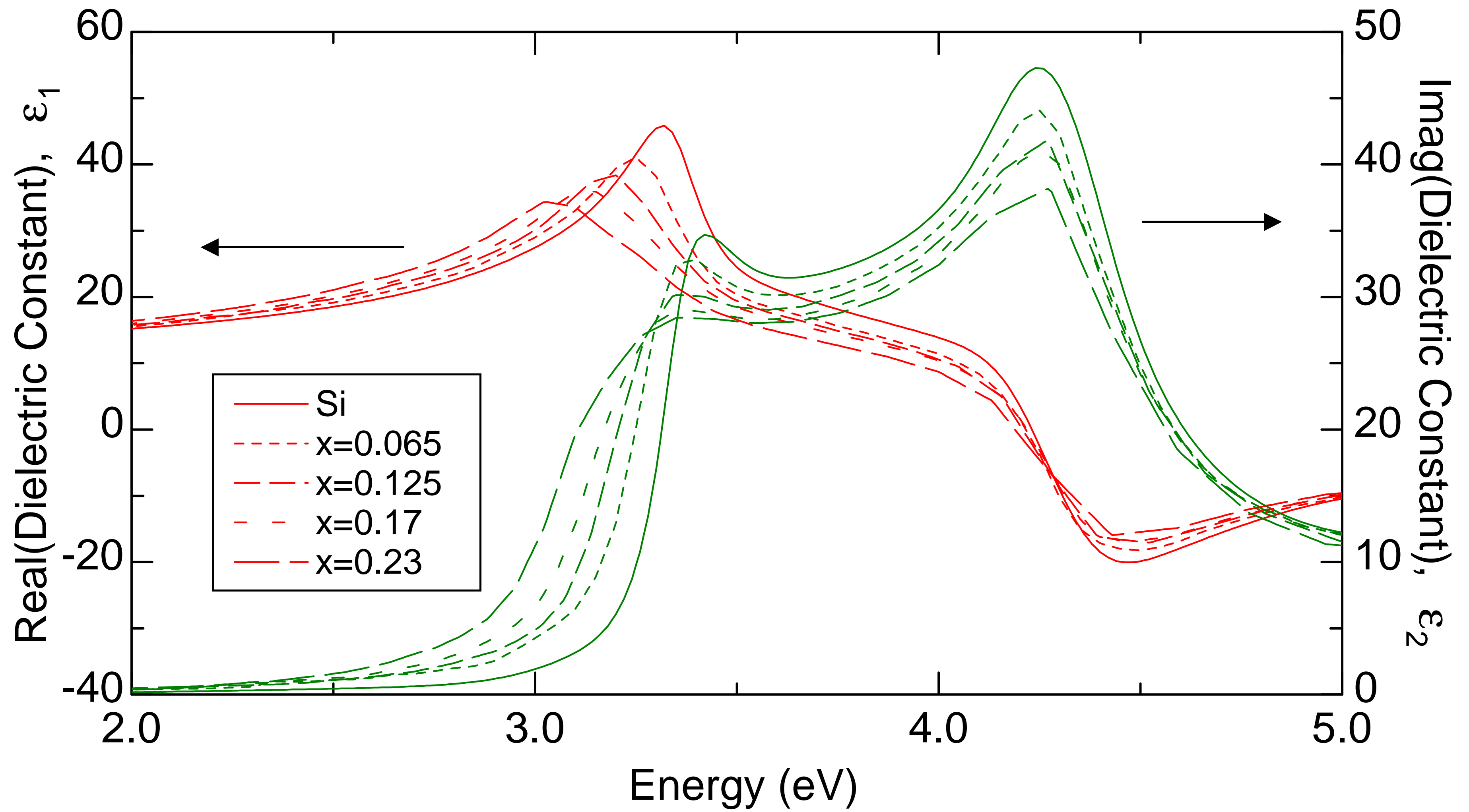
Strained Si(1-x)Ge(x)



