Plasma-Therm

A LEADING SUPPLIER OF PLASMA PROCESS EQUIPMENT

Trends in Plasma Etching and Deposition for LED Fabrication

NCCAVS Plasma Applications Group

July 15, 2010

David Lishan

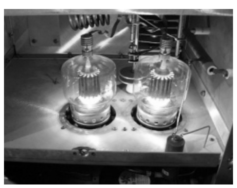
Overview

- Plasma-Therm Introduction
- LED Applications and Market
- LED Manufacturing
  - Cost/Performance Evolution
  - Process Flow Overview
  - Front End Processes and Endpoint Controls
- Conclusions

Plasma-Therm Re-Established as Independent Operation

1974 | 1975 | 1983 | 1990 | 1994 | 2000 | 2006 | 2009

Origin:
RF power
supplies



Incorporates

Industry first single wafer production plasma etch reactor

Relocates to
St. Petersburg, FL

First ever Photomask plasma etch system introduction

Acquired by
unaxis

Re-branding to
oerlikon

Independently operated company with Headquarters in USA

St. Petersburg, FL Corporate Headquarters

- Integrated office and manufacturing facility (65,000 ft^2)
- Class 1000 manufacturing area
- Class 100 Demonstration Laboratory

Production and R&D Solutions for Specialty Markets

- Leverage our Etch and PECVD platforms and experience for applications in:
  - Solid State Lighting
  - Wireless
  - Photomask
  - Nanotechnology
  - MEMS/NEMS
  - Renewable Energy
  - Data Storage
  - Photonics
  - R&D



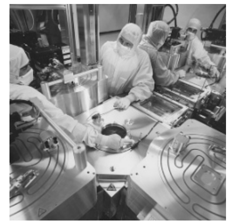





Advancing Wafer and Mask Processing Equipment for 35 Years


Mask Etcher II


Mask Etcher III

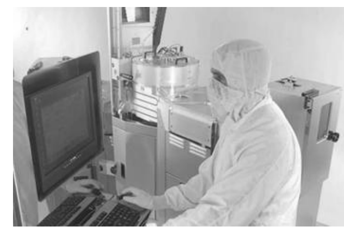

Mask Etcher IV

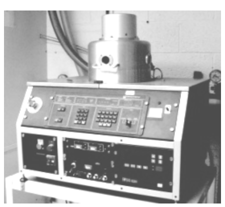

Mask Etcher V


Shuttlelock


Shuttleline


Versalock


VERSALINE


BatchTop


790


7000


790+

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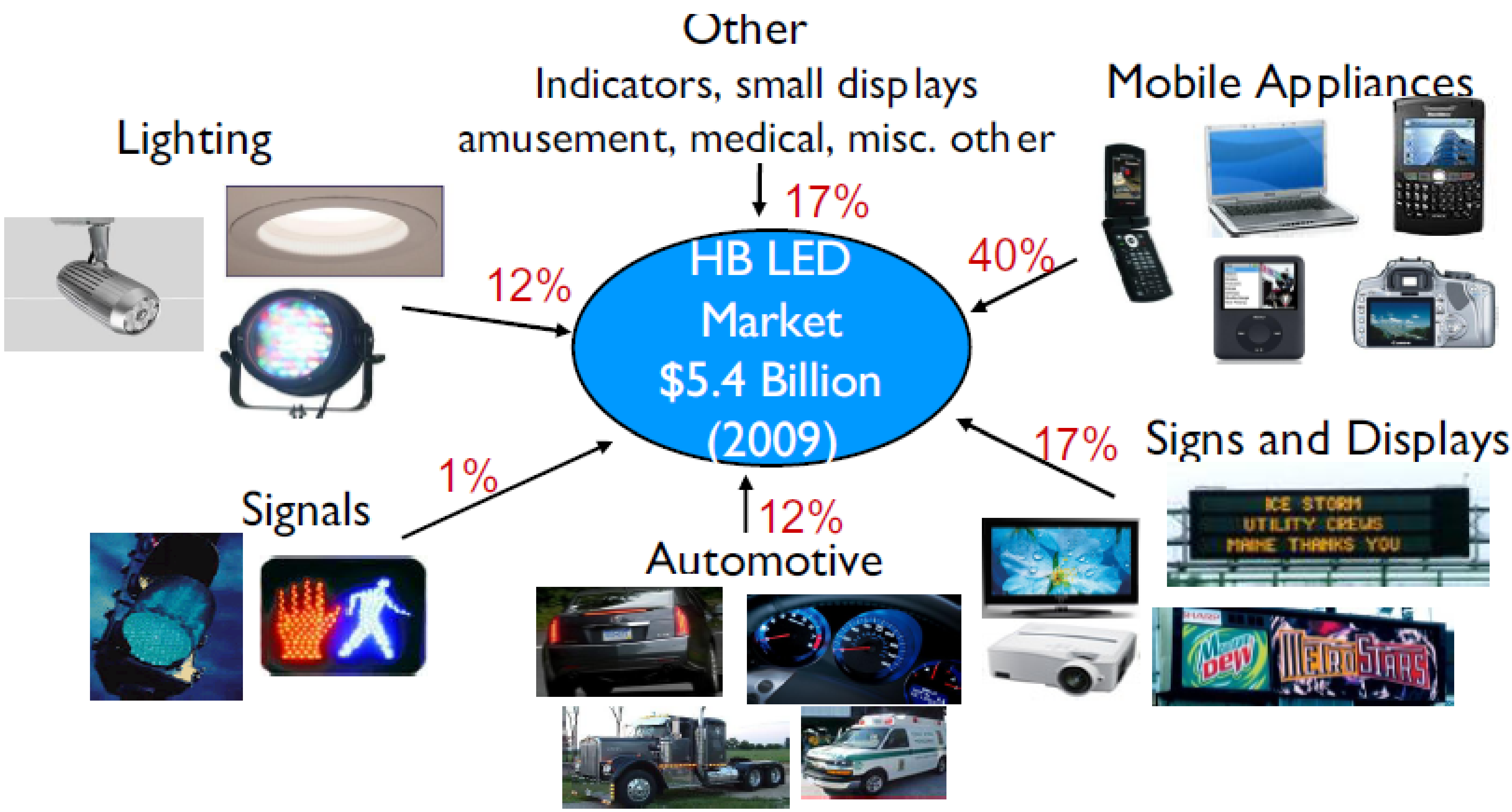
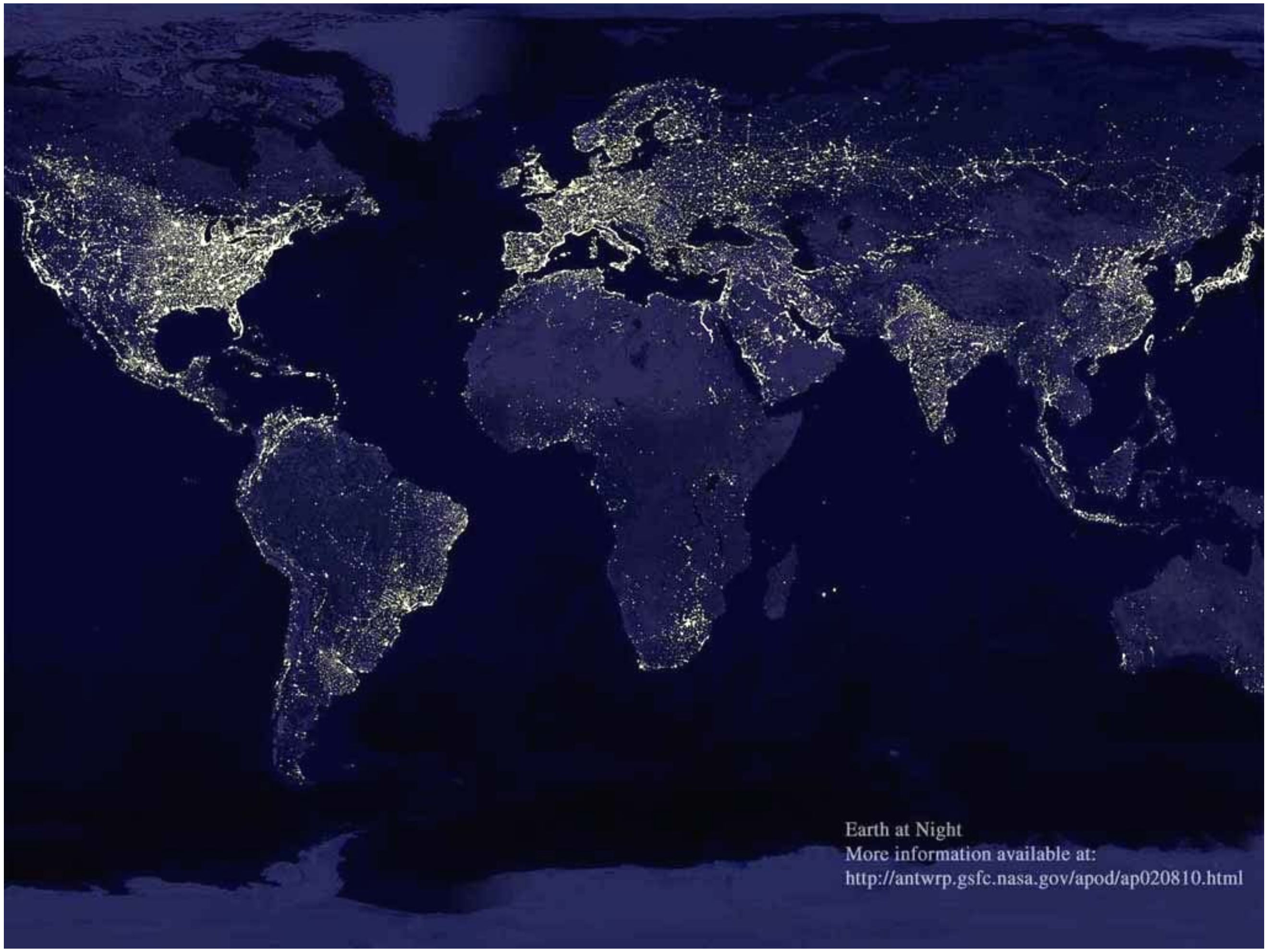
High Brightness LED Market and Applications

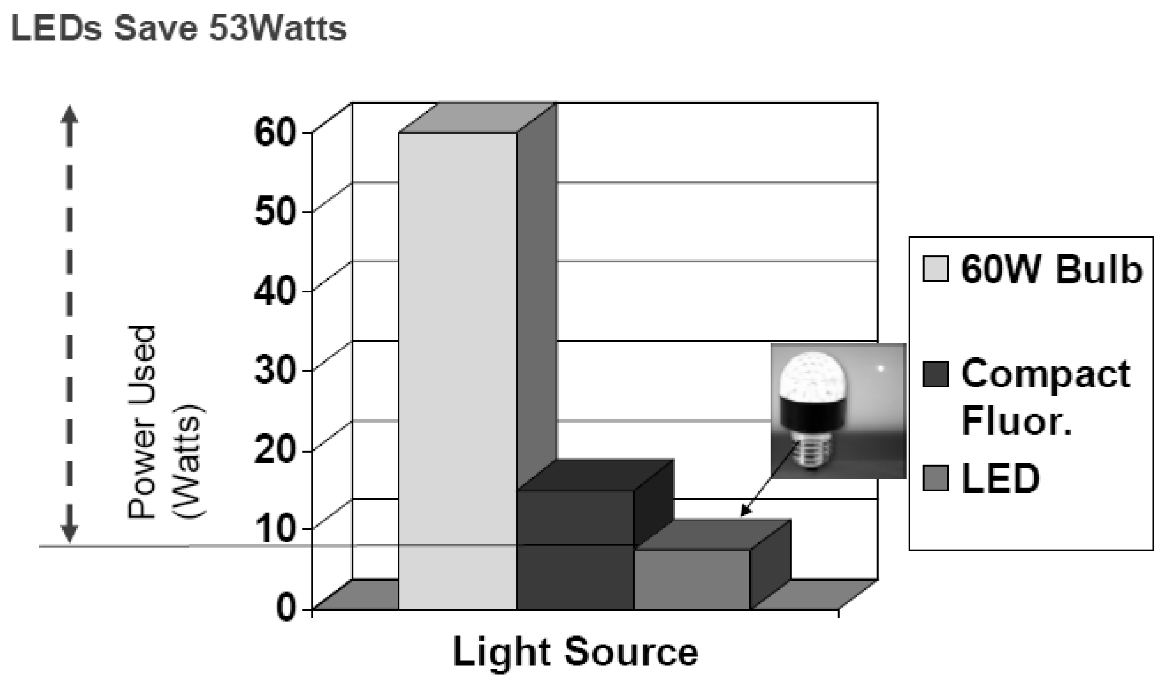


Source: Strategies Unlimited, 2010

Earth at Night – SSL Opportunity



Solid State Lighting Opportunity



If a 150 lm/Watt Solid State White LED source was deployed Globally then:

