Innovative provider of process metrology & diagnostic solutions to the semiconductor manufacturing industry

Plasma Applications Group, August 13, 2009

Stephen Daniels, Lexas Research
Didier Florin, EmbeddedMetrology.com

Invent Centre,
Collins Avenue,
Dublin, Ireland
info@Lexas.ie

2009 Confidential This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent. © 2006 Lexas Research

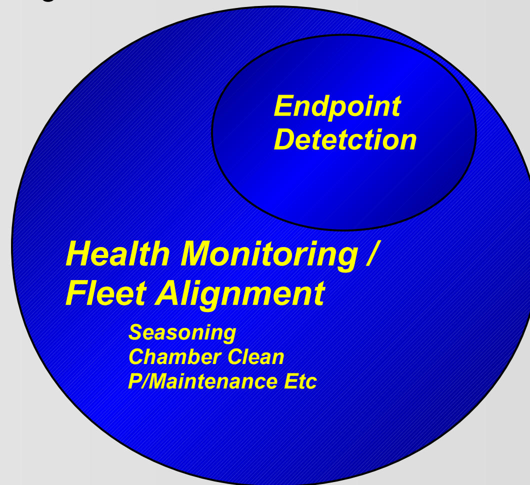
State of affairs

- Dimensions are Shrinking
- Stringer tolerances across wafer

- Narrowing of Process windows, requiring higher precision from sensors

- Chamber Matching / Fleet alignment

- Chamber design; impact of components aging.



- OES for Endpoint Determination

- OES struggling with Robust LOA EP Dominated by emissions from Plasma Bulk

- P/IV Probes for RF Power Measurement and RF Fault Monitoring

- Measures Input Power – Difficult to Assess the RF yield.

- System State Monitoring (PCA / PLS)

- Not always sensitive to what is important; lots of data

Lexas Research
Nanotechnology Solutions

2008 Confidential This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent. © 2006 Lexas Research

Why Something New?

- Need highly pertinent (RF) energy and chemistry information that a process engineer can quickly assimilate, while providing a robust signal
- Need for a plasma measurement technique that “sees” beyond the process chemistry
- Need to be able to decouple sources of variation and identify corresponding degrees of variation

Lexas Research / ***Phitell***™ Value Proposition

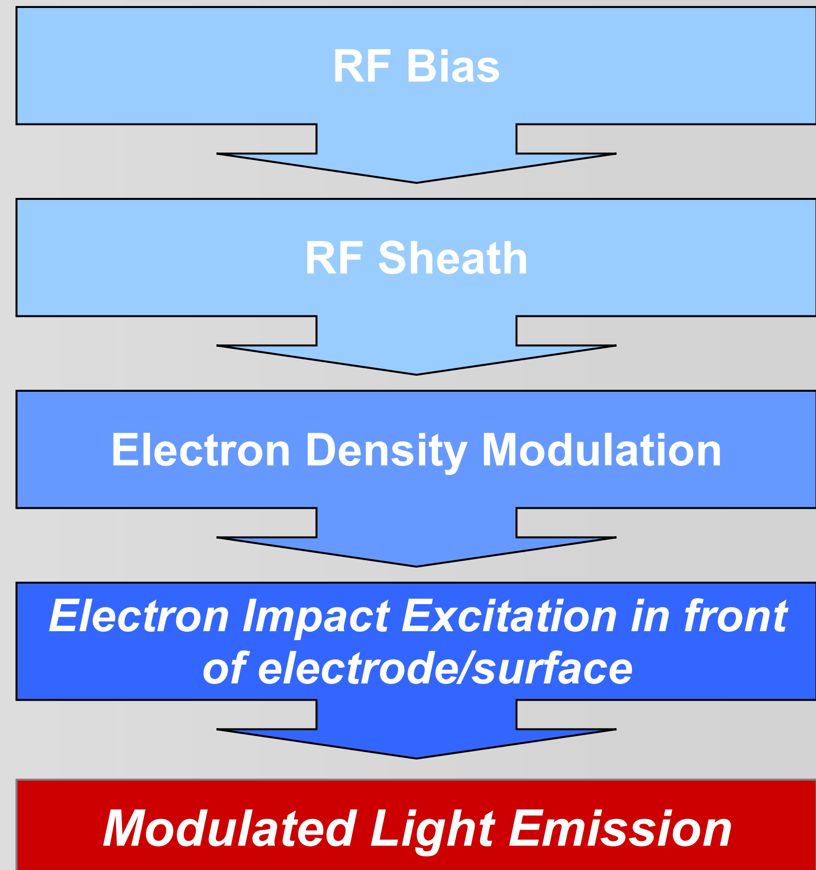
Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Phitell™ Operating Mechanism Summary

- The electron density is strongly modulated in the sheaths at the driving radio-frequency
- Electron collisions create excited states, which later decay and emit light
- Modulated light originates at the sheath, ***above the processing wafer***
- Modulated light is a ***localised measurement***
- The light emission from the sheaths is strongly modulated at the radio-frequency



Lexas Research
Nanotechnology Solutions

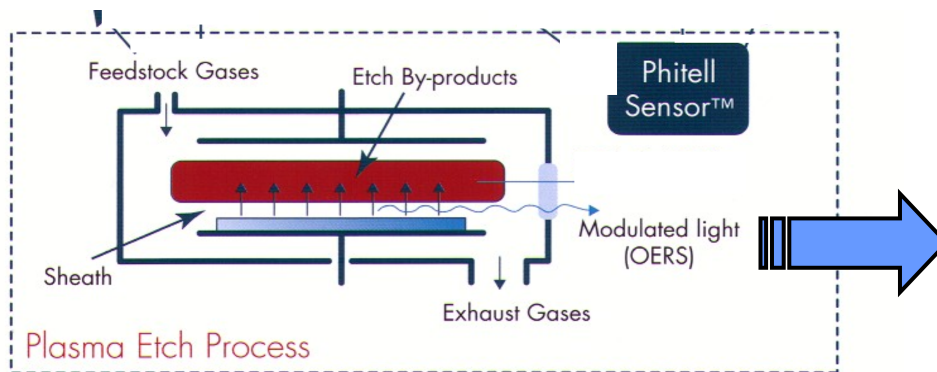
2008 Confidential This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent. © 2006 Lexas Research

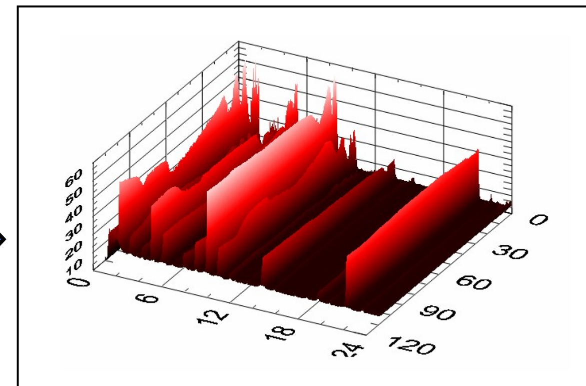
Phitell™ Optical Emission Radio-Spectroscopy (OERS)

- ❑ Phitell™ sensor Captures modulated light
- ❑ Data presented in frequency domain

From Modulated Light Generation At Plasma Sheath

Light Modulation to Rich Frequency Domain





Phitell™ focuses on Sheath Light ... Yielding Information Highly Sensitive to the Wafer – Plasma interface

Lexas Research
Nanotechnology Solutions

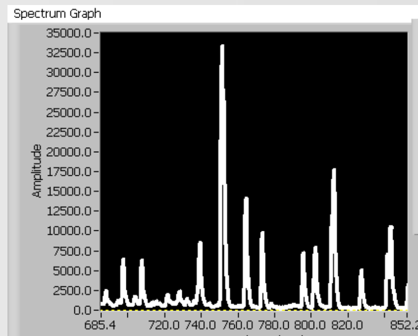
This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

OERS comparison with OES

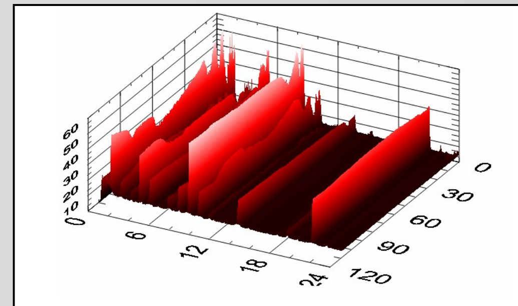
Optical Emission Spectroscopy (OES)