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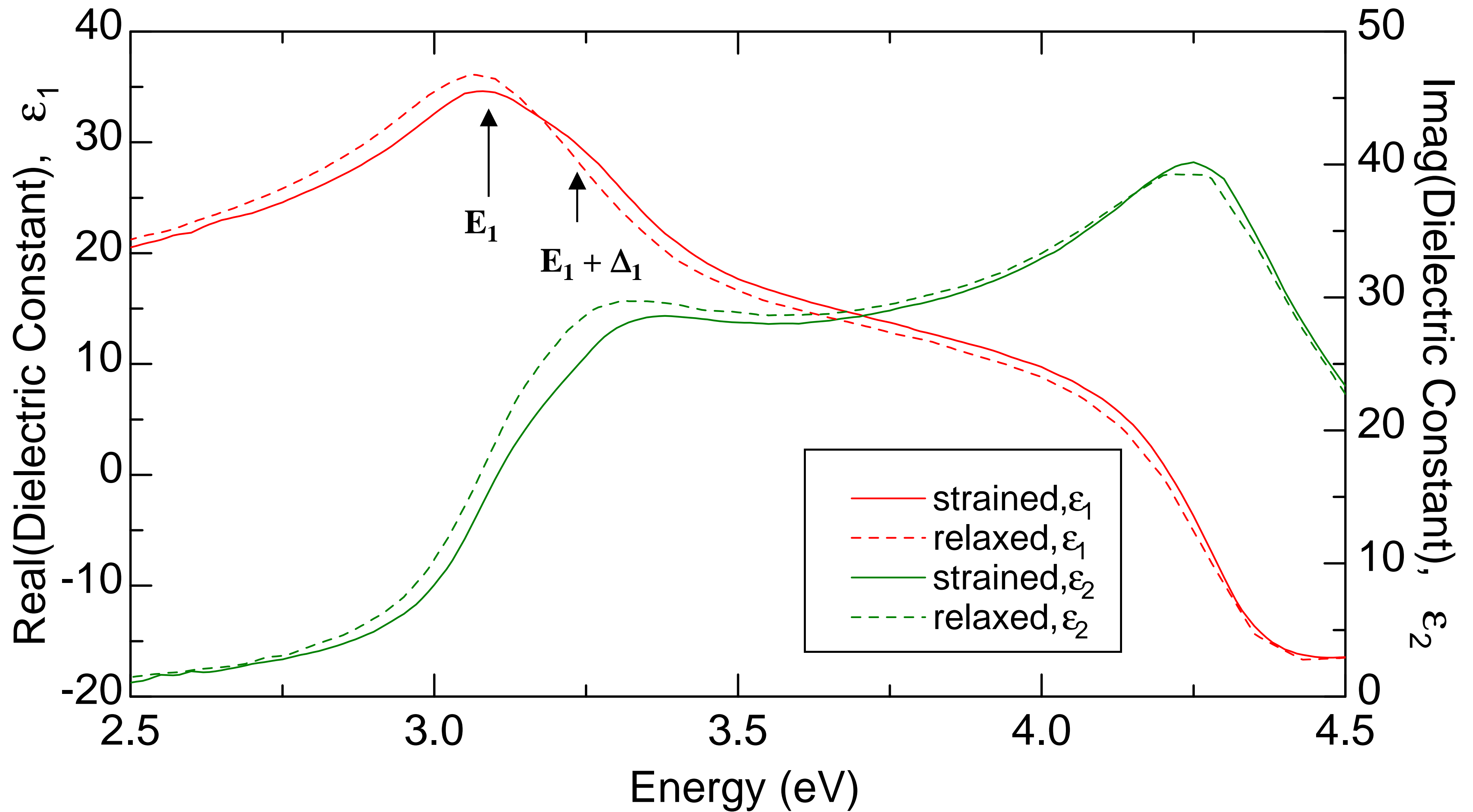

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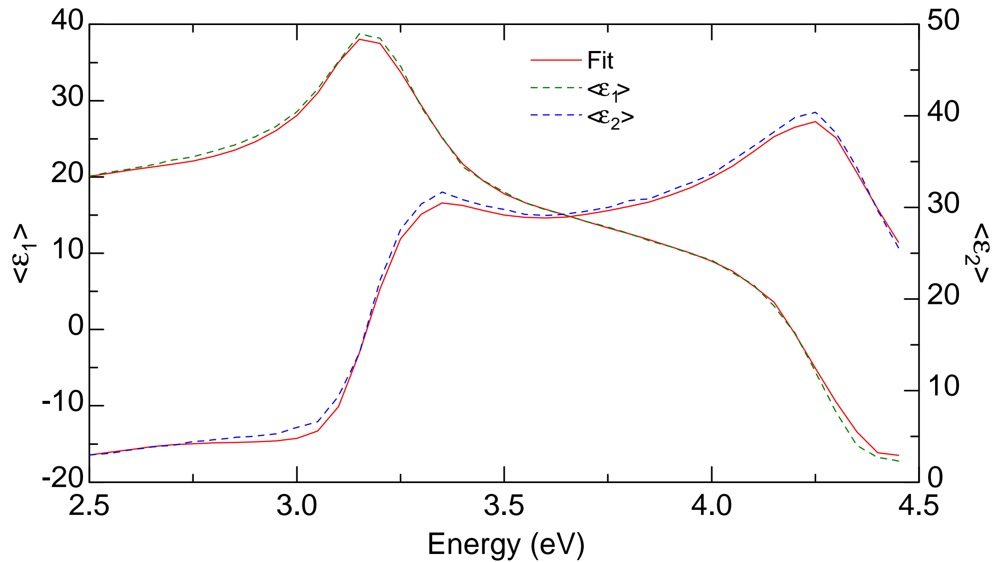
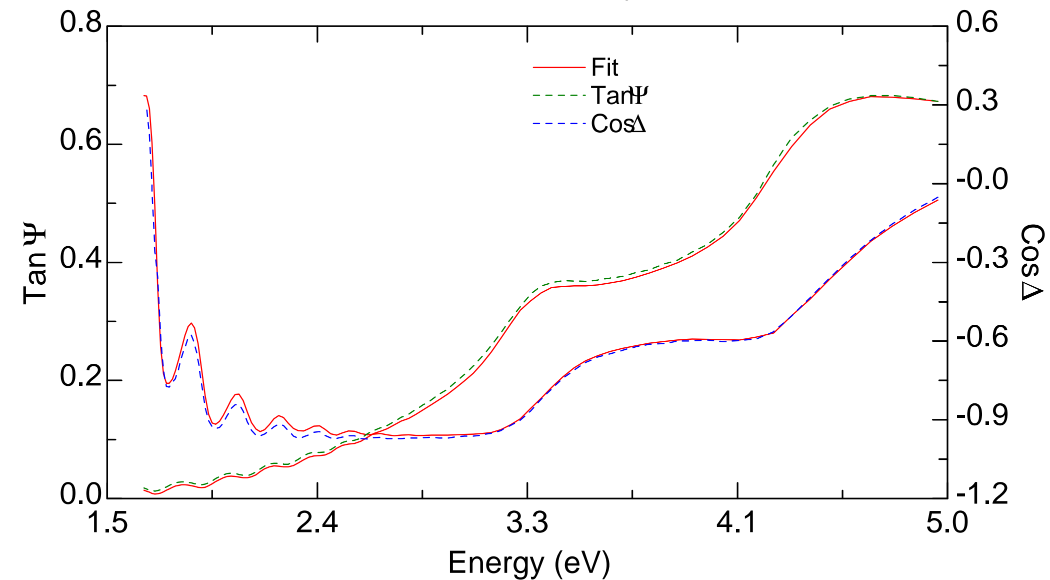
SE Characterisation of Single SiGe Epitaxial Layers