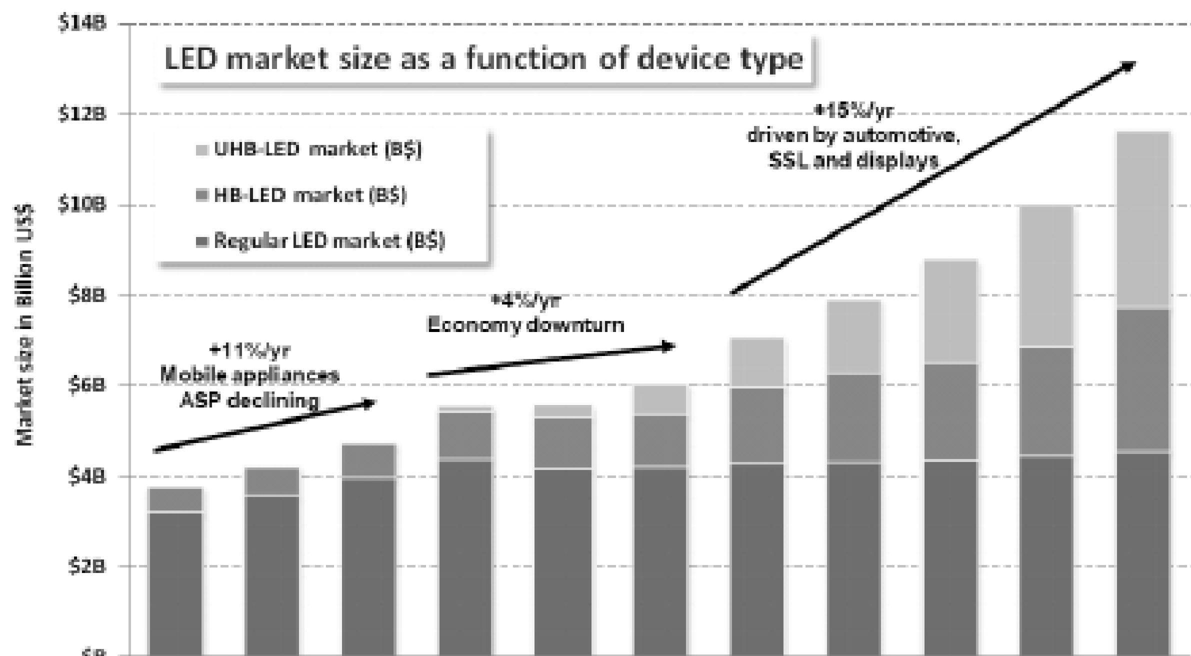
We would realize savings of $100 Billion/year

Alleviate the need of 380 new power stations!*

Source: DOE SSL Workshop 2010

HB-LED Market Forecast
2005 to 2015

- Drivers
  - Backlighting
  - General lighting
  - Increasing govt. legislation phasing out incandescent lighting
    - EU (2009)
    - Australia (2009)
    - Cuba (2009)



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
UHB-LED market (B$)	$0.00B	$0.01B	$0.06B	$0.14B	$0.28B	$0.67B	$1.11B	$1.63B	$2.26B	$3.10B	$3.95B
HB-LED market (B$)	$0.57B	$0.63B	$0.72B	$1.04B	$1.14B	$1.17B	$1.68B	$2.00B	$2.18B	$2.42B	$3.15B
Regular LED market (B$)	$3.19B	$3.55B	$3.96B	$4.37B	$4.14B	$4.19B	$4.28B	$4.28B	$4.33B	$4.46B	$4.55B

Source: Yole, 2010

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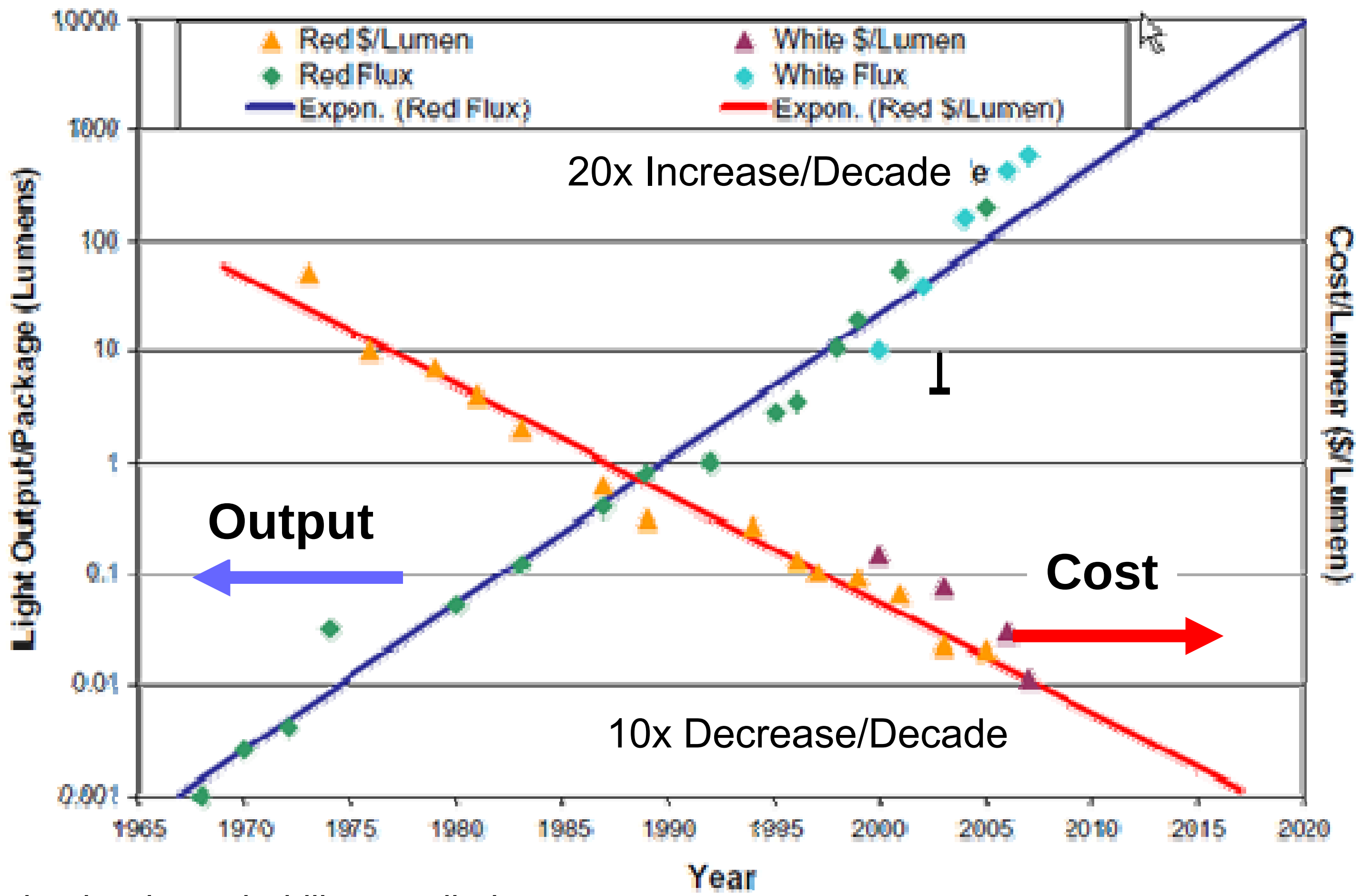
Components of LED Luminaire

