MBE, Production Ready?

Sensor-Based MBE For PHEMT Growth

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OUTLINE

- ***Motivation and Overview***
- ***Current "Near" Production MBE Status***
- ***How to Make Current MBE Production Ready?***
- ***Sensor-Based MBE and Impacts***
- ***Conclusion***
- ***IntelliEPI: A Merchant MBE Company***

MOTIVATION

Refine MBE into a truly production-ready tool to produce epi-based devices at low cost

- ***Dimensional accuracy: thickness, composition, interface***
- ***Reproducibility: run-to-run drifts elimination***
- ***Optimization: higher strain; sharper interface***
- ***Development: selective-etch PHEMT, metamorphic HEMT, InP-based HEMT, InGaP/GaAs HBTs***

OVERVIEW

- ***A production system has to be based on commercially available MBE systems***
- ***Current system hard to retrofit***
- ***Add-on instruments requirements***
  - Non-intrusive, robust, compatible with rotation
  - Real-time information of system and wafer states
  - Simple setup/maintenance, outside growth chamber installation, low cost
  - Fast processing of data

Current MBE

Current commercial MBE can provide:

- ***Scalability up to multi-6in with great uniformity***
- ***Low defect density epi for designated applications***
- ***Improved source cells with thermal stability***
- ***Fully automated growth after each batch loading***
- ***Long growth campaign with large capacity Cells***

Limitations of current MBE:

- ***Require dedicated calibration time/runs***
- ***Growth process is time-based dead-reckoning***
  - No information to pass down to next wafer or next batch
- ***Lack of early-warning for out-of-spec epi-growth***
- ***No structural growth record along growth direction***

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How to Make MBE Production Ready?

- ***Real-time non-intrusive, robust sensors to monitor growth parameters:***
  - Thickness --> pyrometry, atomic absorption
  - Composition --> atomic absorption
  - Surface roughness --> laser light scattering (LLS)
  - Shutter actions --> atomic absorption, reflection mass spec (REMS)
  - Temperature --> pyrometry, band-edge detection
- ***Integrate sensors to commercial MBE systems***
- ***Change growth control from time-base dead reckoning to real-time sensor-controlled***

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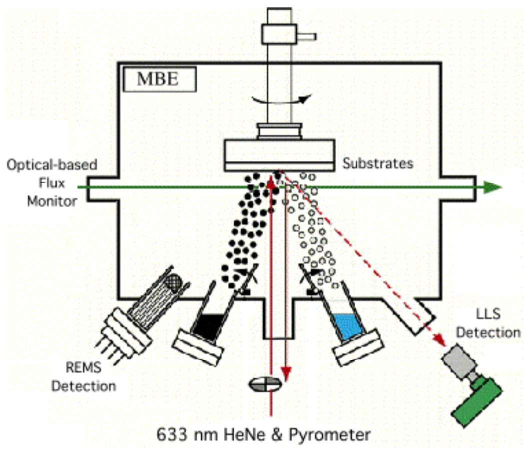
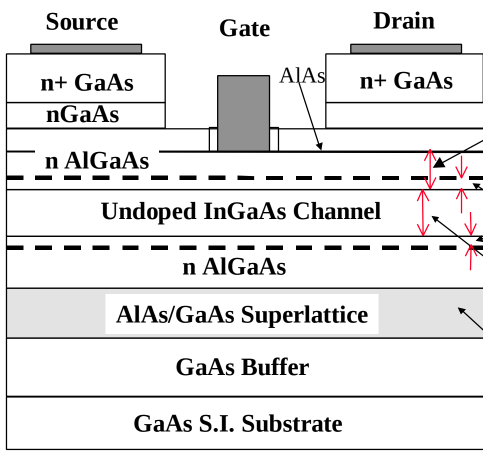
Sensor-Based MBE System

Sensor systems should be installed outside of the chamber through access ports to wafers



Sensor-Based MBE
Case Study: Selective-Etch PHEMT

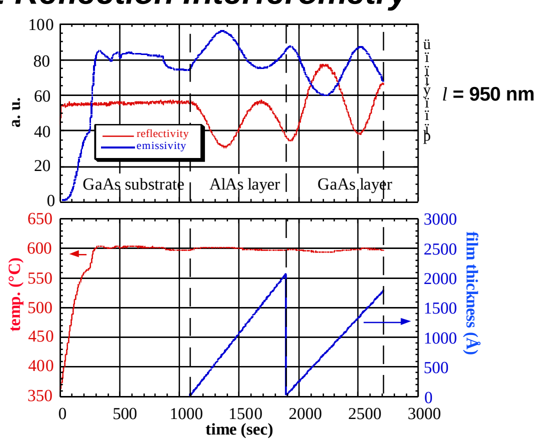


Critical Parameters

- ***AlGaAs thickness***
  - No trimming for selective etch PHEMT process
- ***Si Pulse doping/spacer***
  - Control I-V characteristics
- ***InGaAs thickness/comp.***
  - Strained active channel
- ***Superlattice buffer improvement***
  - Surface smoothness
  - Critical layers uniformity