- ❑ Dominated by continuous light
- ❑ Chemistry analysis, based on ***wavelength*** (color)



Optical Emission Radio-Spectroscopy (OERS)

- ❑ Captures (RF) modulated light
- ❑ Analysis based on **RF modulation**
- ❑ @ discrete wavelength or broadband



OERS delivers a unique dimension to Plasma Process Characterization

Lexas Research
Nanotechnology Solutions

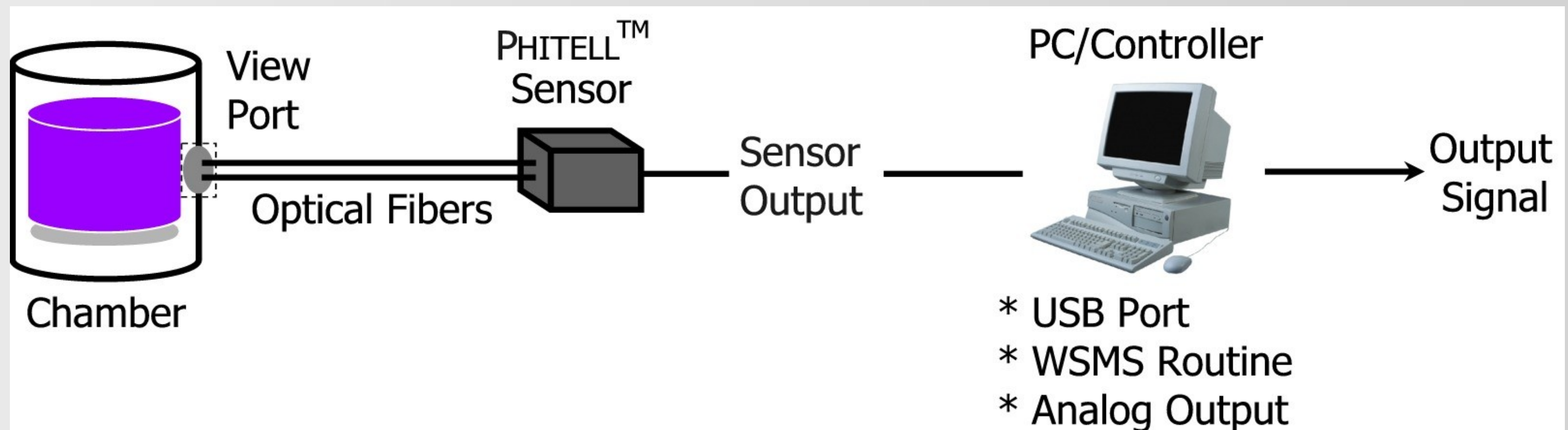
This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Phitell™ System Configuration

Phitell™ system consists of:

- Optical sensor
- Optical fibers
- PC or controller



Phitell™ is a non-invasive, easily integratable Plasma Characterization Tool

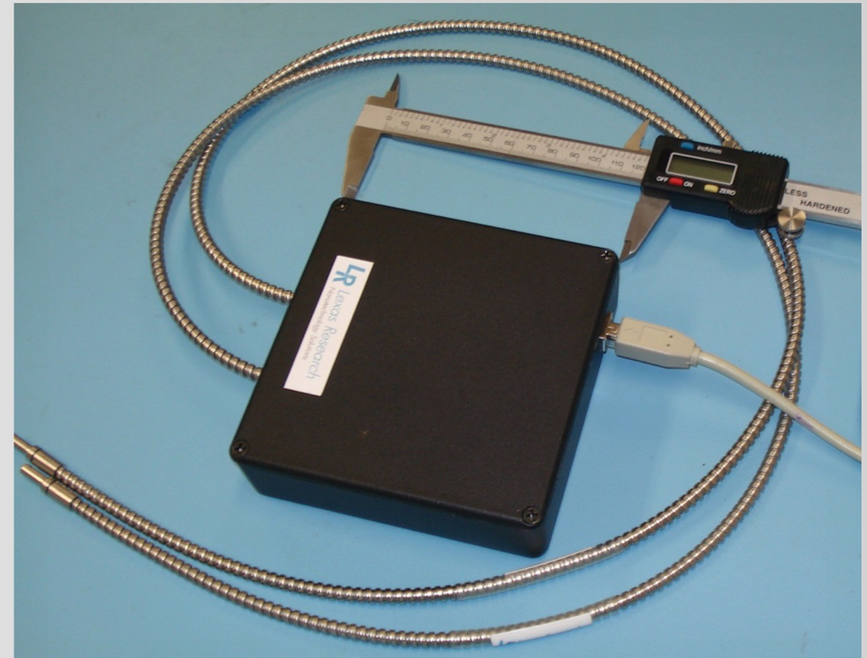
Lexas Research
Nanotechnology Solutions

2008 Confidential This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent. © 2006 Lexas Research

Phitell™ System Configuration

Optical Sensor:

- Si-PIN photodetector
  - λ = 400 - 1100nm
  - P_{min} = 5μW
- Single or dual channel operation
- Frequency
  - Range (MHz) = 0.1 - 150
  - Resolution = < 2KHz
- Analog-to-Digital Conversion
  - Sampling Speed up to 60 MSPS
  - Resolution = 14 bit
- Connectivity
  - USB2.0



Non-Invasive – Viewport Mounted

Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.
© 2006 Lexas Research

Phitell™ for RF Troubleshooting

High speed oes samples light changes with picosecond resolution compared to microsecond resolution of standard oes: somewhat like AC compared to DC

High speed oes can be transformed into information about both the frequency and amount of RF applied during a process.

It is possible to detect both the primary RF drive frequencies of dual power RF sources as well as the harmonic resonances generated.

RFOES is completely non invasive to the process and like other oes methods has very high reliability which makes it well suited for critical process control and continuous monitoring.

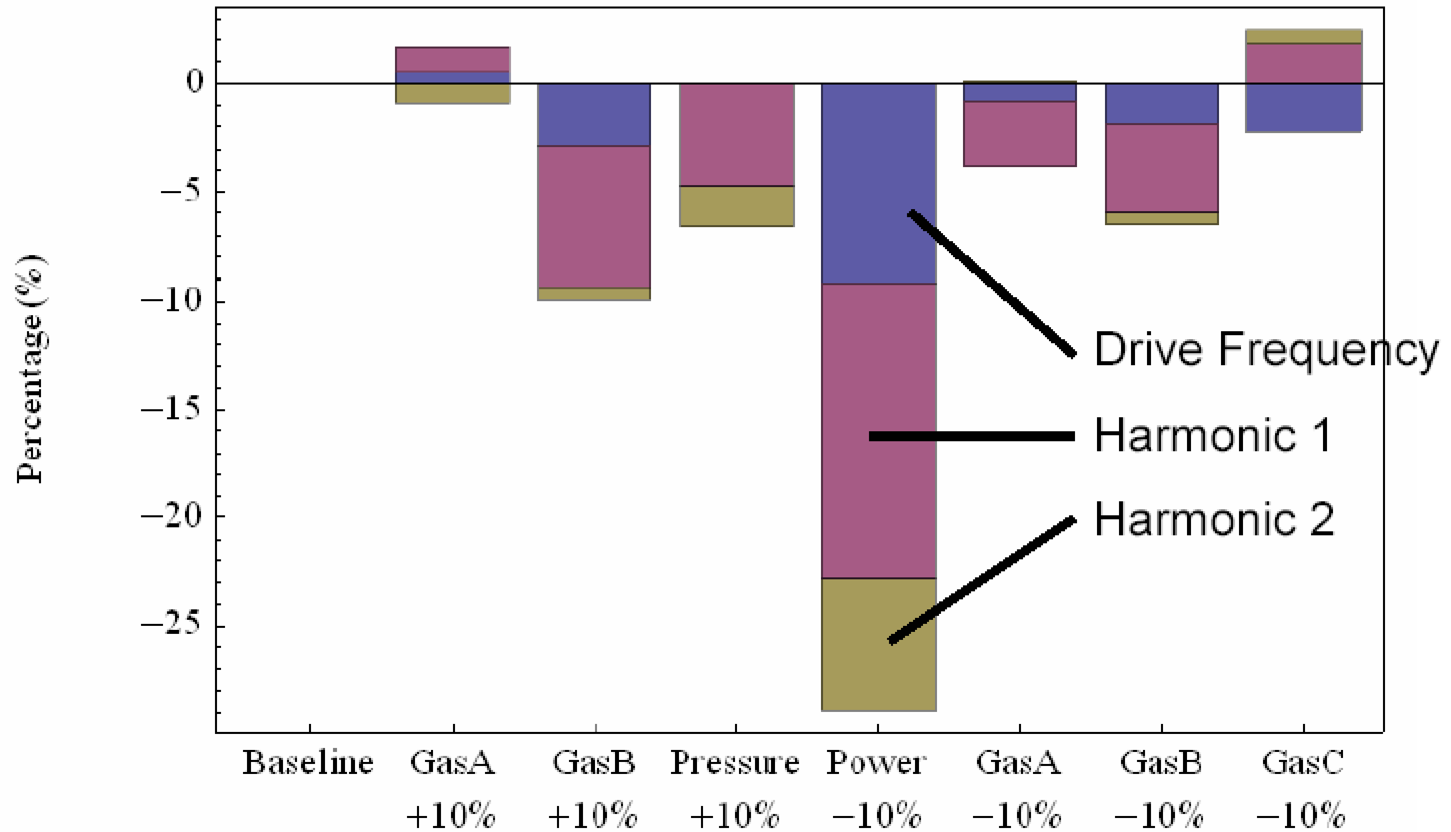
Non invasiveness and speed of implementation also make this a viable technique for RF troubleshooting.