Packaged LED

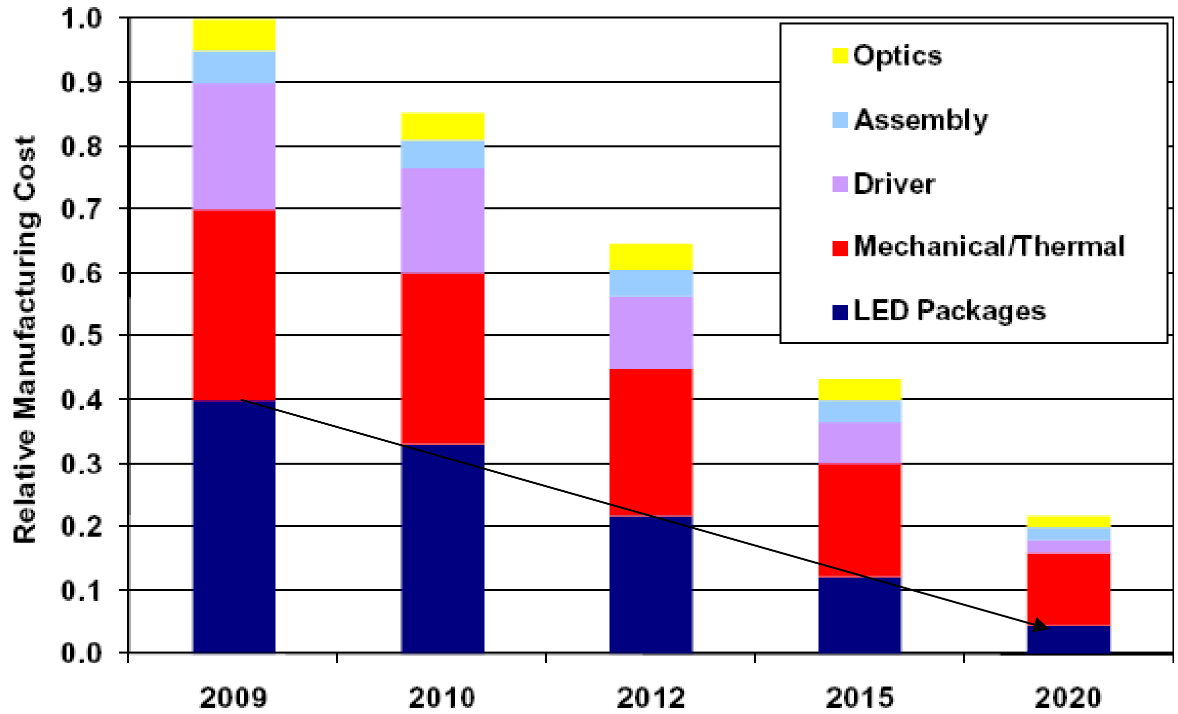
Haitz Law – Performance/Cost Evolution



Source: Roland Haitz and Philips Lumileds

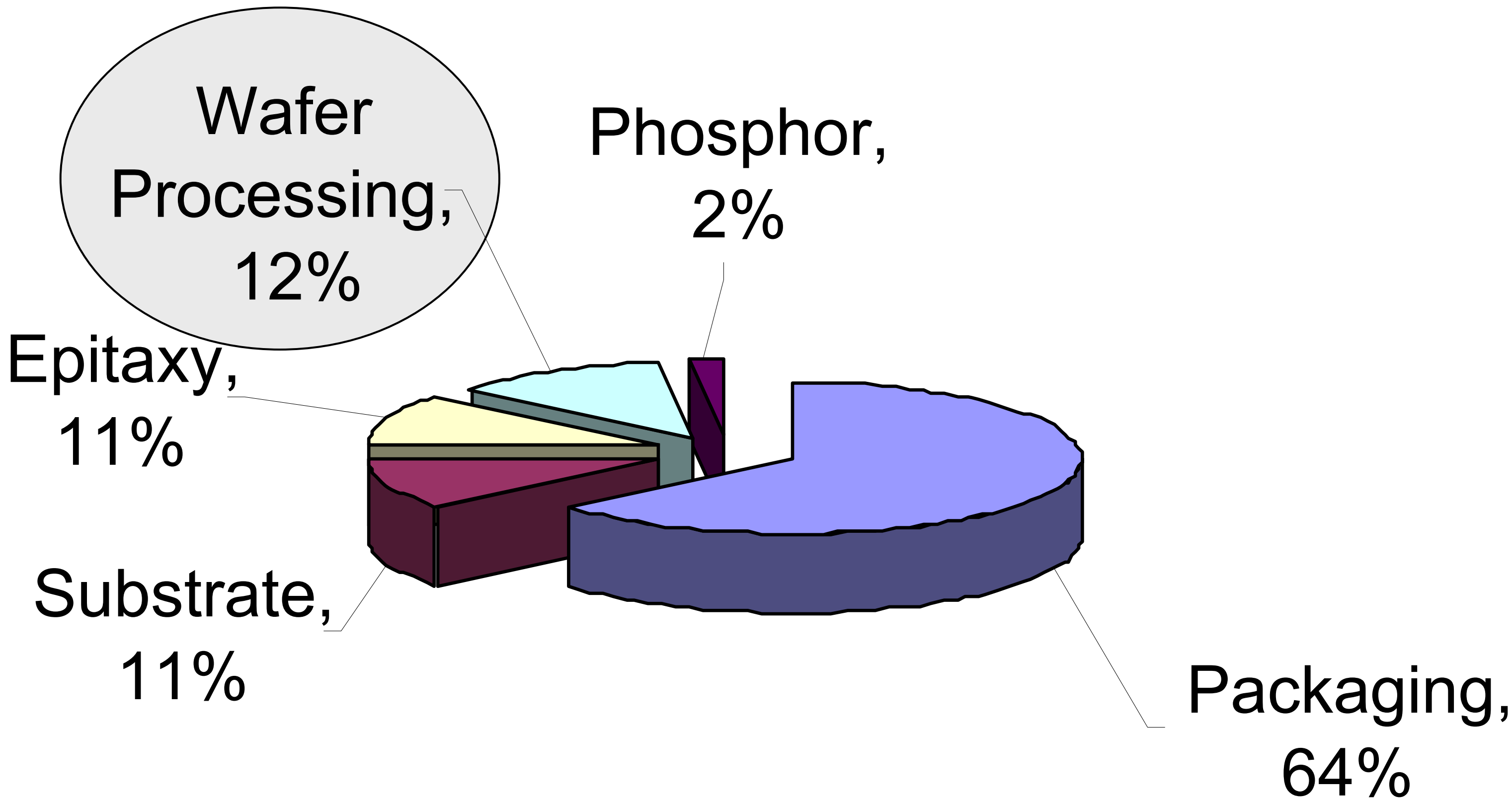
Cost Reduction Targets in HBLED
> 10x Cost Reduction

Cost savings opportunities identified: improvements in manufacturing process, equipment productivity, and process control



Source: Solid-State Lighting Research and Development: Manufacturing Roadmap, July 2010, DOE Manufacturing Workshop consensus

Cost Breakdown for a Packaged LED



Source: Solid-State Lighting Research and Development: Manufacturing Roadmap, July 2010, Preliminary data provided by the Cost Modeling Working Group

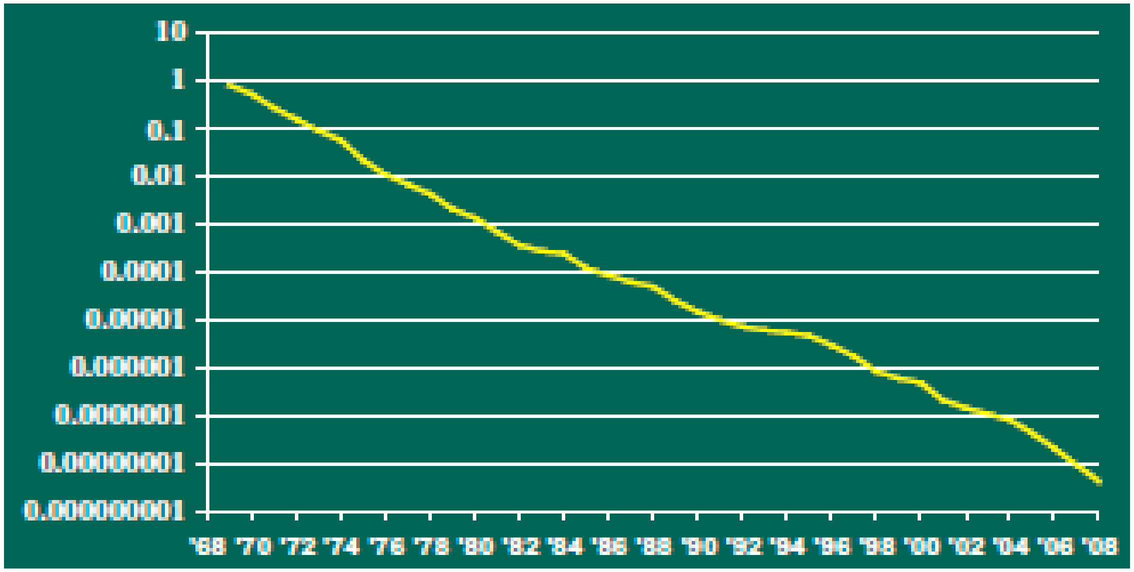
Low Yields – Key Manufacturing Issue

18% yield for entire process

- Electrical failure
- Binning for color
- Binning for output
- Optical alignment

Source: IMS Research Jan 2010, industry-wide 2009 yields

Manufacturing Tools Contribute ~500x Price Reductions in Processed Silicon



- 1975, the average price per transistor was ~$0.02 (4 µm features)
- 2008, the average price per transistor was ~$5x10^{-9}$ (45 nm features)
  - This is a 4,000,000x reduction in cost
  - Device scaling accounts for ~8,000x cost reduction ($/transistor)
  - Manufacturing efficiencies account for ~500x reduction in the price of processed silicon

Source: Intel/WSTS, 8/07

Where Will LED Cost Improvements Come From?

Silicon History

	Semi Status: early 70's	Semi Status in 2008	Semi Gain
Wafer Size (mm)	50	300	36x
Throughput (wafers/hour)	~50	~200	4x
Yields (%)	<50%	>90%	2x
Utilization (%)	<50%	>95%	2x

- LED Manufacturing Cost reductions will come from a combination of:
  - Improved LED efficiencies and drive current: (~2-4x)
  - Larger Wafers: (~2x)
  - More Productive Tools (higher throughput & yields; lower COO): (~2-3x)
  - Better Utilized Tools (Uptime): (~2x)

Source: Ultratech

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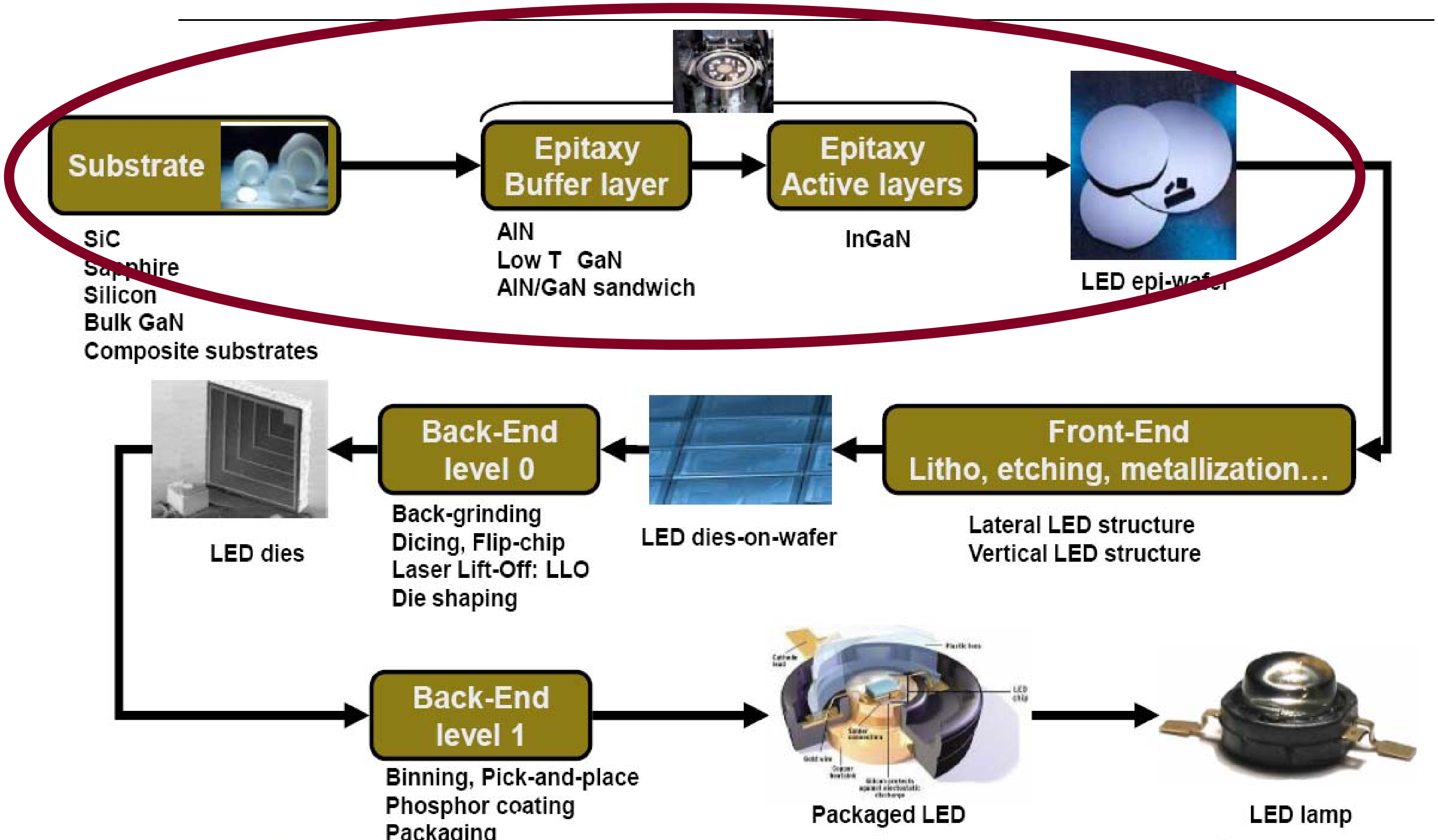
LED Manufacturing Process Flow