Sensor-Based MBE
Case Study: PHEMT

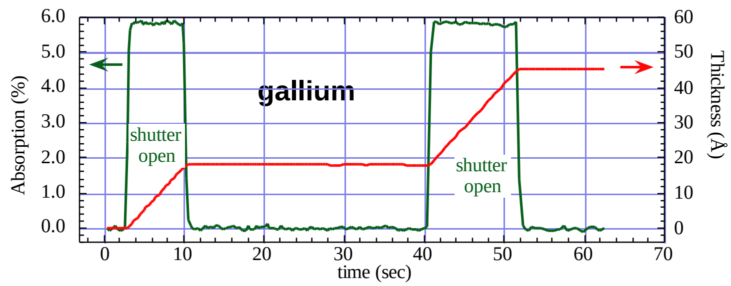
Pyrometric & Reflection Interferometry



- ***Simultaneously monitor substrate temperature & layer thickness in real-time***

Sensor-Based MBE
Case Study: PHEMT

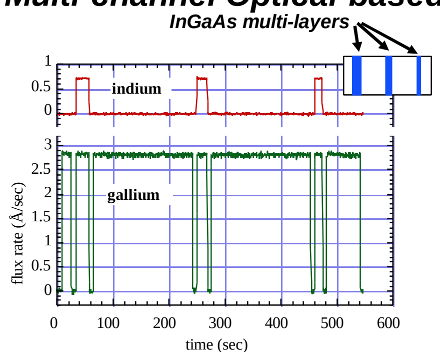
Optical-based Flux Monitor (atomic absorption)

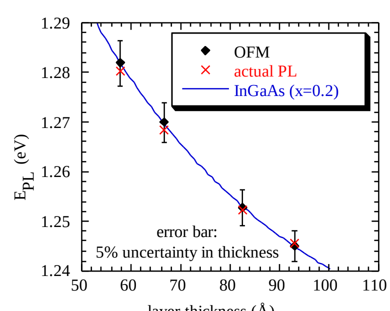


- ***Measure atomic absorption of molecular beam flux during shutter openings and closings***
- ***Layer thickness is proportional to the integrated atomic absorption***

Sensor-Based MBE
Case Study: PHEMT

Multi-channel Optical-based Flux Monitor





- ***Simultaneous monitoring of indium and gallium fluxes using atomic absorption***
- ***Real-time determination of InGaAs layer thickness and composition***

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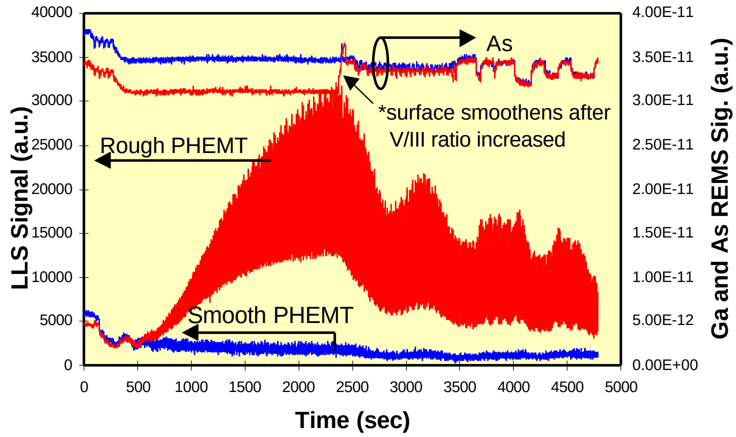
Sensor-Based MBE: PHEMT

Surface roughness monitored by laser light scattering



- ***LLS record roughness information along growth direction***
- ***Real-time roughness monitoring critical for PHEMT buffer optimization by superlattice and growth conditions***

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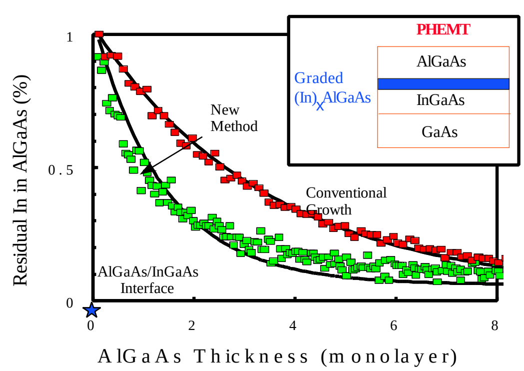
Sensor-Based MBE Case Study: PHEMT

