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
  - \textit{in-line SE for SiGe process development}
- Real-time in-situ monitoring/control of SiGe
  - \textit{data analysis methods}
- Development of integrated metrology
  - \textit{advantages and future work}
INTEGRATED METROLOGY USING SPECTROSCOPIC ELLIPSOMETRY

IN-SITU REAL-TIME (during process)

INTEGRATED IN-LINE (between processes)

IN-LINE/OFF-LINE (after process)
Variable-Angle SPECTROSCOPIC ELLIPSOMETER

In-line: Si Cleanroom
- Robot wafer-handling
- Pattern recognition
- Scribe line measurements
- Multilayer mapping
- High throughput

AUTOMATIC SE Multi-Layer Monitor
- [0.23 - 1.7 µm]
- Up to 1 spectrum per sec

AMAT Epi Centura Cluster Tool
- Combination of MLM and RTSE Cool-down chamber measurements

INTEGRATED METROLOGY SE

FTIR interferometer [600 - 6000 cm⁻¹]
- Far-IR detector

Scanning prism-grating monochromator
- UV/vis PM
- NIR detector

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

REAL-TIME SE + LASER LIGHT SCATTERING

In-situ: SiGe reactor
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
Representative Device Structures

**HBT**

- Si emitter
- SiGe base
- Ge ~ 15% (strained)
- Si collector

**QWIP**

**HCMOS**

- Ge ~ 25% (relaxed)
- Strained Si
SOPRA Multi-Layer Monitor

Scanning

O.M.A.

Prism

Entrance Fiber

Grating

PMT

Scanning channel

OMA channel
Strained and Relaxed Si(0.8)Ge(0.2)

![Graph showing the real and imaginary parts of the dielectric constant for strained and relaxed Si(0.8)Ge(0.2) as a function of energy.](image)
SE Characterisation of Single SiGe Epitaxial Layers

Thin SiGe Layer

Energy (eV)

\[\varepsilon_1\] \[\varepsilon_2\]

Energy (eV)

\[\varepsilon_1\] \[\varepsilon_2\]

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
Calibration of DERA SiGe Epi Process

- **Germanium Content Vs Gas Ratio**
  - XRD
  - SE

- **Growth Rate Vs Germanium Content (610C)**
  - XRD
  - SE
SE Characterisation of Graded SiGe Layers

Energy (eV)

-20 -10 0 10 20 30 40

<\varepsilon_1>  

0 10 20 30 40 50

<\varepsilon_2>

2.0 2.5 3.0 3.5 4.0 4.5

Energy (eV)

Fit
- high-low
- low-high

15% 7% 992 Å

substrate

10% 18% 917 Å

substrate

high-low

low-high

DERA
Real-time Spectroscopic Ellipsometry and Laser Light Scattering

- PRISM SPECTROMETER WITH INTENSIFIED PHOTODIODE ARRAY (250 - 825 nm)
- Ellipsometer Control Electronics (DSP)
- Ellipsometry PC
- Reactor Control PC
- To Reactor Mass Flow Controllers and Heater
- Optical Fibre
- Collimating Optics
- Diaphragm
- Heater and Wafer
- Analyser
- Windows
- Zoom Lens
- PM Tube
- Shutter
- Ar Laser (488 nm)
- Xe Lamp
- Xe Lamp Power Supply
- Filter
- Amp-Disc
- 70°
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)
Controlled Growth of 550 Å SiGe Layer

- Ge fraction, $x$
- Thickness

- $\text{GeH}_4$ valve closed at 550 Å
Sequential Bayesian estimation of composition

Bayesian approach to composition estimation using state of the art tracking methods:

- Prior knowledge is updated to posterior knowledge in the light of observations.
- Incorporation of system model to track specified trajectory
Real-time SE and Off-line SIMS Data for Stepped Ge Layer Profile
MEDEA T618 Metrology Platform WP3.2

- Spectrometer
- Cool-down chamber
- Ellipsometer head
- X-Y-Z stage with Autofocus & Pattern Recognition
- Optical fibre
- Transfer 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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