Source: Yole, 2010

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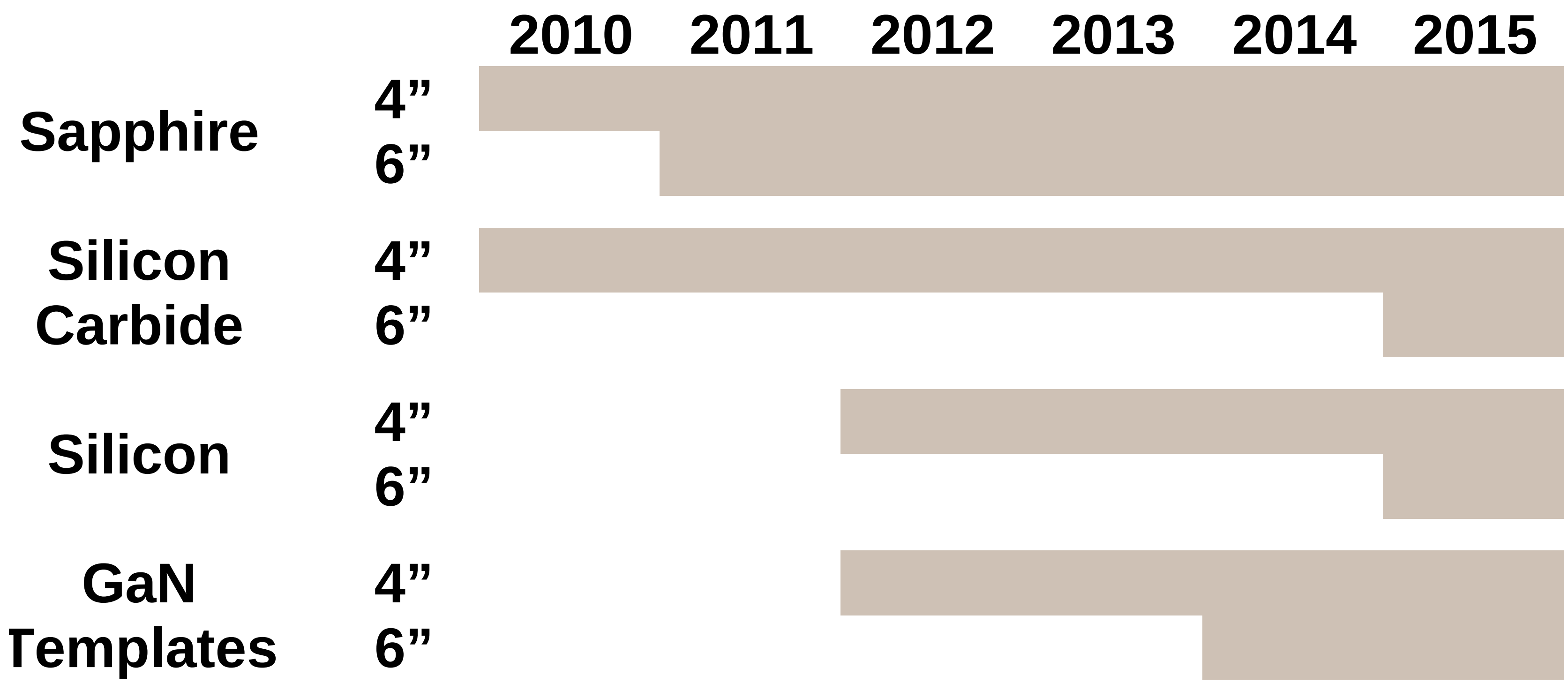
Lowering Epitaxy Manufacturing Costs

- Large impact on subsequent wafer fabrication costs

- 150mm Sapphire
  - ~50% epitaxy cost reduction
  - 150mm sapphire substrate expected to be majority of total epi cost

- 150mm Si Substrates
  - Substrate cost reduction ~75% by replacing sapphire with silicon
  - Substrate cost becomes minor contributor to total epi cost

Substrate Roadmap – Size and Material Commercial Implementation

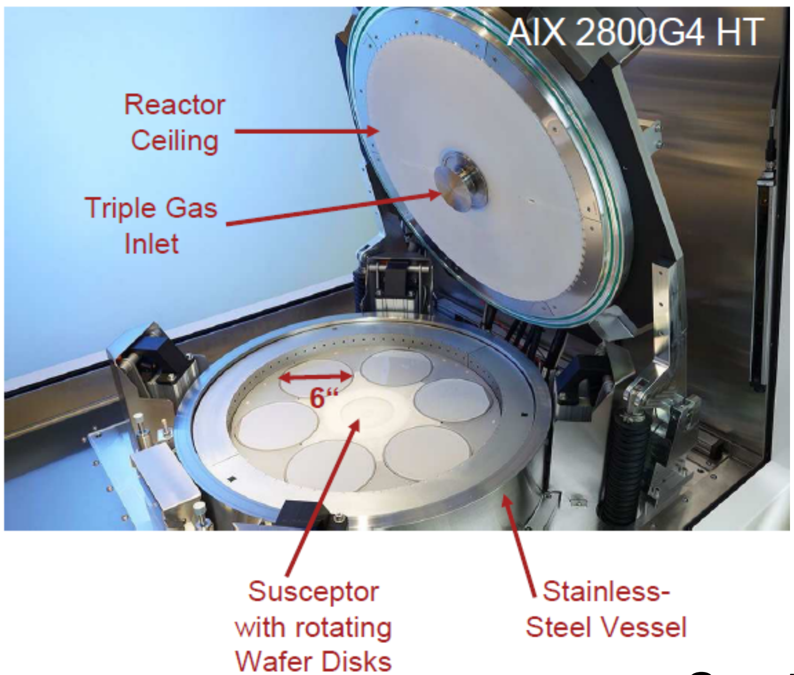


Source: DOE SSL Workshop Consensus, 2010

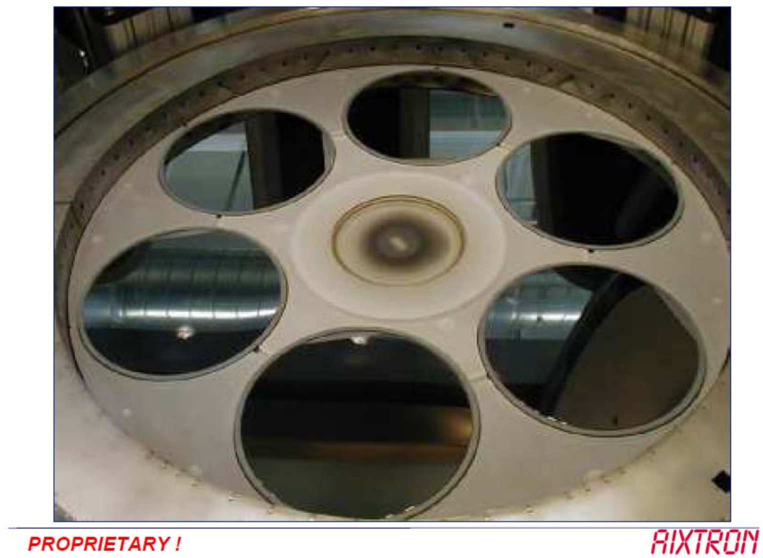
GaN Epitaxy on 150mm Sapphire and Silicon

Planetary Reactor®:

6 x 6” – 11 x 4” – 42 x 2”



Buffer: 1µm GaN on 6x6" Si – Crack free



Courtesy of AIXTRON

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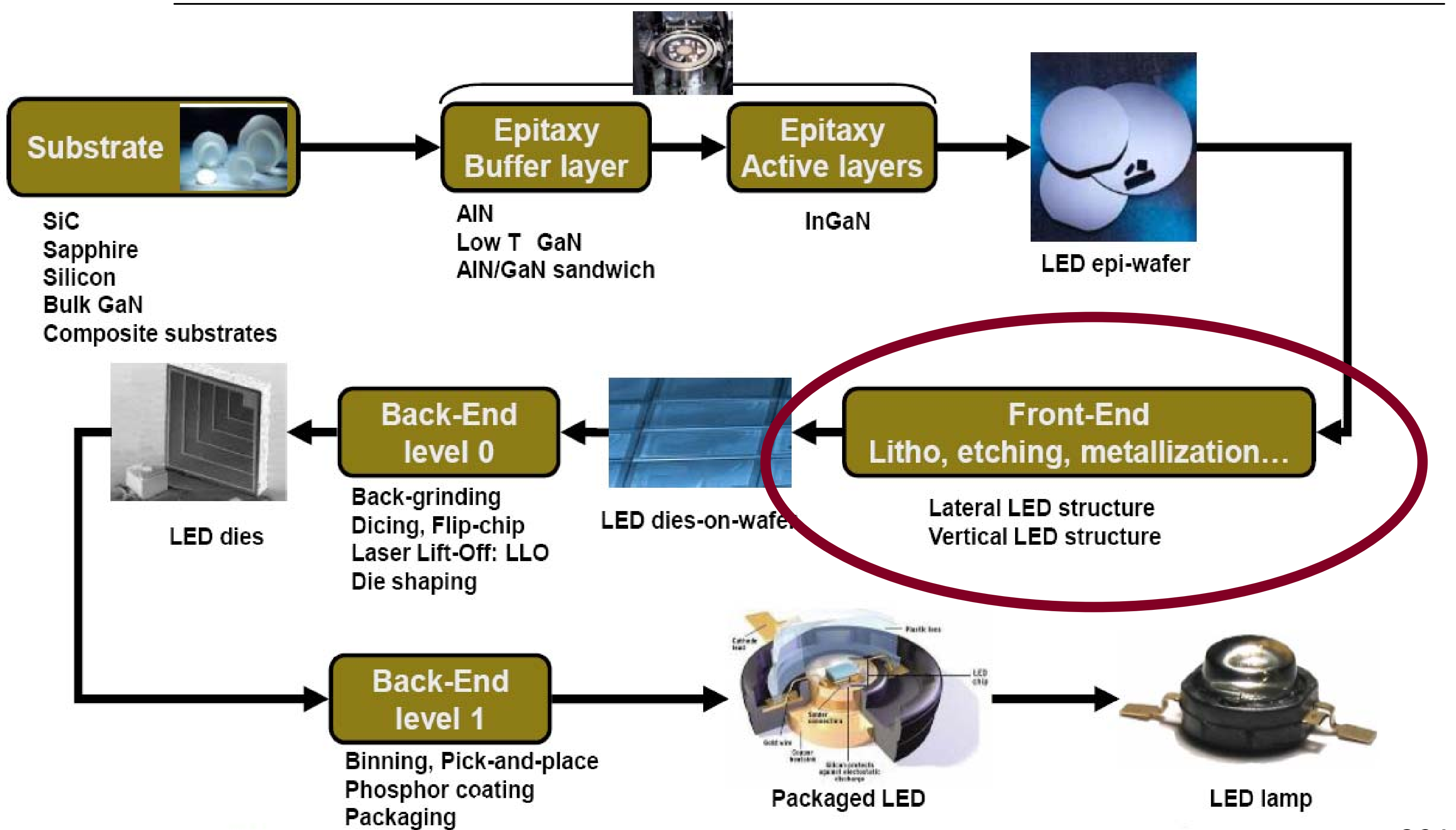
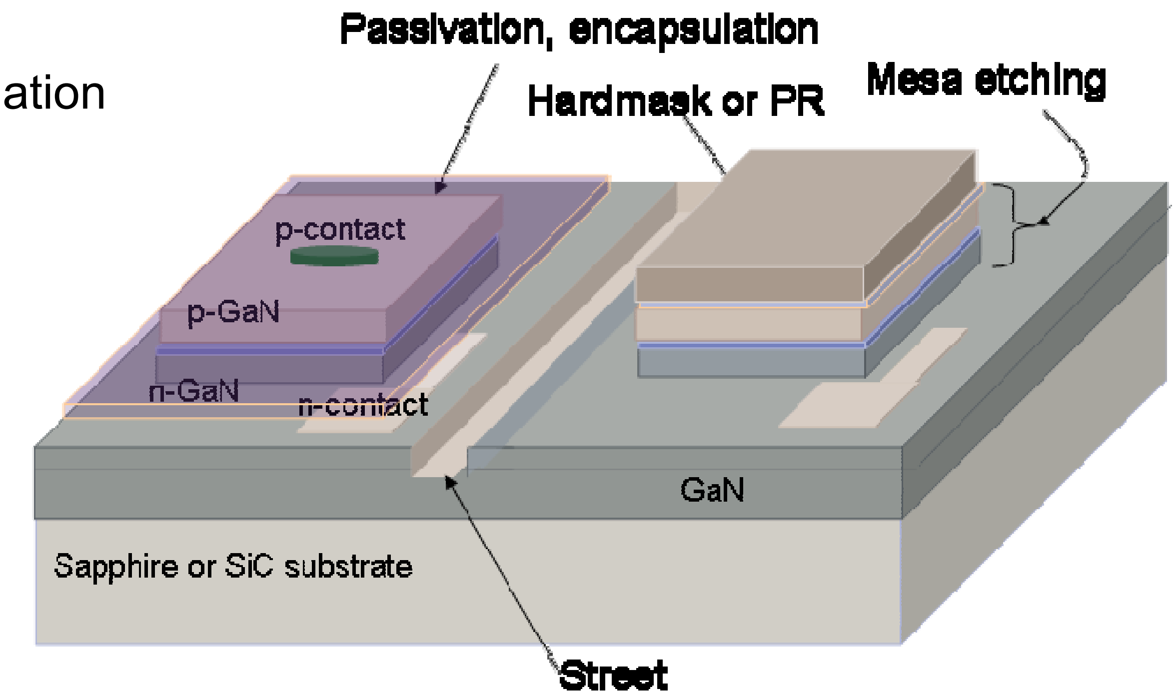
LED Manufacturing Process Flow