2	sio2	3.8448 Å
1	sigewv x=0.140	359.57 Å
0	si	1 mm

2	sio2	9.9339 Å
1	sigewv x=0.110	6067.6 Å
0	si	1 mm

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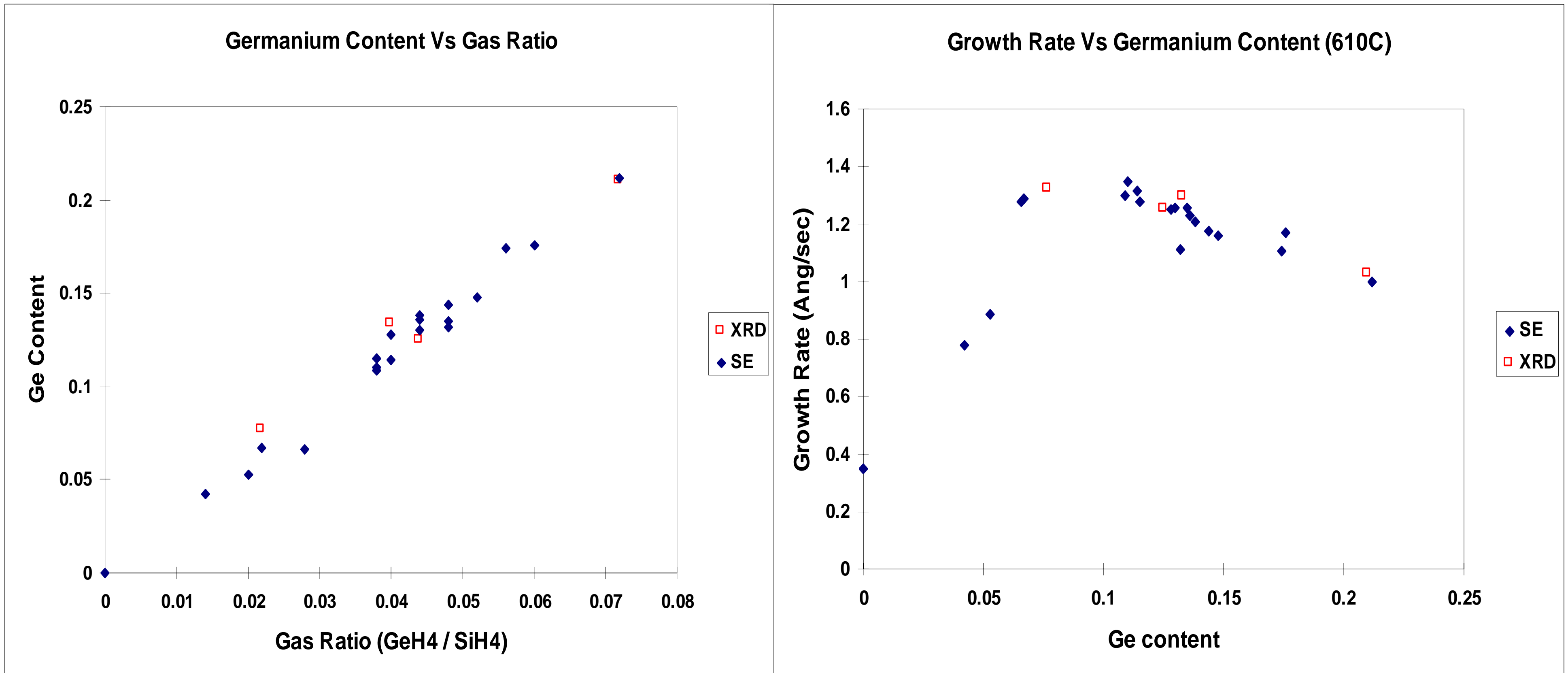
Calibration of DERA SiGe Epi Process