Lexas Research
Nanotechnology Solutions

2008 Confidential This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent. © 2006 Lexas Research

Response to Process Changes

Test System Data: Single Frequency Etcher

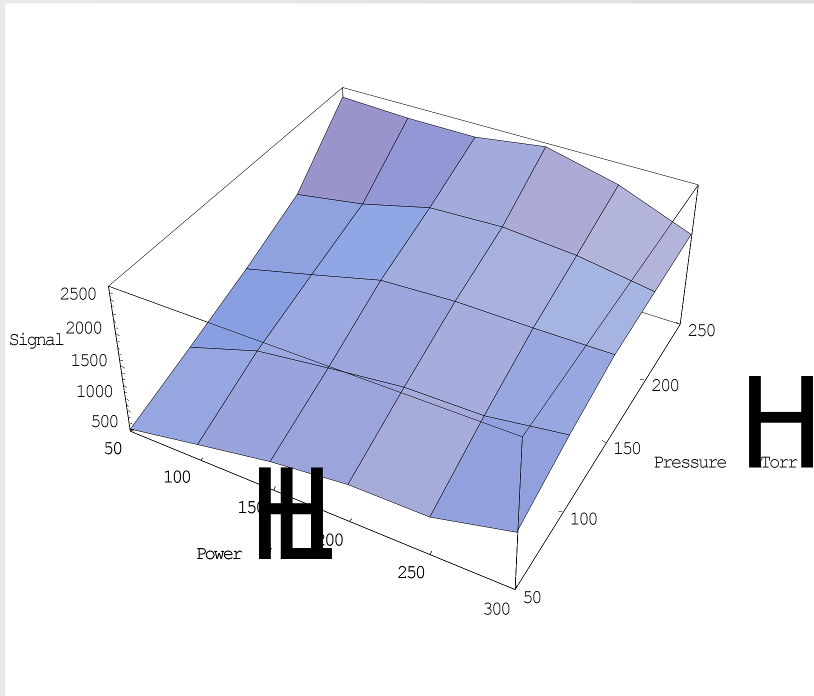


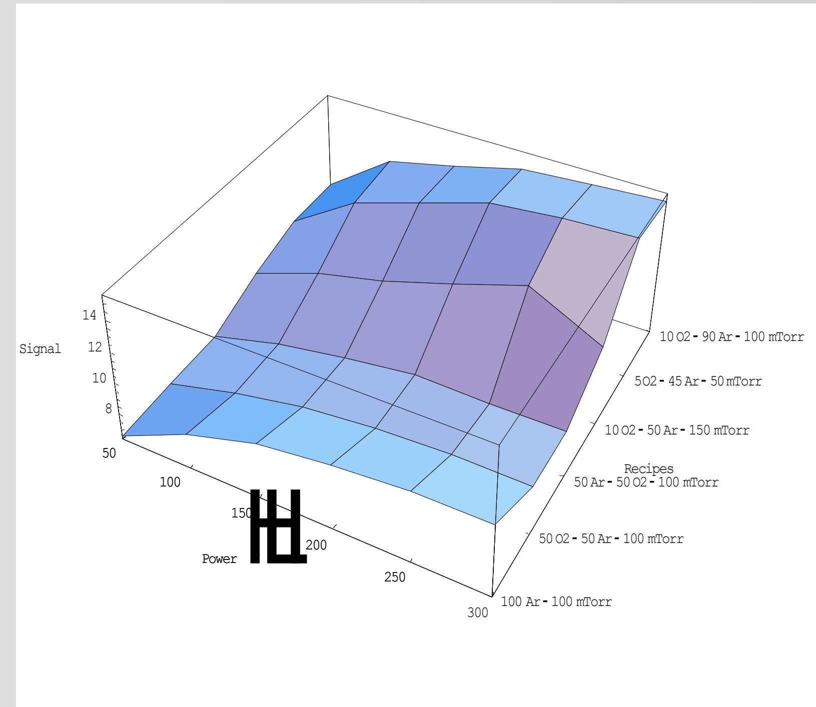
Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Lab Data – Power and Chemistry





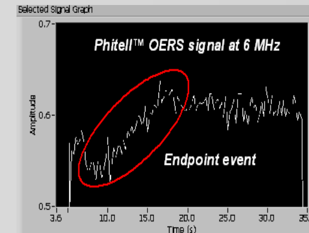
Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

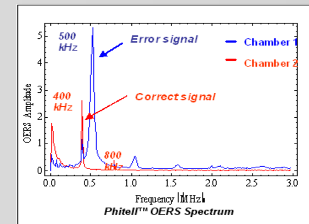
© 2006 Lexas Research

Product Applications – Successfully Achieved in Major Fabs

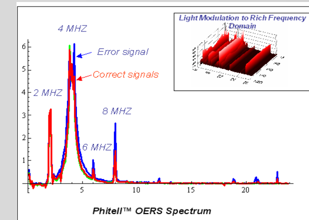
- Low Open Area Endpoint



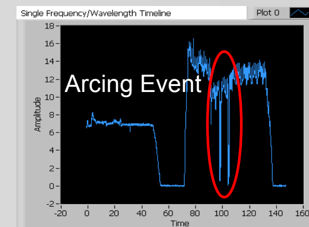
- Chamber Matching



- Fault Detection



- Arc Detection



Lexas Research
Nanotechnology Solutions

Diagnostic & Continuous Modes Available

2008 Confidential

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

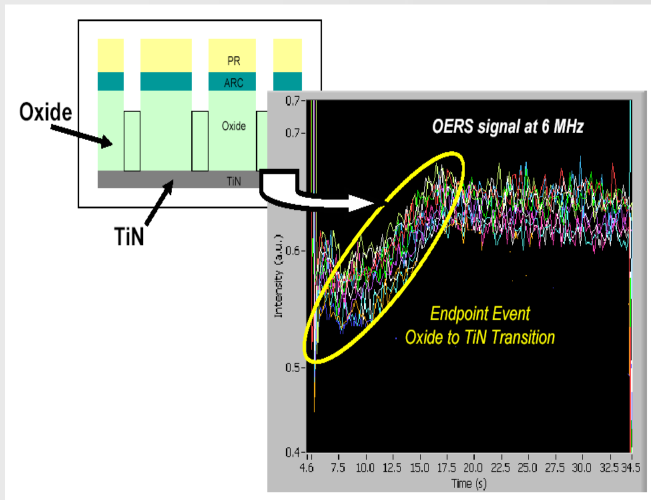
Endpoint Field Data
&
Process Chemistries