Source: Yole, 2010

Front-End LED Process

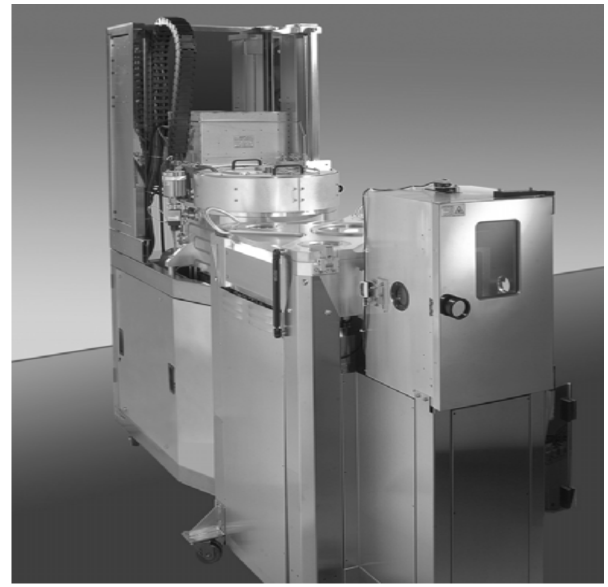
- Lithography
- PECVD
  - Passivation/encapsulation
  - Hardmasks
- Etching
  - Mesa
  - Streets
  - Hardmasks
  - Contacts
  - Sapphire patterning
- PVD
  - Contacts
  - Reflective layers



Market Segmentation
Conventional vs HB & UHB

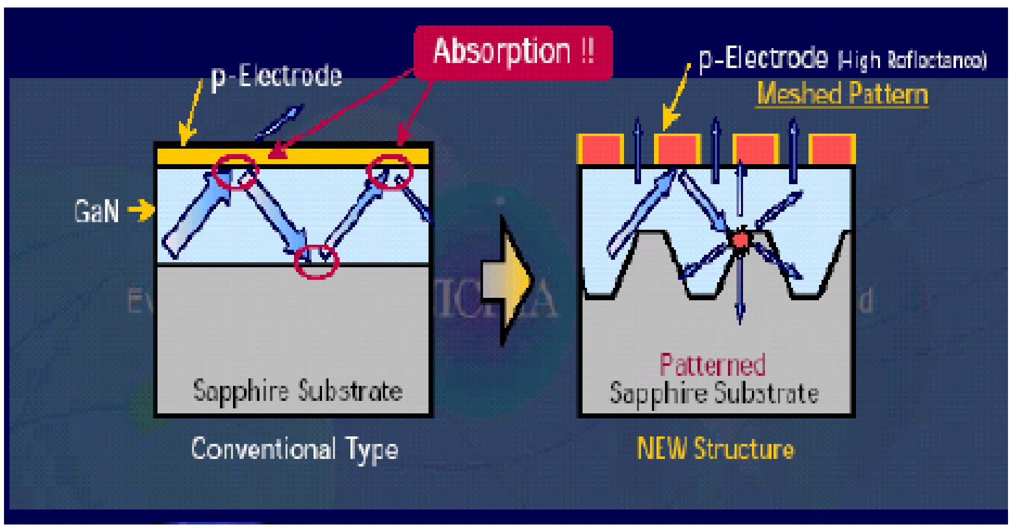
- HB & UHB
  - Automated processing
  - Larger substrates
  - Single wafer processing

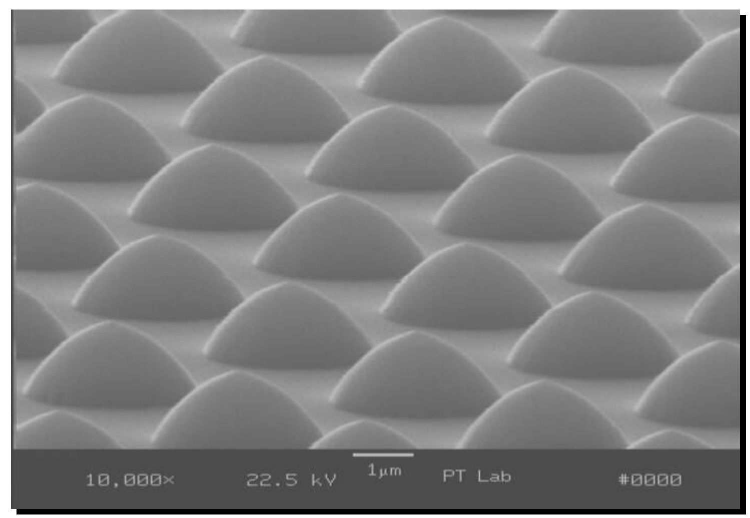
- Conventional LED
  - Semi-automated processing
  - Wide range of substrate sizes
  - Batch processing



Patterned Sapphire Substrate (PSS) System Specific

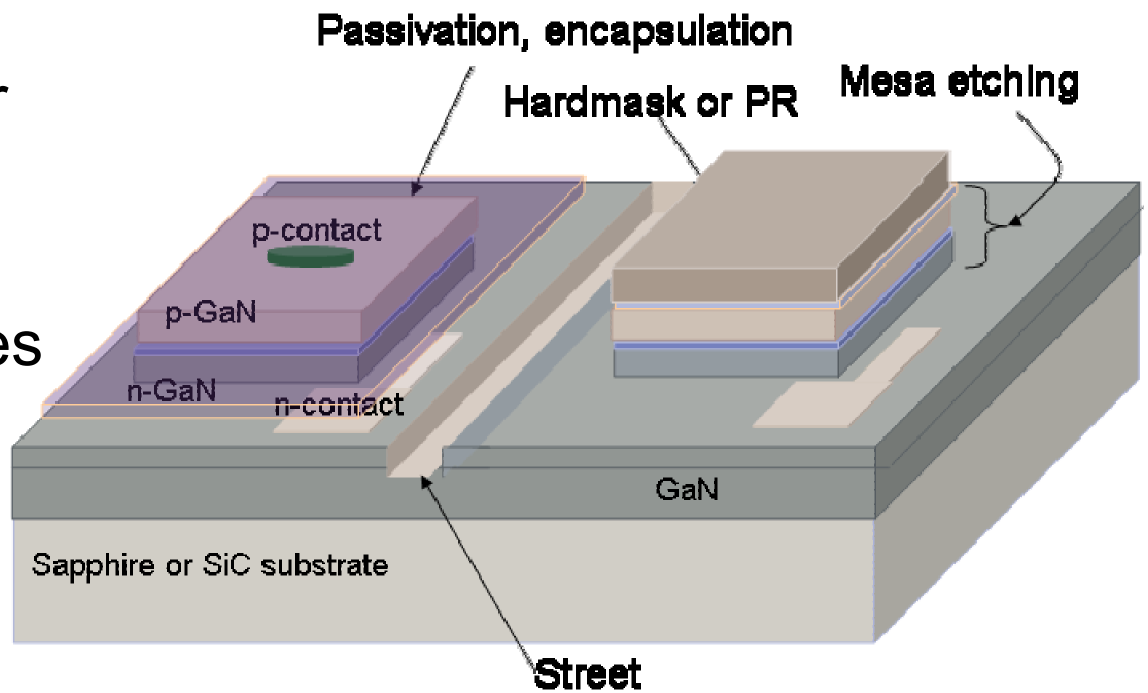
- Enhanced light extraction
- Improved epitaxial material (lower defects)
- Requires purpose built tool for LED Market





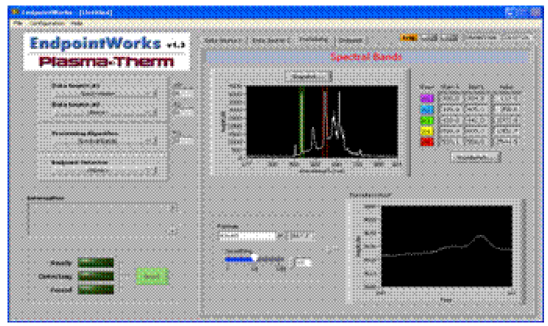
Etch & Deposition Process Control

- Detection of material interfaces
- Process control for specified depth or thickness
- Real time etch rates and selectivity

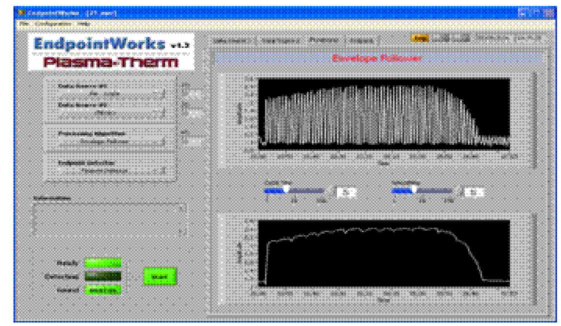


Process Control
Endpoint Techniques

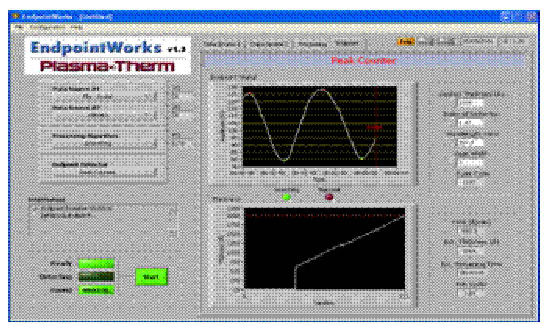
- Desired Measurement Technique
  - Accurate
  - Non-invasive
  - Robust
  - Direct measure
  - Inexpensive
  - Flexible