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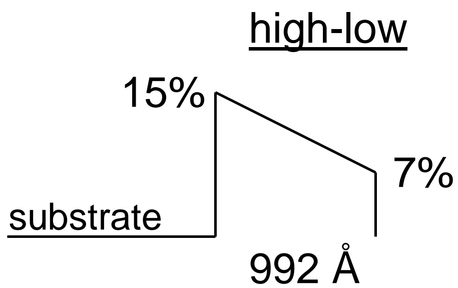
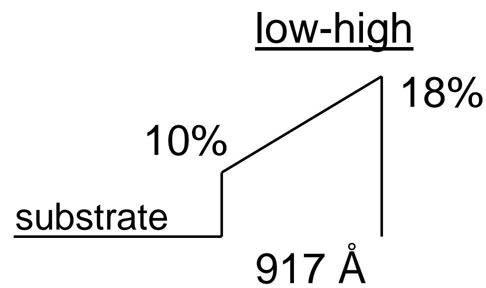
SE Characterisation of Graded SiGe Layers

40
30
20
10
0
-10
-20
$<\varepsilon_1>$
50
40
30
20
10
0
$<\varepsilon_2>$
2.0
2.5
3.0
3.5
4.0
4.5
Energy (eV)
Fit
high-low
low-high





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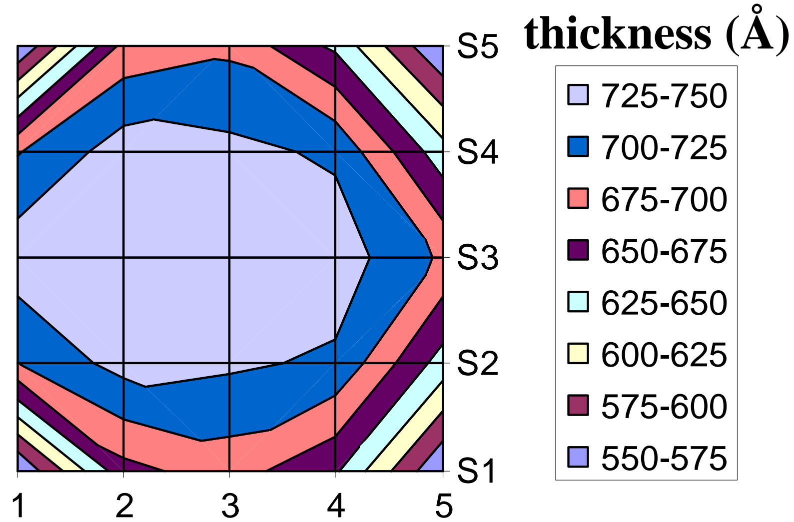
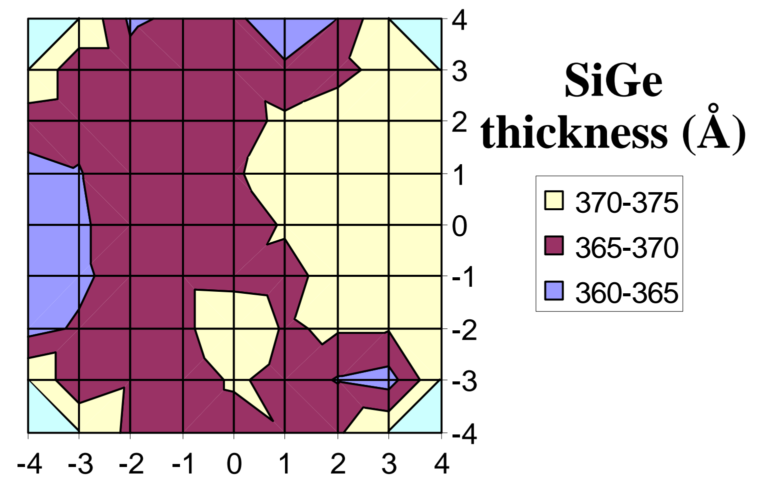
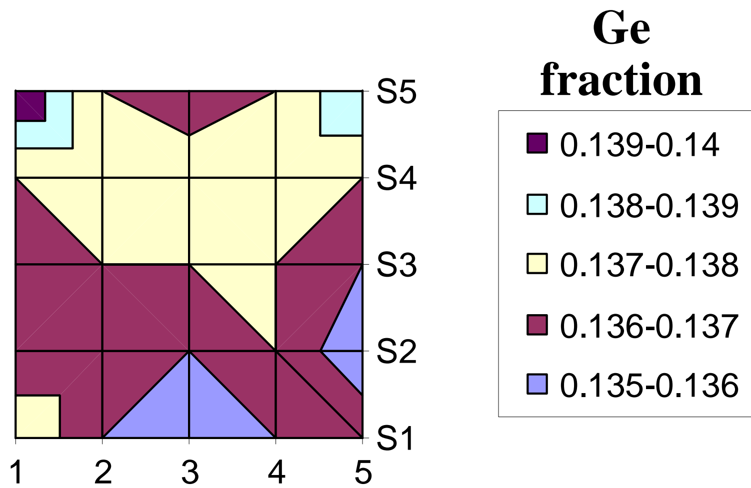
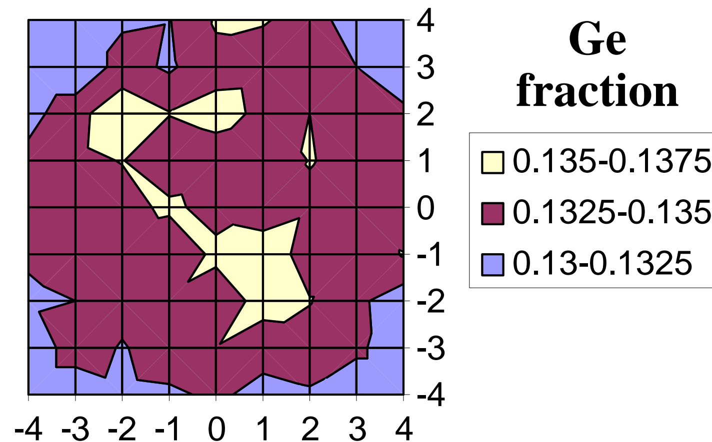
VG Reactor