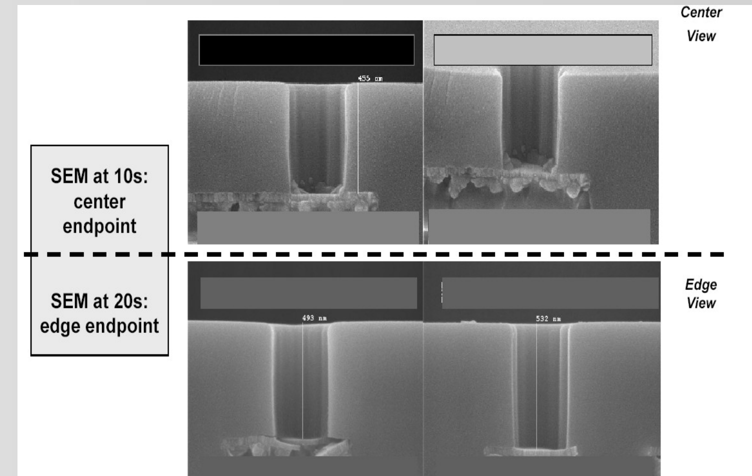
Lexas Research
Nanotechnology Solutions

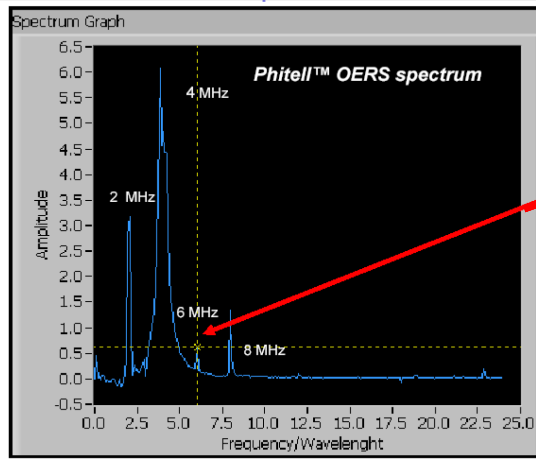
This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Oxide to TiN Endpoint LOA (<0.5%)







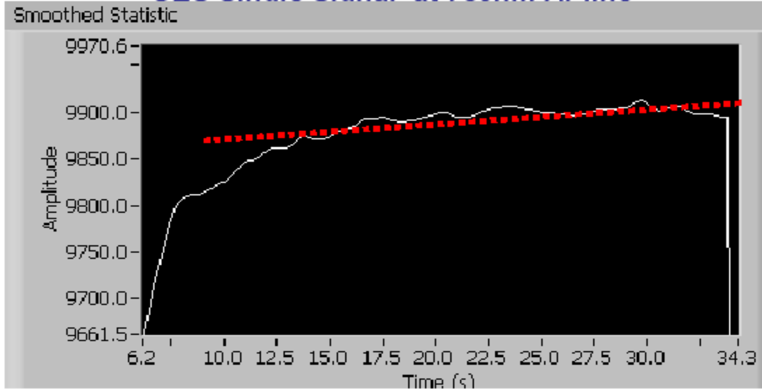
- Harmonic used reliably for endpoint
- Not visible with OES

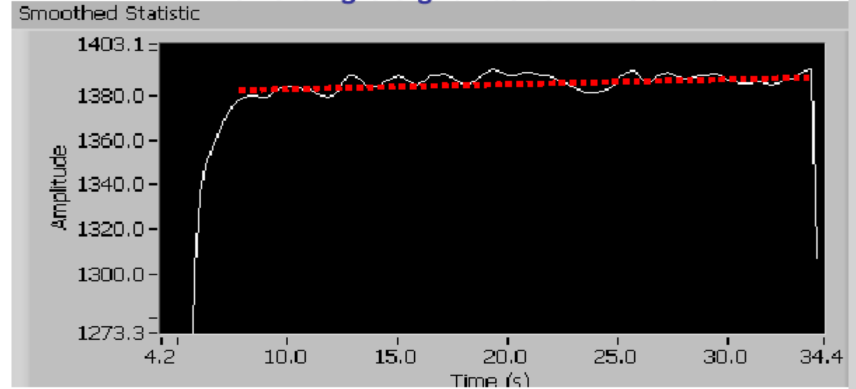
Lexas Research
Nanotechnology Solutions

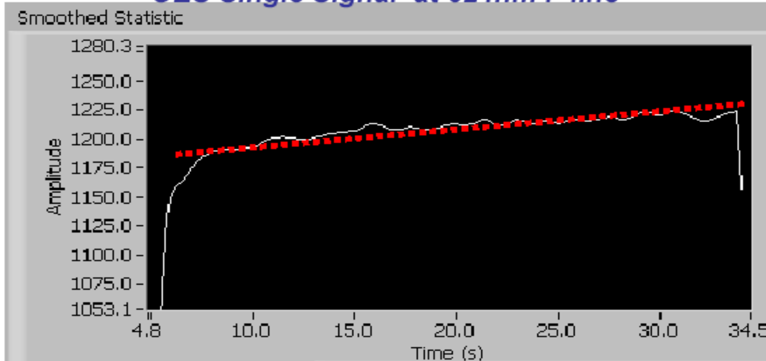
This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

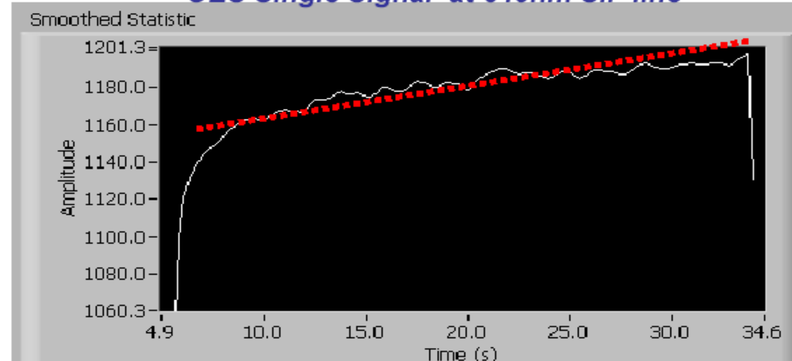
© 2006 Lexas Research

OES Response for Previous Process









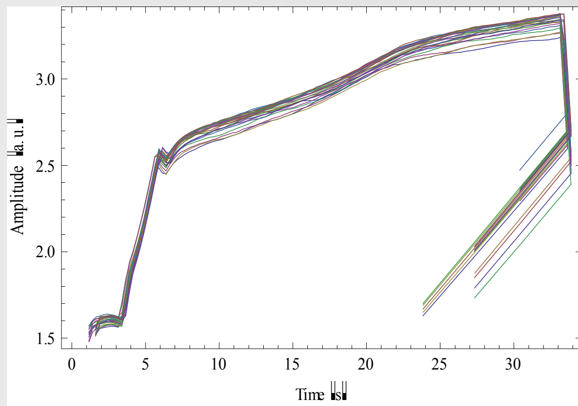
OES signals for AR, CO, F and SiF lines contain no endpoint

Lexas Research
Nanotechnology Solutions

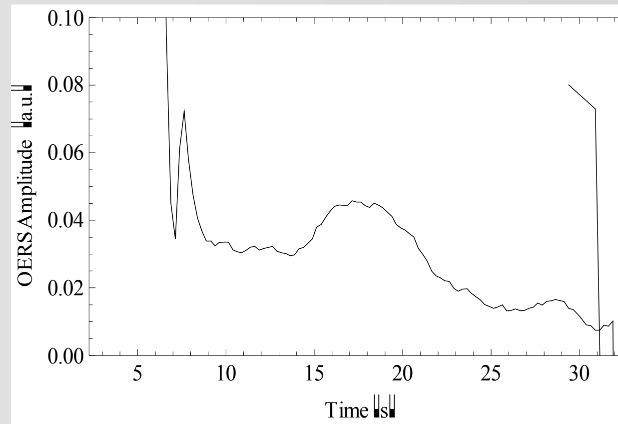
This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