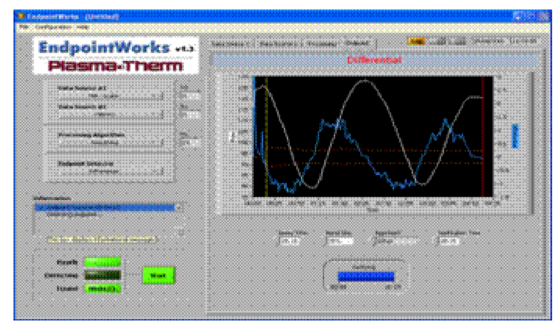
Generic OES Endpoint Detection



Endpoint for DSE®



Endpoint for Deposition



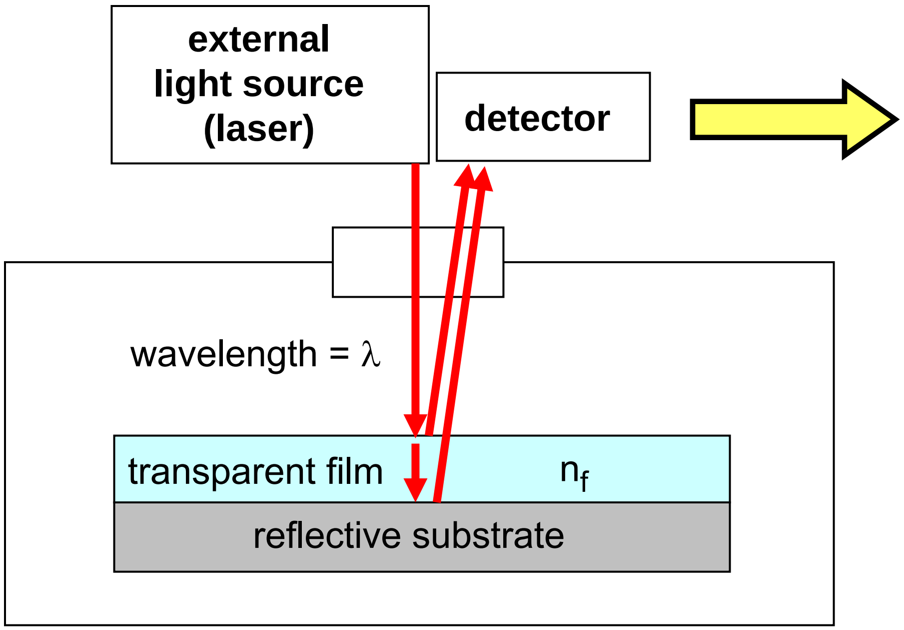
Endpoint for Dielectric Etch

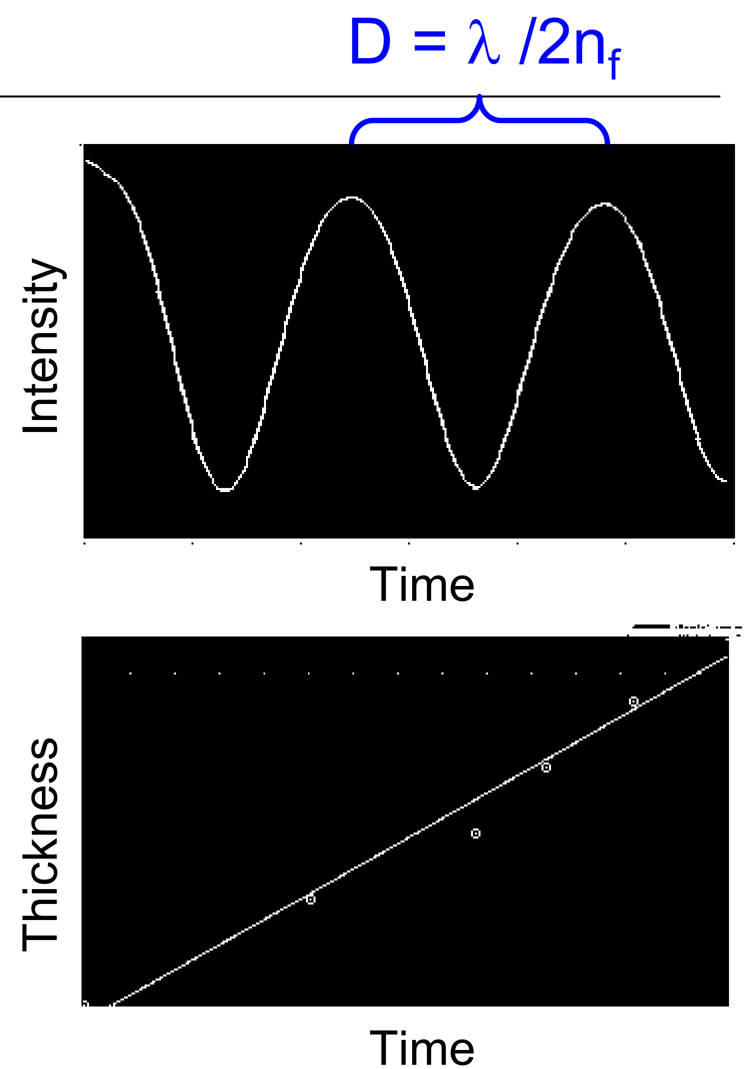
Background
Diagnostic Candidates

- Plasma Measurements
  - Optical
    - Optical Emission Spectroscopy (OES)
  - Electrical (e.g. RF match positions)
  - Species Analysis (e.g. RGA))
  - Tool response (e.g. throttle valve position)

- Optical
  - Laser Interferometry
  - Optical Emission Interferometry (OEI)

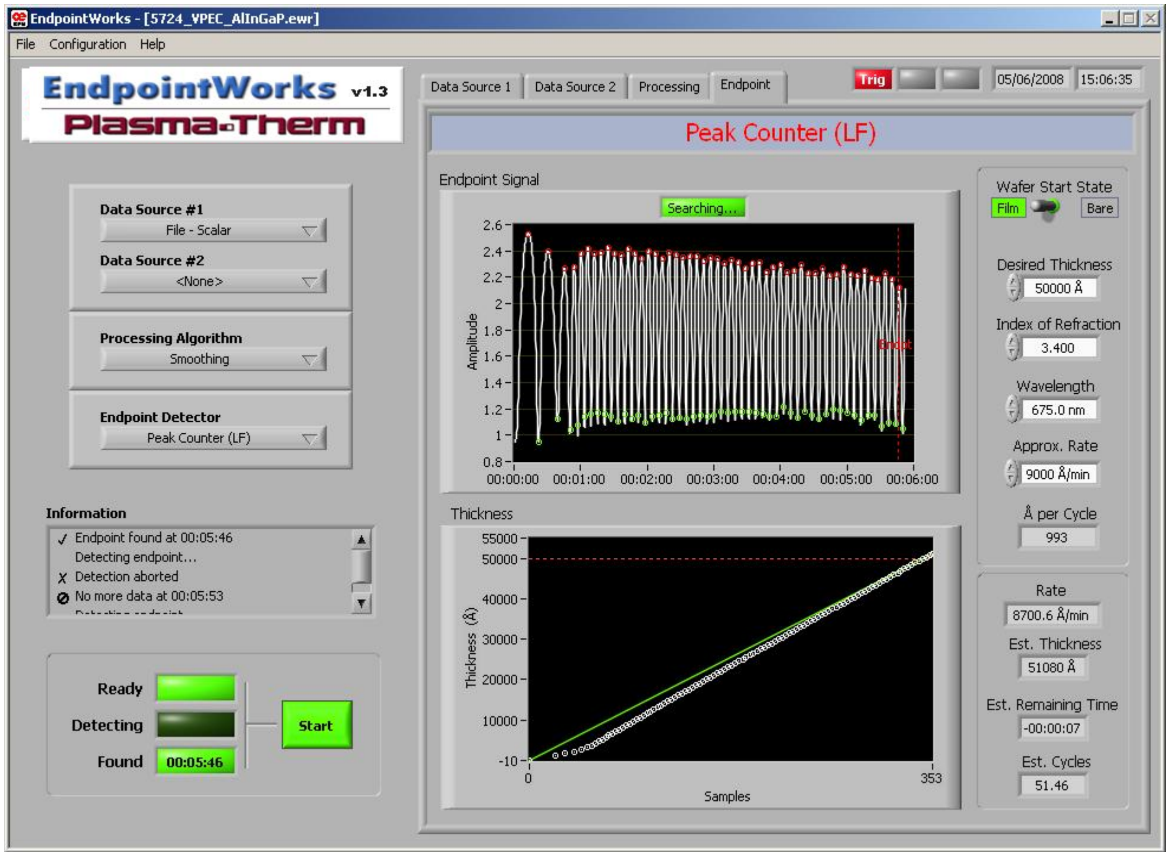
Optical Diagnostics
Laser Interferometry

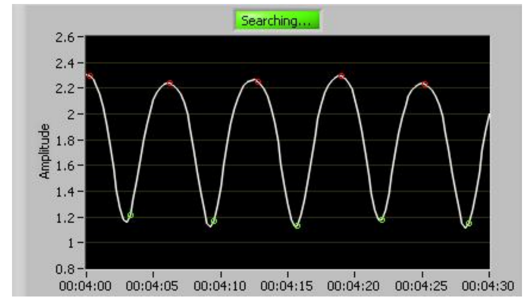




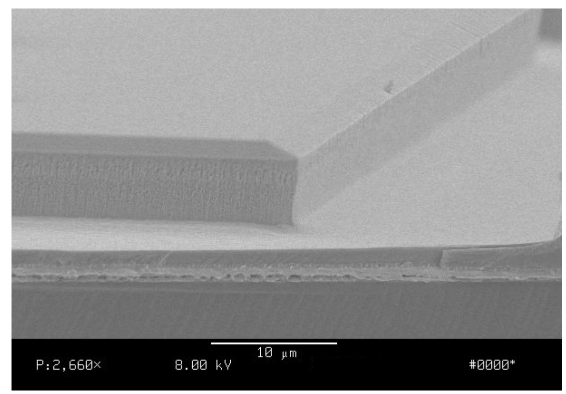
Reflected Light gives Thickness vs Time = Etch Rate

Etch Depth Monitoring using Plasma-Therm EndpointWorks™





Laser Interference signal of AlInGaP Etch



EndpointWorks™ peak counting algorithm – User Interface

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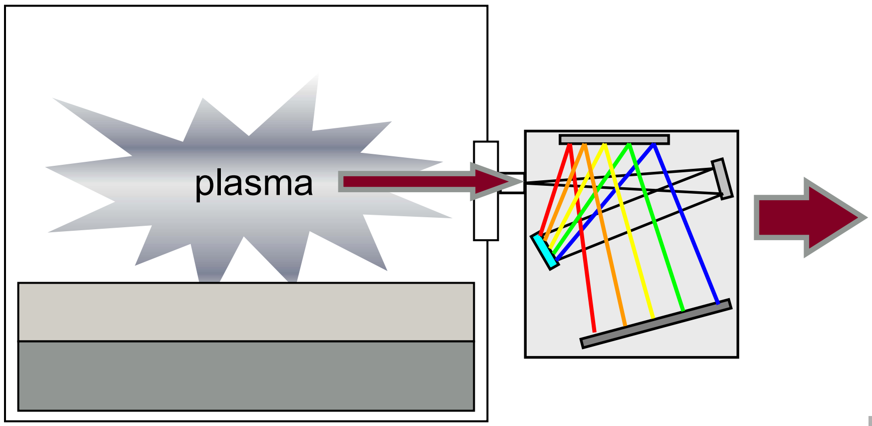
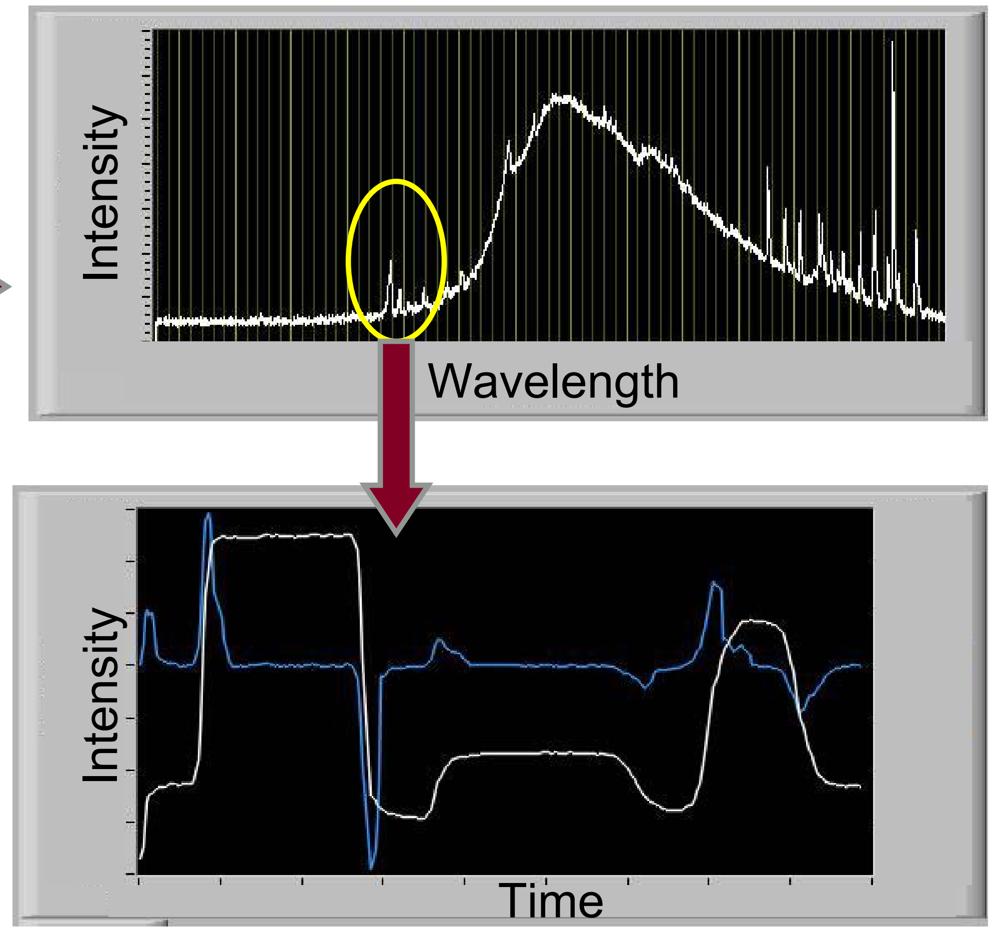
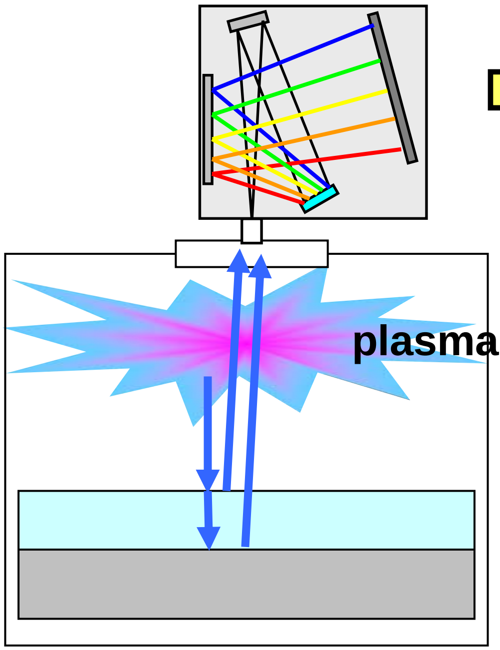
Etch Process Control using Compositional Change – OES