AMAT Reactor









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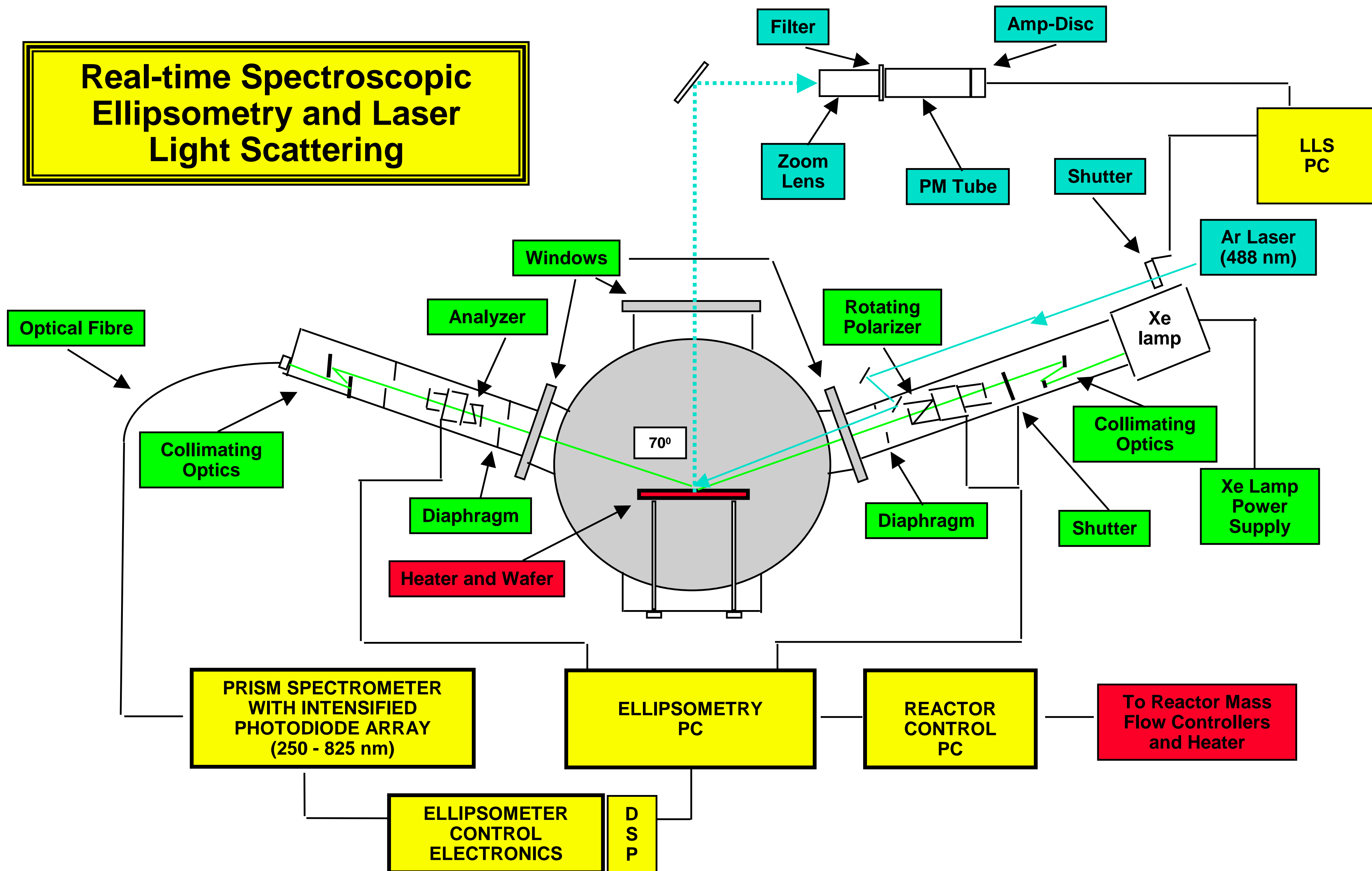