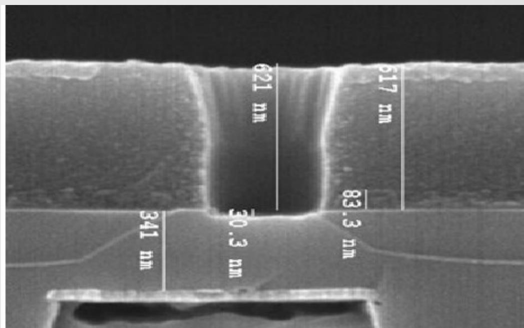
ARC to Oxide Transition



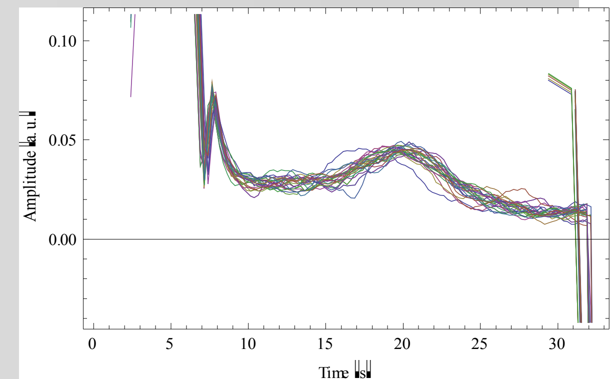
First Harmonic Signal



First Derivative



Confirmed with SEM



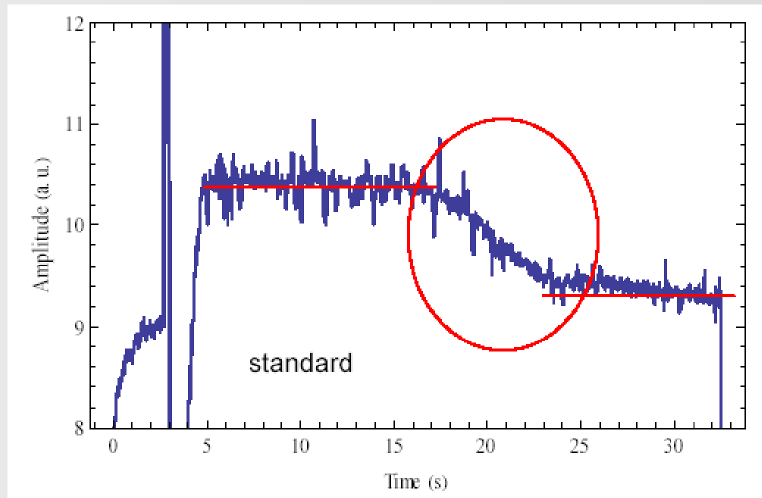
Repeatability

Lexas Research
Nanotechnology Solutions

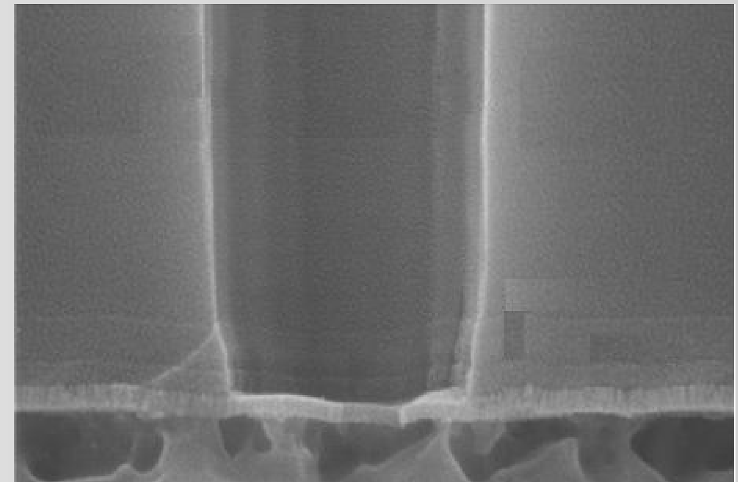
2008 Confidential This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent. © 2006 Lexas Research

Fab Data: Si_3N_4 to TiN Etch Process LOA (<1%)

Recipes	Step	RF_Up	RF_Lo	AR	O2	CHF3	CF4	CO2	O2	C4F8	CO
RECIPES D	Stand alone tool										
6SF_MIM_V3	step I	1000	2000	300		30		85		9	
	step II	600	1800	430			4			2	220
	step III	600	300	450		20	18		10		



First Harmonic Signal

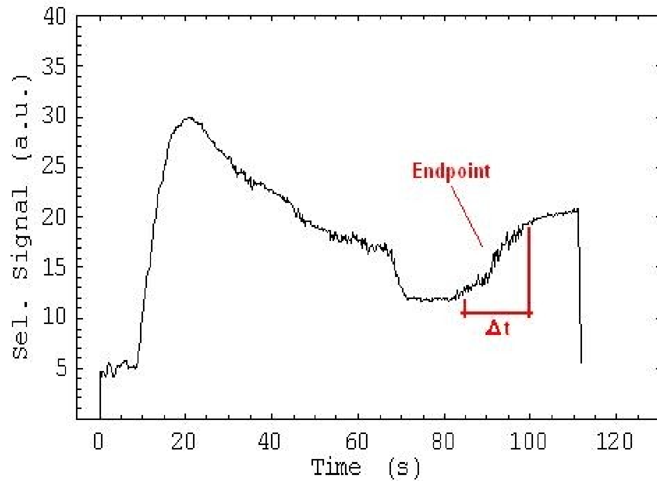


SEM Confirmation

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Fab Data: PolySi Etch Process (OA < 5%)



13MHz CCP Fab Tool

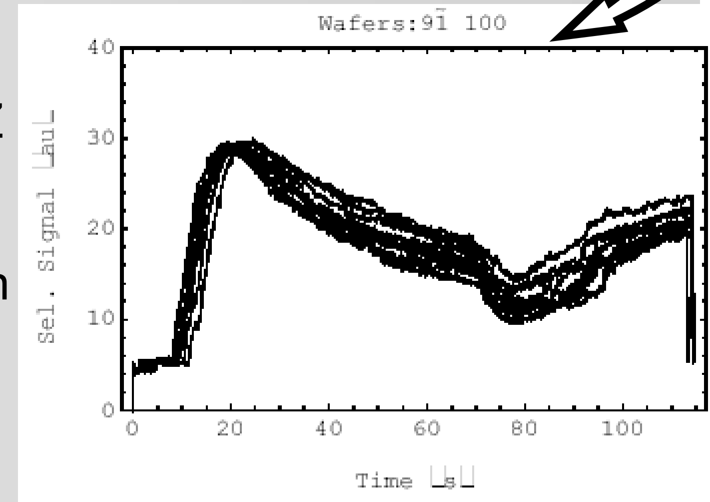
Chemistry : Cl2, HBr, C2F6, O2 and He
No Ar on these.

Main issue was process repeatability

Source of variation – polymer build-up changes Z

Phitell™ used to distinguish between electrical and chemical contributors and to validate solution