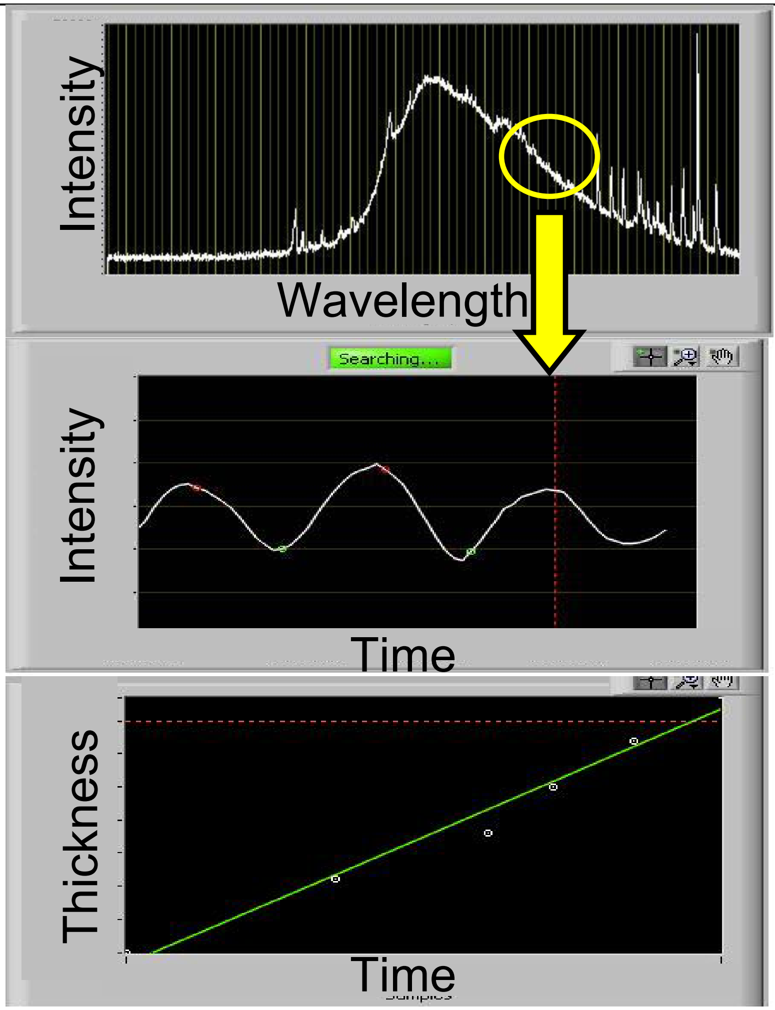




Plasma spectrum gives Composition vs Time

Etch Depth Process Monitoring Using OEI

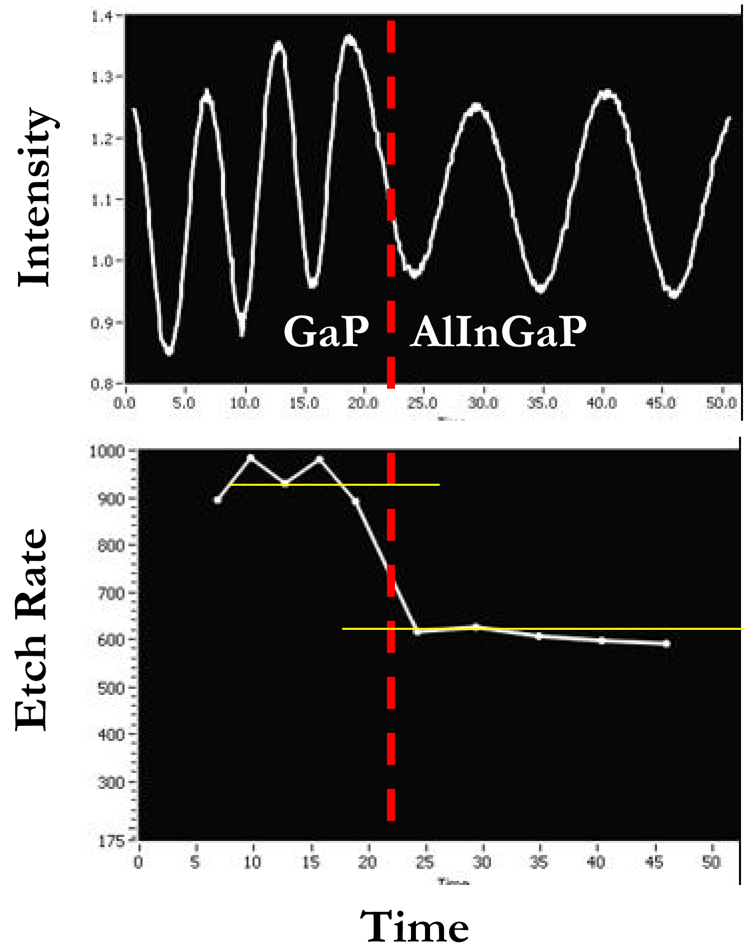




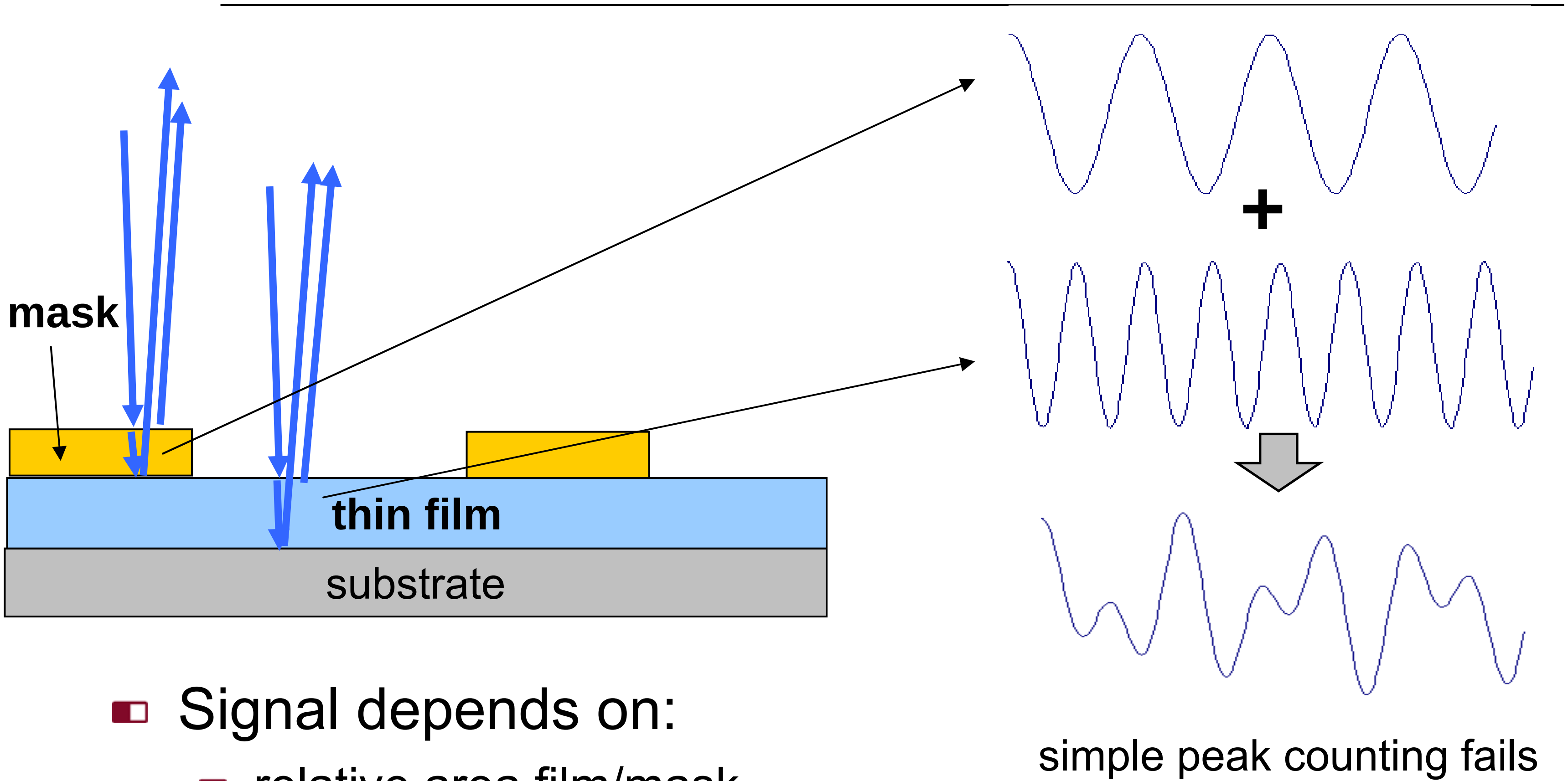
Signal intensity gives
Thickness vs Time
= Etch Rate

Example GaP/AlInGaP Etching with OEI

- Benefits
  - Etch rate estimates every ½ cycle
  - Real time etch rates of individual materials
  - Real time selectivity data for sequential films