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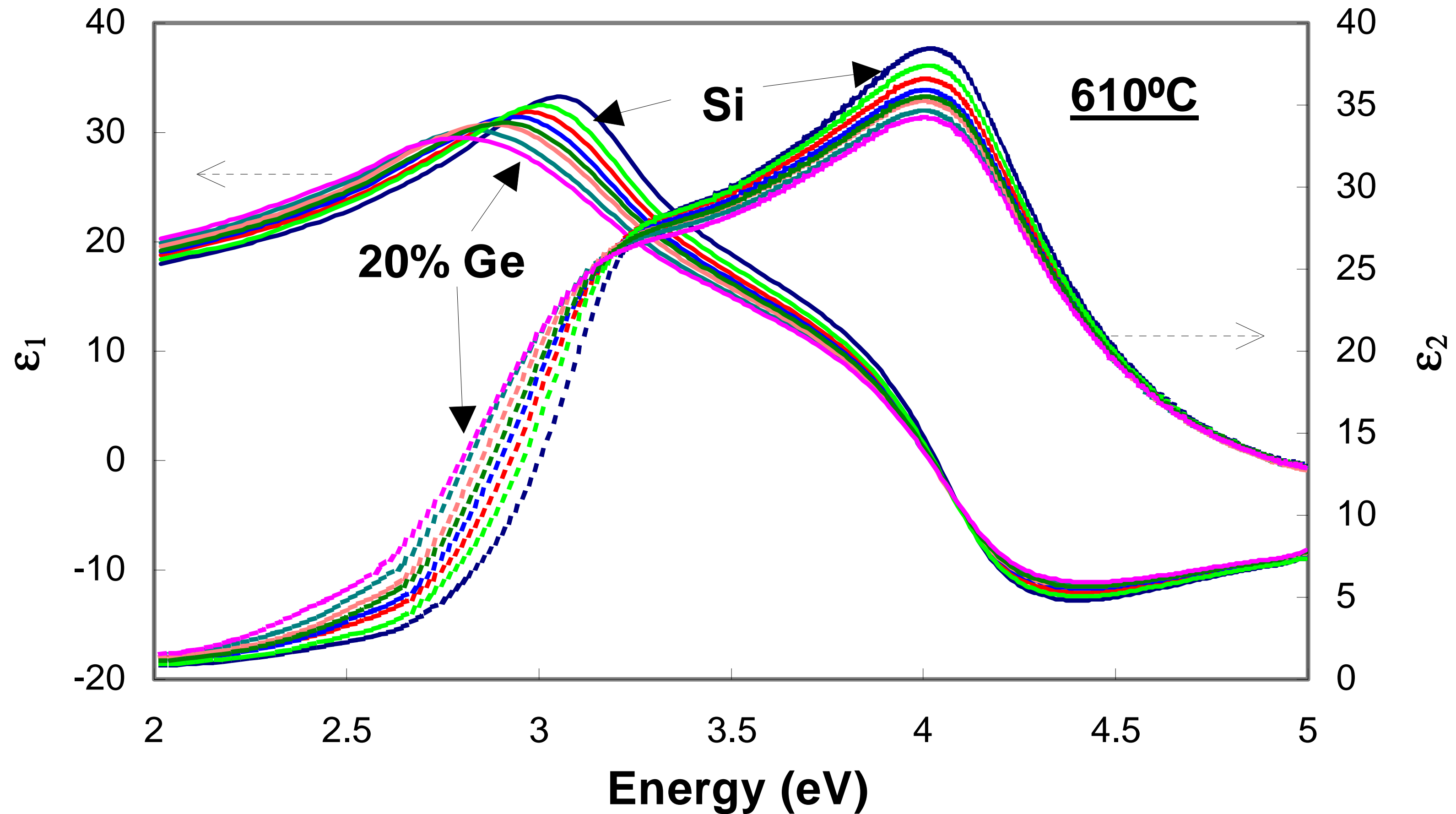
ANALYSIS OF REAL-TIME MULTI-WAVELENGTH DATA

- Normal Spectral Regression
  - ➔ average x and total thickness
- Virtual Interface Spectral Regression
  - ➔ surface x and growth rate as f(time) - *demonstrated*
  - ➔ accumulated thickness - *endpointing demonstrated*
- Artificial Neural Networks (with Principal Components)
  - ➔ surface x as f(time) independent of growth rate - *achieved*
  - ➔ extensive training required for specific structures
  - ➔ very fast
- Bayesian Statistical Tracking
  - ➔ surface x and growth rate as f(time) - *achieved*
  - ➔ predictive tracking based on trends and system models
  - ➔ provides statistical confidence limits

SiGe High Temperature Reference Spectra

(0, 4, 6, 9, 11, 14, 17, 20% Ge)