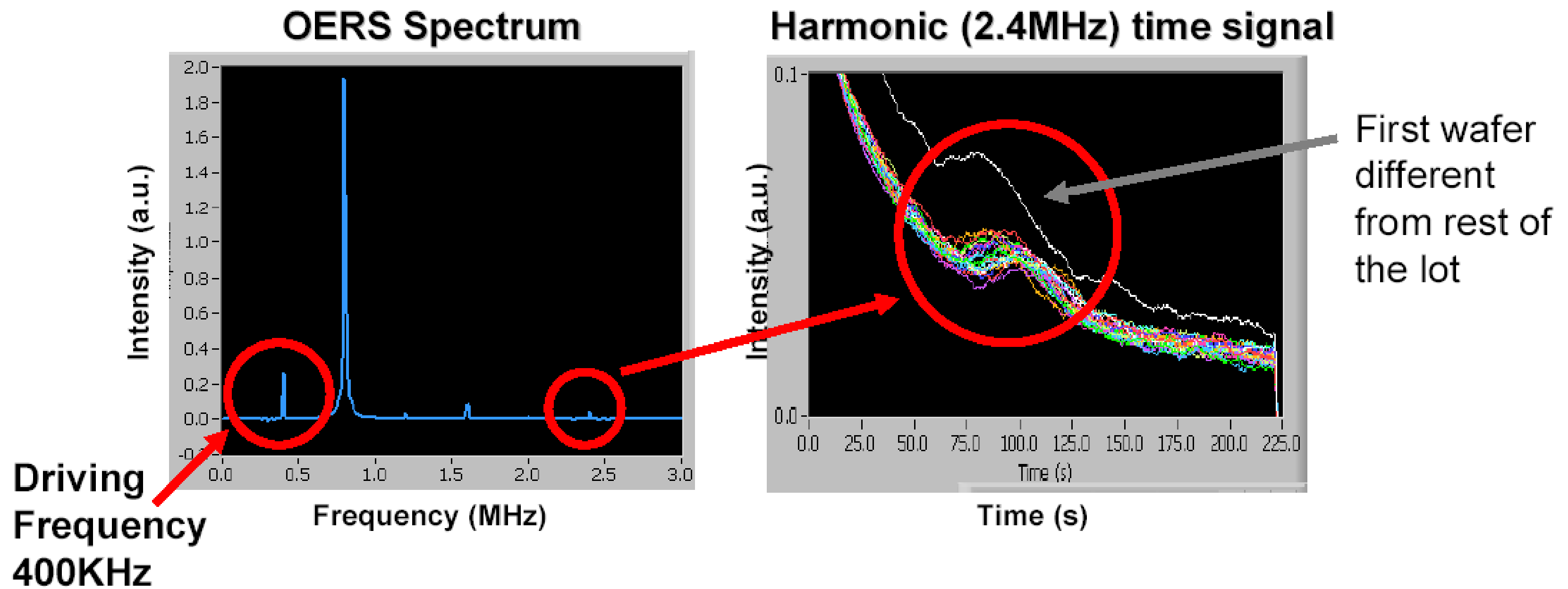
This work is ongoing with exciting potential



This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Fab Data: Oxide Etch Process LOA (<0.5%)

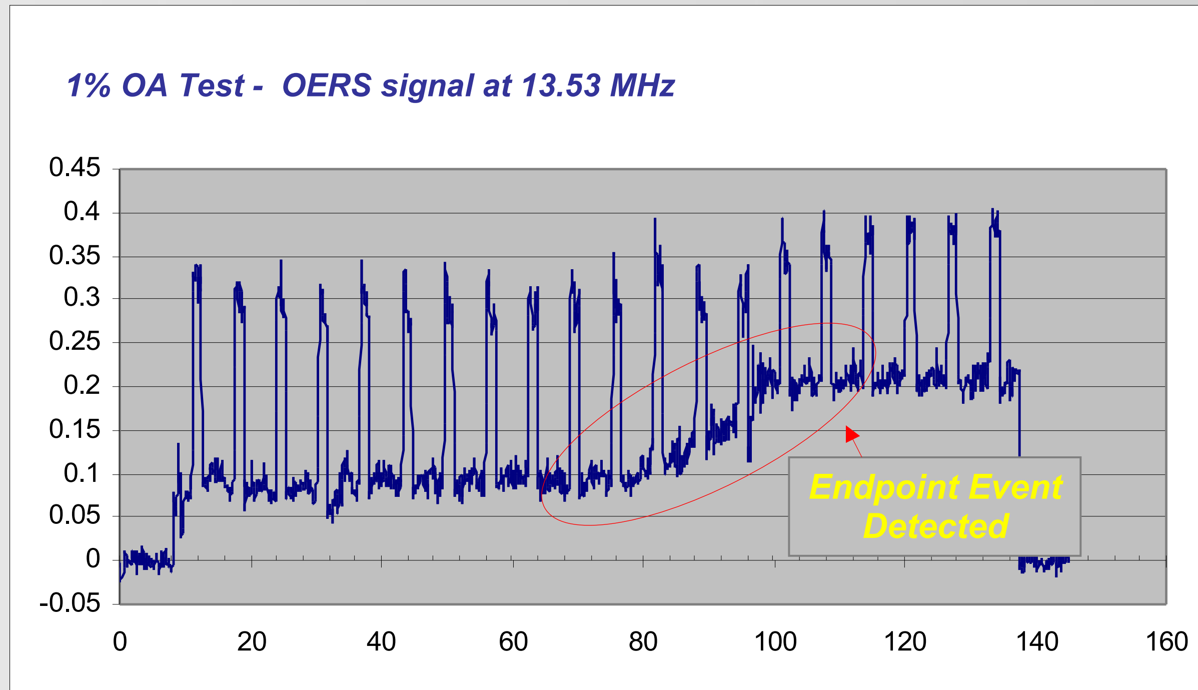


Oxide Etch Low Open Area (<0.5%) endpoint signature detected on harmonic signal at 2.4MHz. Consistent endpoint signature on 25 wafers.

Lexas Research
Nanotechnology Solutions

2008 Confidential This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent. © 2006 Lexas Research

Endpoint Detection Bosch Process – Deep Silicon etch



Note: Current OES Technology was unable to detect Endpoints with this Bosch Process

Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Chamber Matching

Field Data

Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Chamber Matching Methodology

(Define) Identify Sources Of Variation	(Measure) Process of Elimination	(Analyze) Identification
Chamber Walls	Reduce Complexity Ar only plasma Clean walls Virgin Wafer	Visualisation & Data Management
Power Delivery	Response Testing Linearity (P, W, Flo) Hysteresis Wafer	Statistical Rigor
Process Chemistry	Establish Baseline	Practical & Accessible
	Increase Complexity Add reactive gases Active pressure control	

Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Chamber Matching Customer Example

- Intermittent process yield problem (gate oxide damage)
- State of the art HVM fab
- Yield issue confined to a specific chamber
- Customer unable to identify source of variation (OES sensor was installed!)
- Rigorous problem solving methodology and Phitell™ sensor employed

Lexas Research
Nanotechnology Solutions

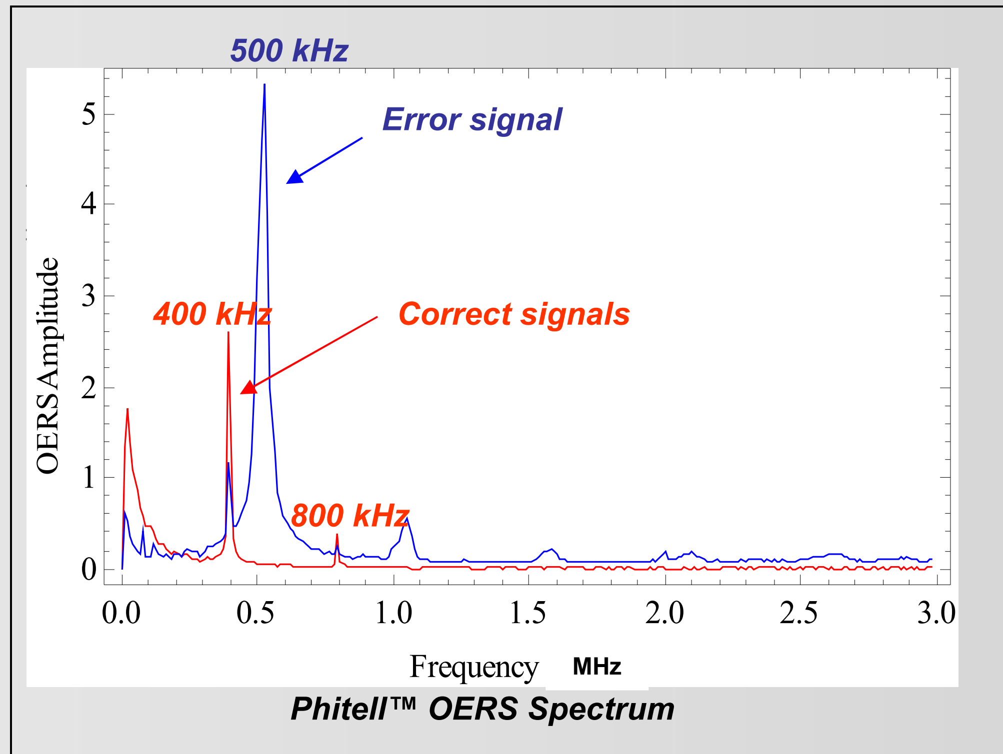
This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.
© 2006 Lexas Research

Chamber Matching – Fault Detection

RF Frequency variation across chambers

— Chamber 1
— Chamber 2

Poly etch process



Phitell™ OERS Spectrum

Frequency Signatures differentiate between good and faulty wafers. Frequencies overlap resulting in signal change.

Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

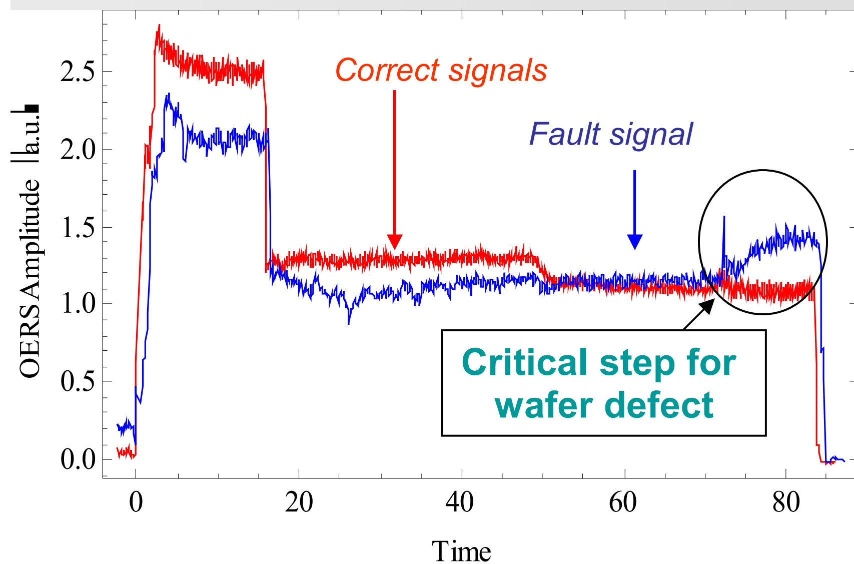
Chamber Matching – Fault Detection

Difference between chambers

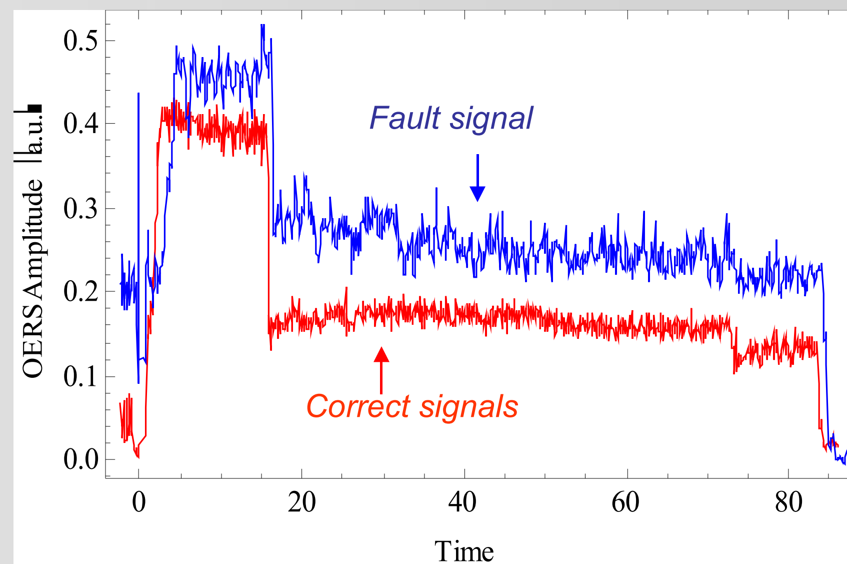
Poly etch process – blank wafers - 400kHz & 800kHz

— Chamber 1
— Chamber 2

Phitell™ OERS signals 400kHz



Phitell™ OERS signals 1st harmonic @ 800kHz



Variation at 75 seconds of Etch Process detected for chamber with frequency shift fault

Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

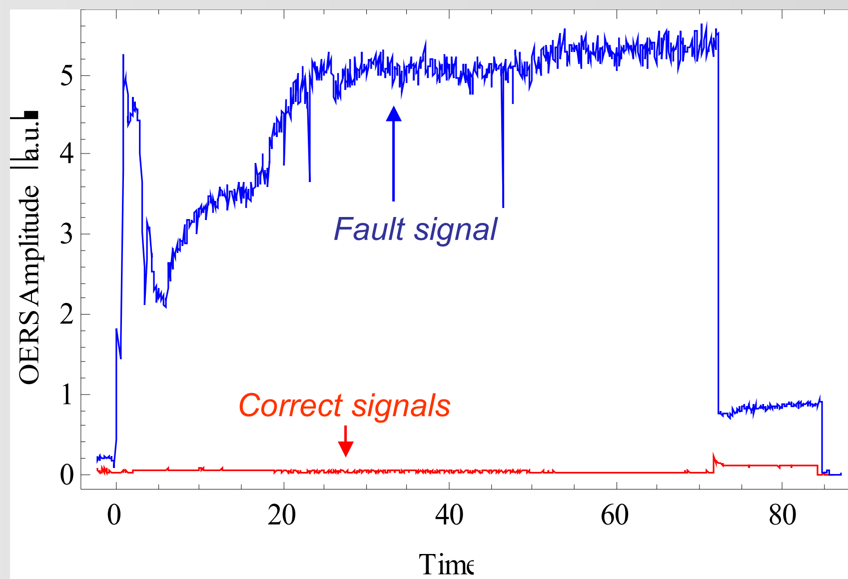
Chamber Matching – Fault Detection

Difference between chambers

Poly etch process – blank wafers - 500kHz

— Chamber 1
— Chamber 2

Phitell™ OERS signals at 504kHz



— Chamber 1
— Chamber 2

Correct signals

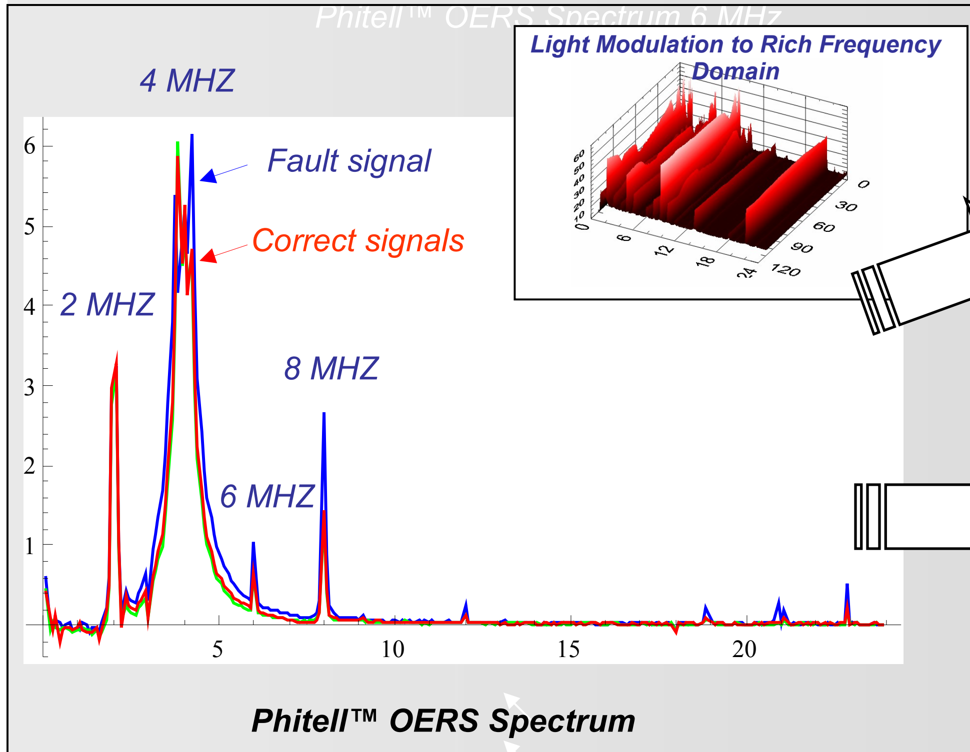
New frequency appears at 500 kHz only for faulty wafer