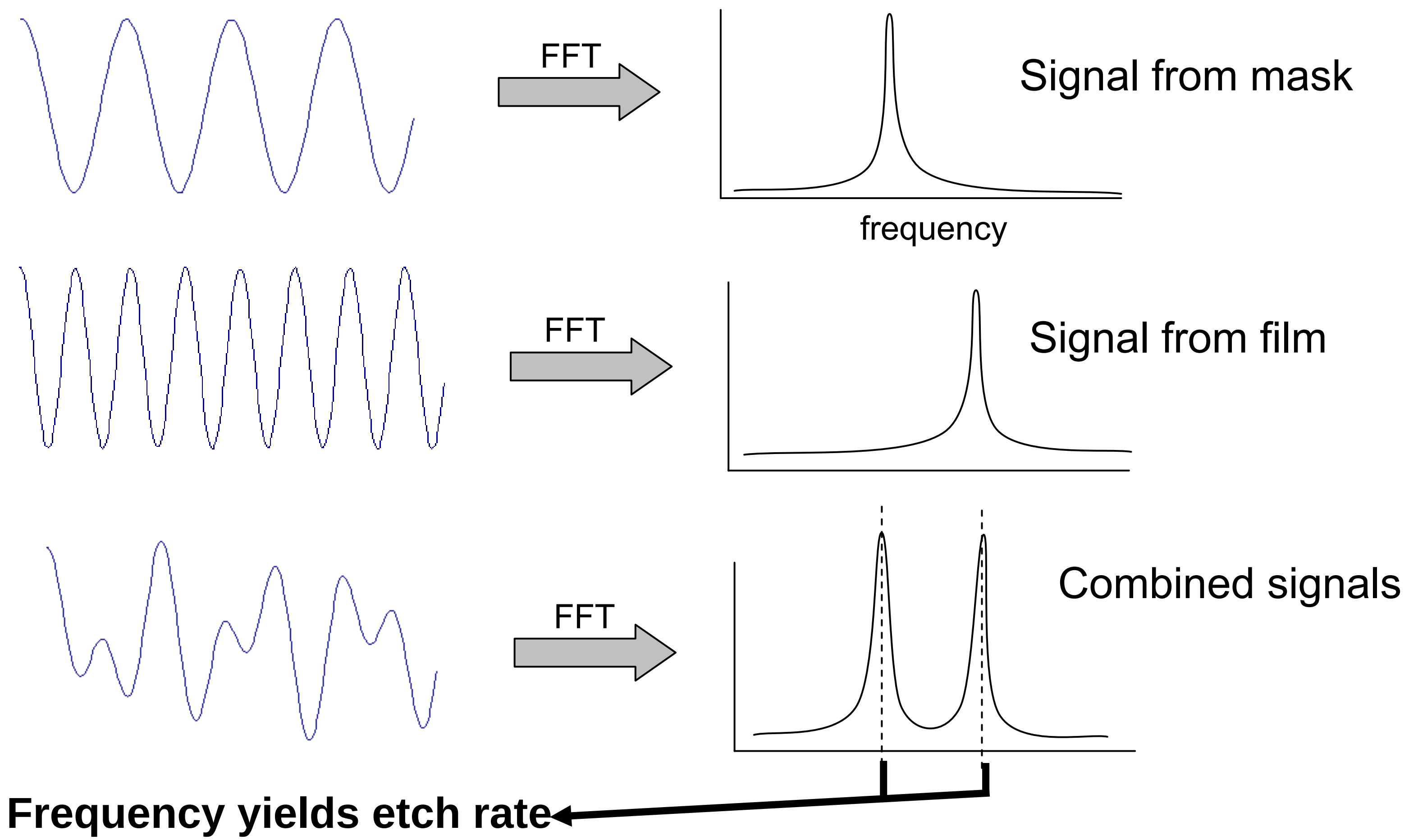


Patterned Material Etching Using OEI



- Signal depends on:
  - relative area film/mask
  - relative etch rate film/mask

Patterned Material Etching Using OEI



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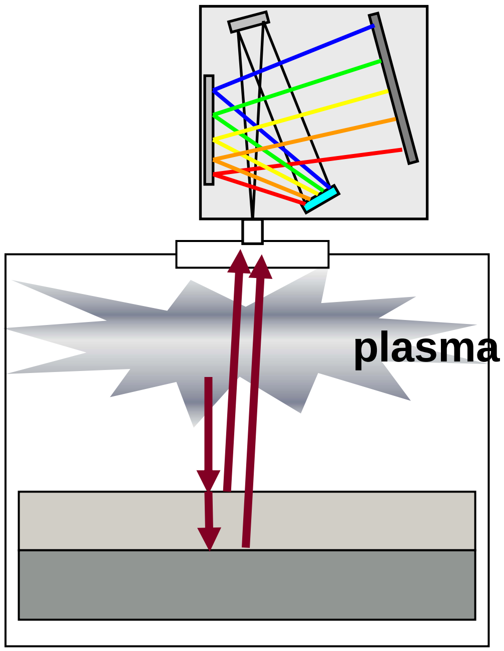
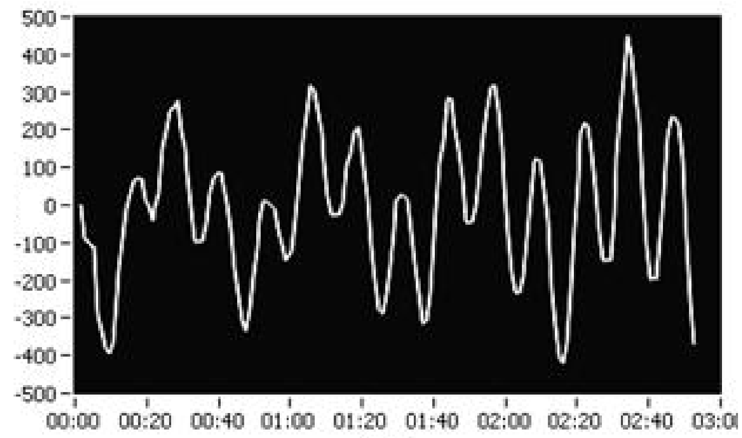
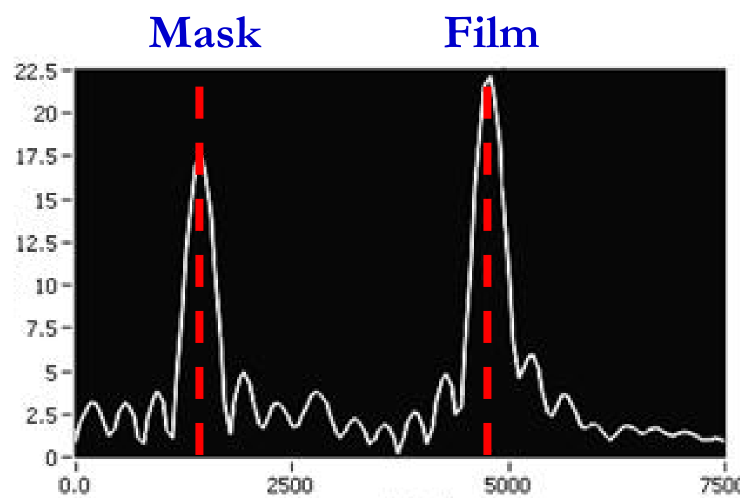
Real Time Etch Rate and Selectivity Monitoring Using OEI

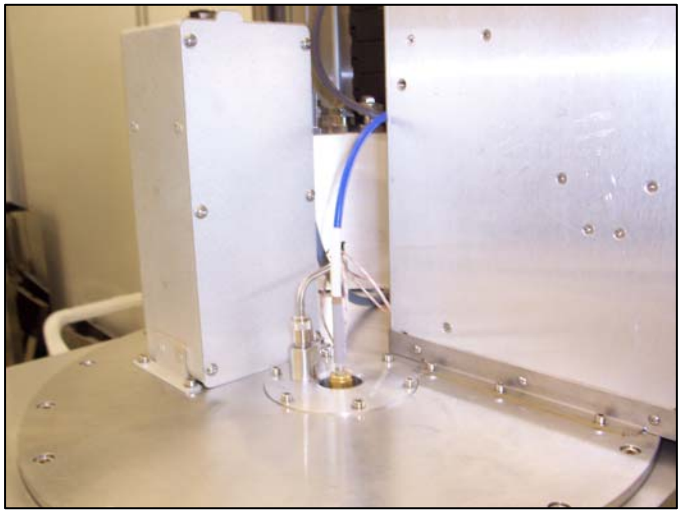


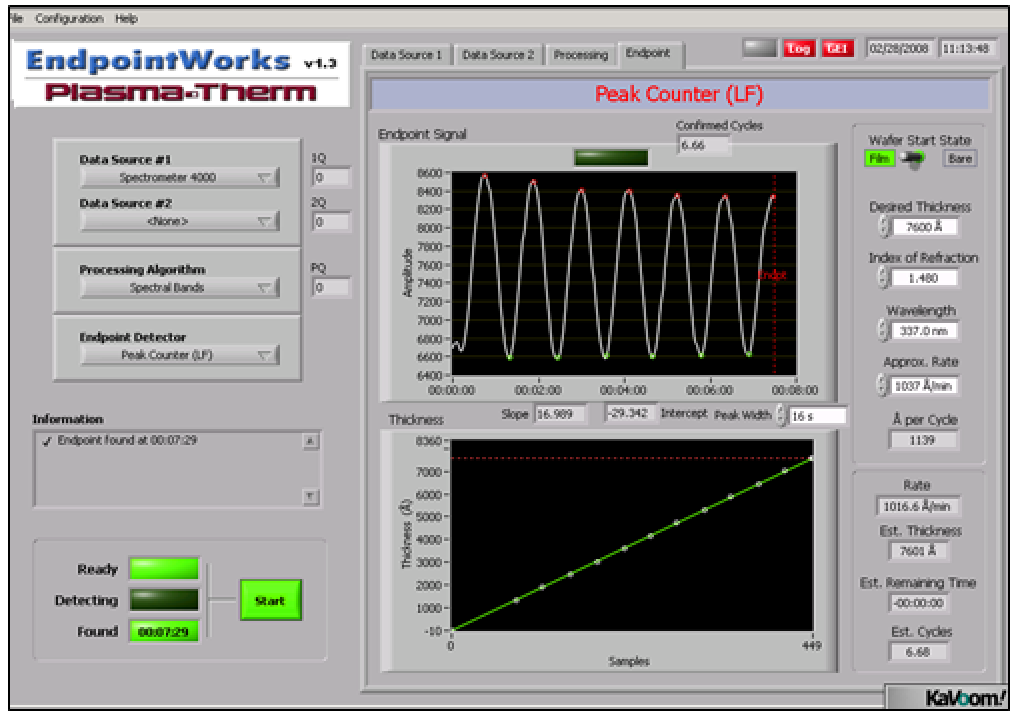




Signal intensity gives
Etch Rates & Selectivity

PECVD Deposition Process Control OEI





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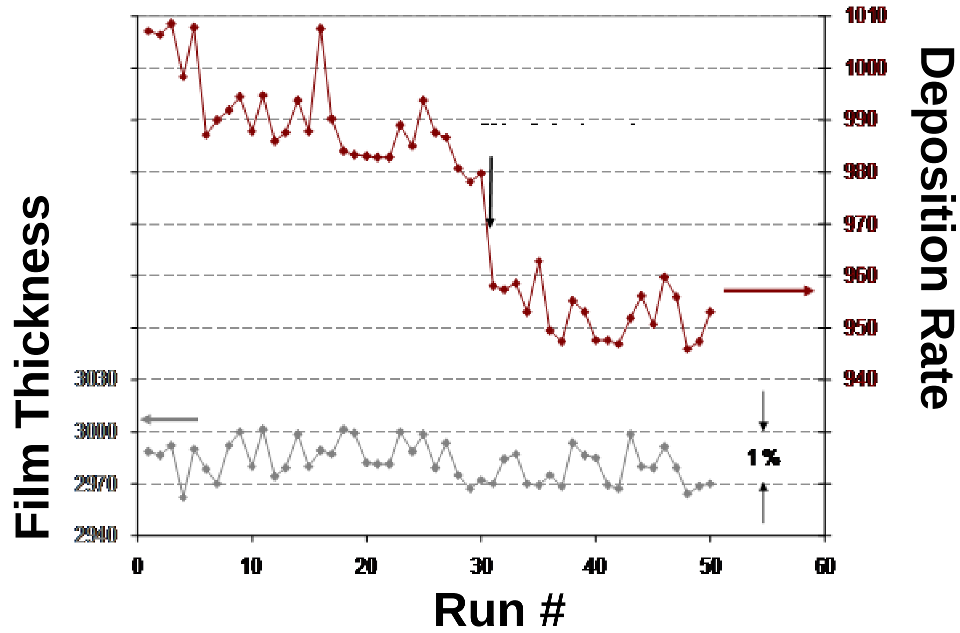
Process Stability with Run-to-Run Repeatability

- Compensates for process disturbances (e.g gas changeouts, cleans)
- Decreases requalification time
- Compensate for material variation
- Compensate for tool variation
- Scrap reduction
- Improve process throughput

Reproducibility

1 σ = 0.37%

Range/(2 x mean) = 0.65%



Conclusions

Market Demand for LEDs will remain strong

- Present – Backlighting applications
- Future – Solid State Lighting

LED Manufacturing vs Main Stream Si

- LED material diversity vs Si critical dimensions
- LED toolsets will continue to mature and realize productivity gains similar to mainstream Si evolution
  - Wafer sizes
  - Process control
  - Tool features for throughput and COO

Collaborators

- Russ Westerman
- Dave Johnson
- Dwaraka Geerpuram
- Chris Johnson
- Linnell Martinez
- Jason Plumhoff
- Applications / Product Development Team

Thank You for Your Attention

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