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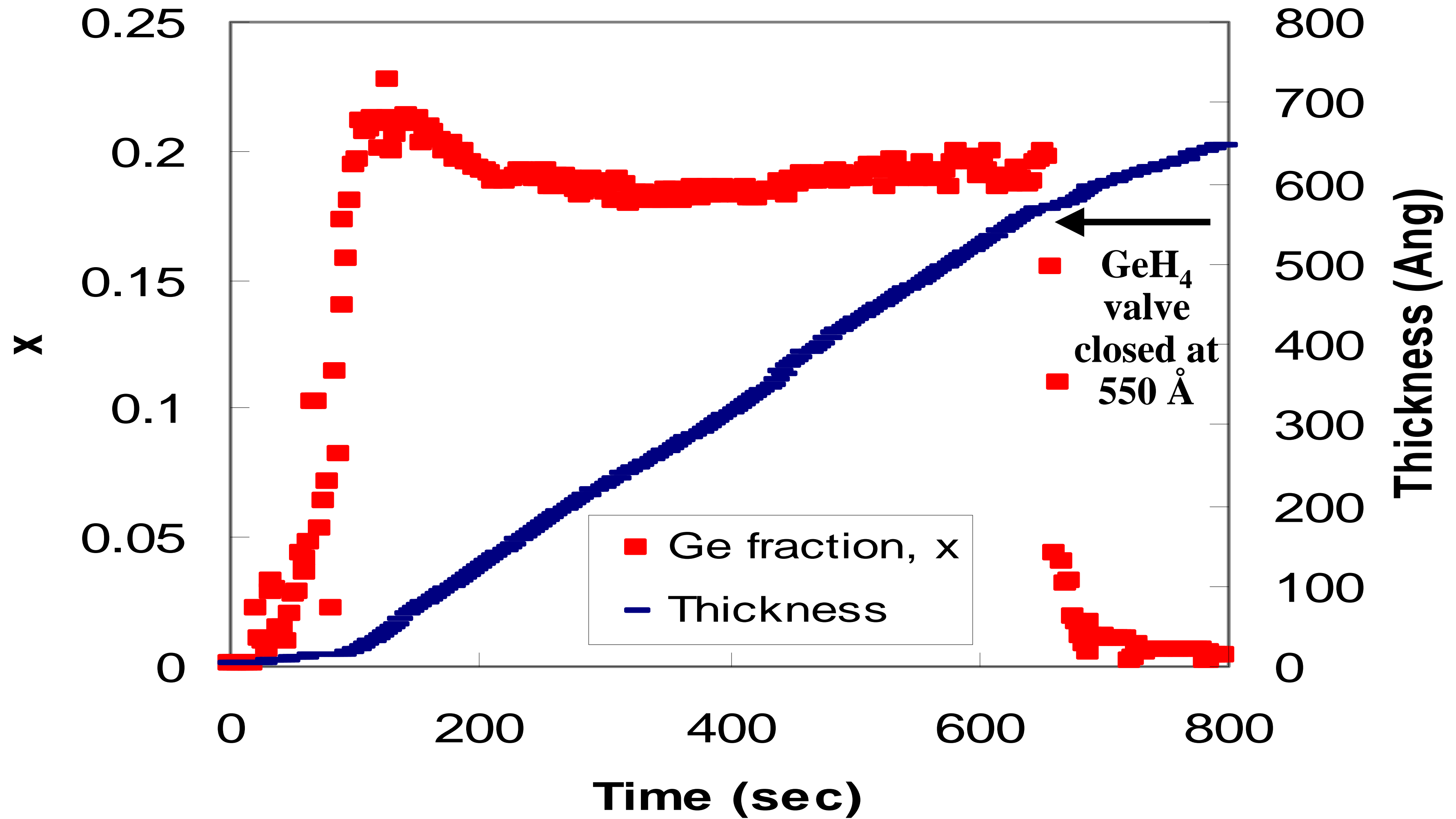
Controlled Growth of 550 Å SiGe Layer



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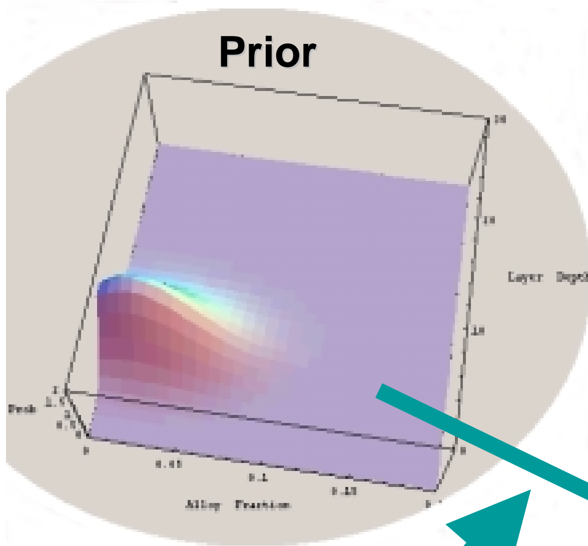
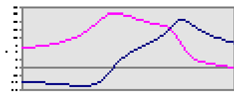
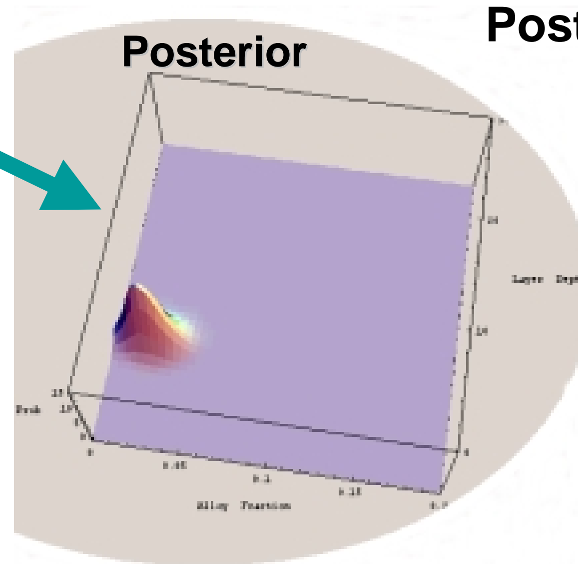
Sequential Bayesian estimation of composition





Observations



Bayesian approach to composition estimation using <u>state of the art</u> tracking methods:

Prior knowledge is updated to Posterior knowledge in the light of observations.