Interface abruptness by Reflection Mass Spectrometry (REMS):



- ***REMS data indicating incorporation of surface Indium into subsequent AlGaAs layer during PHEMT growth. A graded heterojunction is unfavorable in PHEMT growth***

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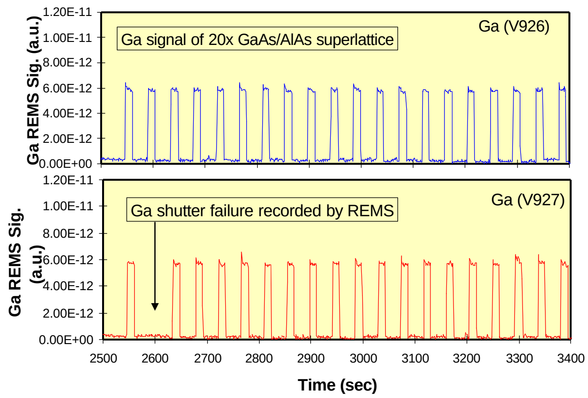
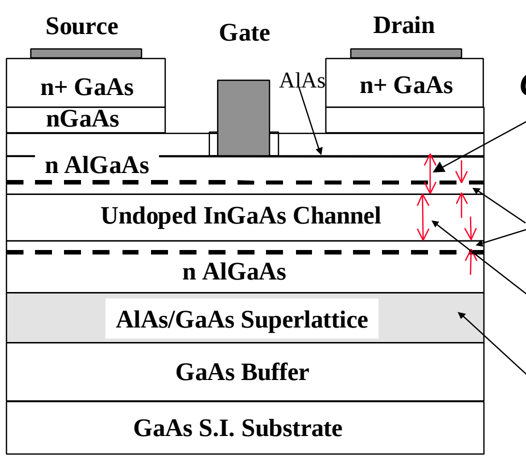
Case Study: PHEMT

Shutter Actions by Reflection Mass Spectrometry (REMS):



- ***All shutter actions recorded so each grown layer confirmed by REMS or other composition sensors***
- ***Detection of critical layer problems:makeup, modify, abort***

Sensor-Based MBE
Case Study: Selective-Etch PHEMT



Critical Parameters

- ***AlGaAs thickness***
  - OFM, pyrometry
- ***Si Pulse doping/spacer***
  - control spacer thickness & composition
- ***InGaAs thickness/comp.***
  - OFM
- ***Superlattice buffer improvement***
  - LLS, REMS

Impact to Devices & Processing

For advanced epi-devices such as selective-etch PHEMTs:

- ***Device performance pre-determined by material growth:***
  - Doping density, layer thickness/composition uniformity
  - Defect density and surface roughness
  - Run-to-run reproducibility
- ***Material growth controls processing steps (recess depth and uniformity), which affects device characteristics (V_{TH} and I_{DSS}). Improved growth reproducibility can:***
  - Improve wafer-to-wafer processing repeatability
  - Reduce cycle time by eliminating error-prone process
  - Improve PHEMT uniformity will increase circuit yield
  - Reduce circuit tweaking so lower cost

For device optimization and new device development:

- ***Sensors provide critical growth record or "pedigree" along growth direction for analysis and evaluation***

CONCLUSION

- ***Sensor-Based MBE (SBMBE) is a commercial MBE loaded with non intrusive and robust sensors to monitor and control multi-layer epi growth. SBMBE***
  - Increases run-to-run reproducibility,
  - allow growth modification or elimination of bad run early,
  - Provide "growth pedigree" of epi-wafers for customers process correlation and feedback
- ***SBMBE will increase yield and decrease cost***
- ***SBMBE is a truly production MBE***

IntelliEPI **: A Merchant MBE Company**

IntelliEPI: Established in Sept. 1998 in Dallas, TX

- ***Focus on MBE for PHEMTs, HBTs on GaAs and InP***
- ***First 4x4" commercial system to be delivered in May, 2nd 4x4" in 4Q, 99***
- ***All systems equip with various sensor ports***
- ***Intelligent sensors facilitate low cost epi-wafers growth with high yield and minimum dedicated calibration runs***
- ***Qualification wafers available in 3Q/99; production in 4Q/99***
- ***Production ramp up to 4 systems in three years***
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