Incorporation of system model to track specified trajectory

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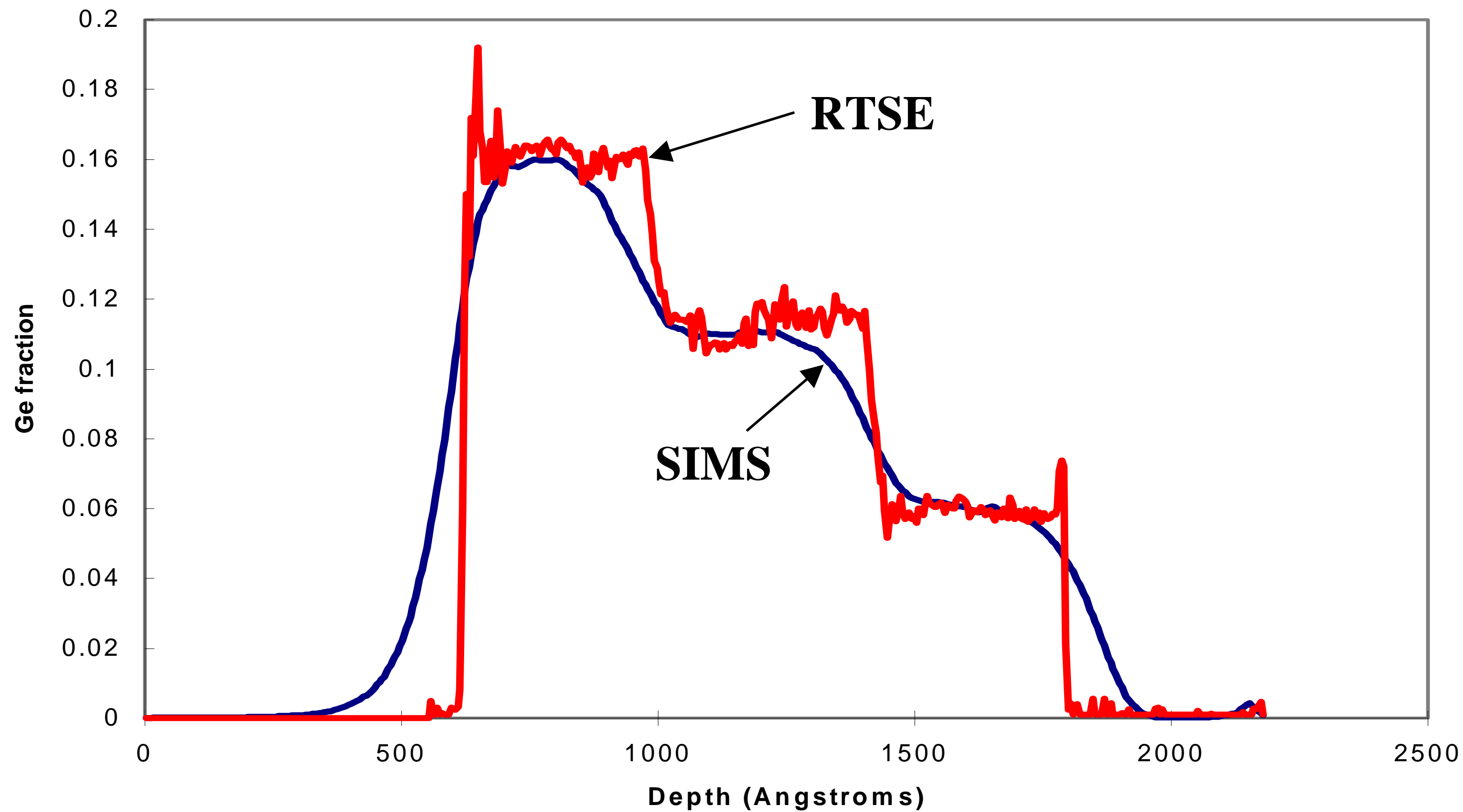
Real-time SE and Off-line SIMS Data for Stepped Ge Layer Profile



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MEDEA T618 Metrology Platform WP3.2

Transfer chamber

X-Y-Z stage with Autofocus &
Pattern Recognition

Ellipsometer
head

Spectrometer

Optical
ibre

Cool-down chamber

Xenon Lamp

Electronics and Power supplies

Advantages of Integrated Metrology

- Rapid process development
- Evaluation of in-situ cleaning
- Run-to-run and chamber-to-chamber repeatability
- Cross-wafer uniformity
- Go/no go after each process step
- Accurate measurement of layers obscured by later processing, eg buried thin Si or SiGe, gradients
- Run-to-run control and early fault detection

Future Work

- Implementation of SE in cool-down chamber of AMAT Epi Centura
  - Adapt and test SE instrument
  - Reference spectra measurement
  - Methodology and system integration
- Evaluation of applicability
  - Measurements between processes and off-line verification
  - Tests on patterned wafers
- Recommendation for improved cost-effectiveness
  - Throughput, minimum requirements

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