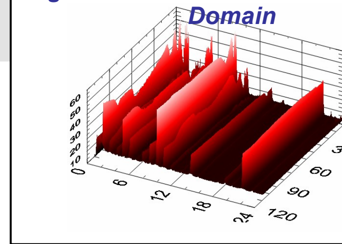
Lexas Research
Nanotechnology Solutions

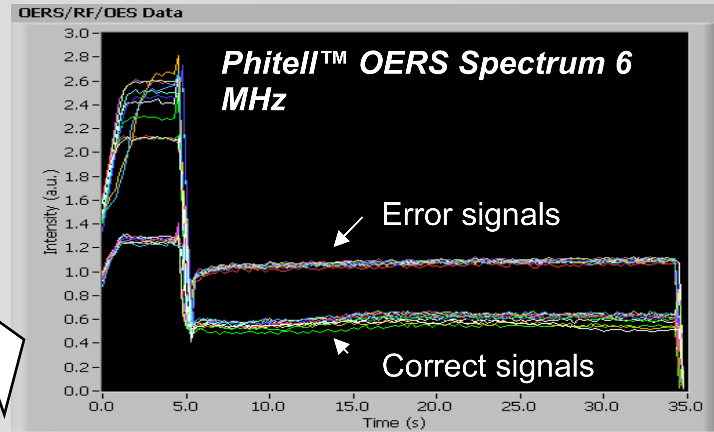
This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

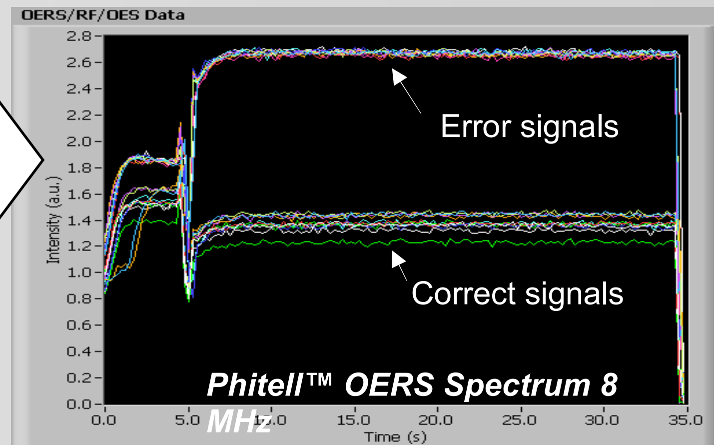
© 2006 Lexas Research

Fault Detection –Special Cause Variation









Incorrect recipe programming .. Phitell™ Detects Immediately faulty wafer production

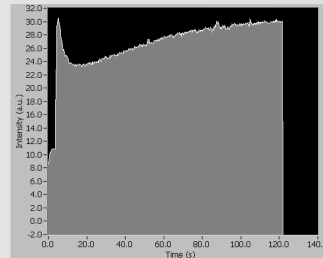
Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

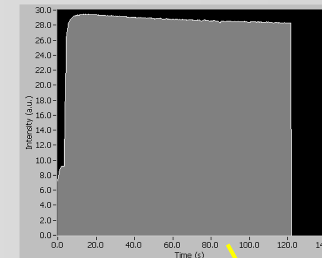
© 2006 Lexas Research

Wet Clean / 1st Wafer Effects / Repeatability

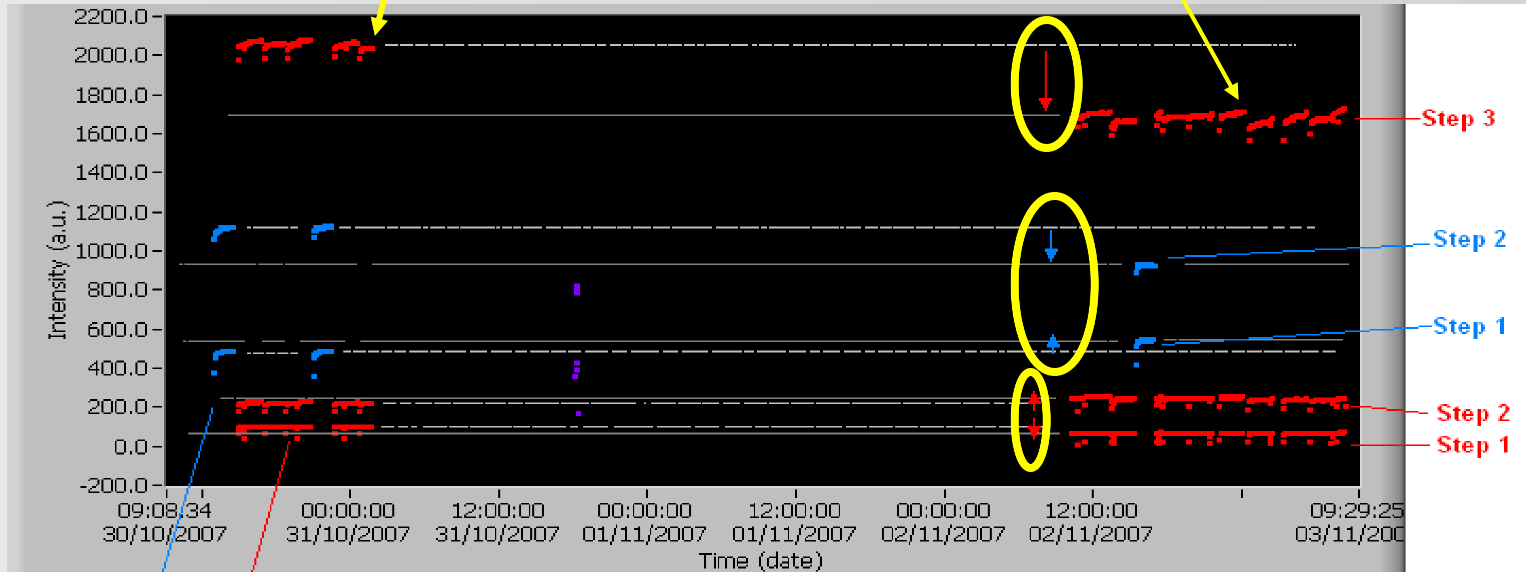
Pre Wet Clean



Area under curve per Wafer plotted before and after wet clean



Post Wet Clean



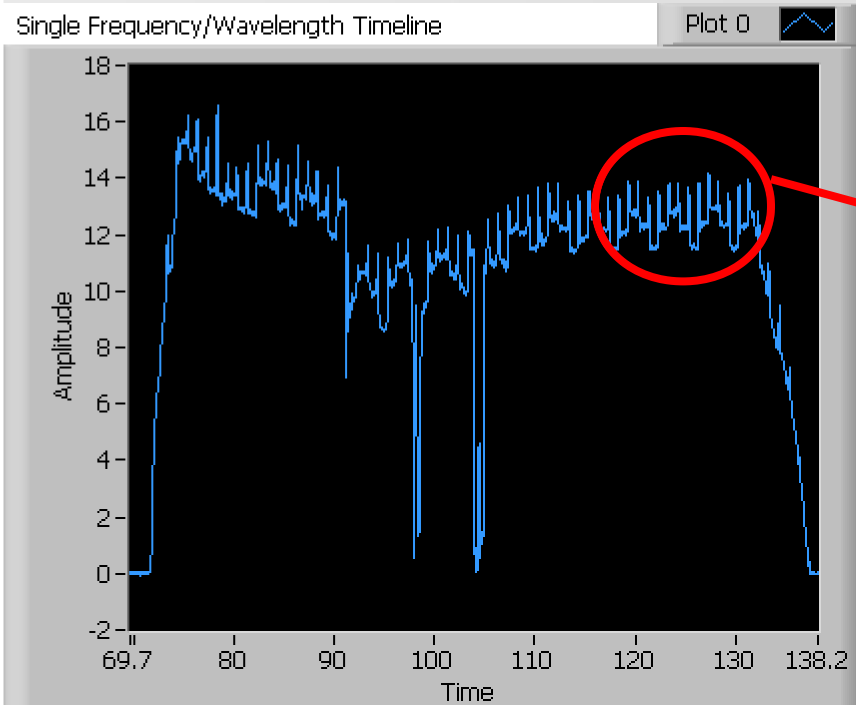
Process Changes, Repeatability & First Wafer Effects Clearly Demonstrated

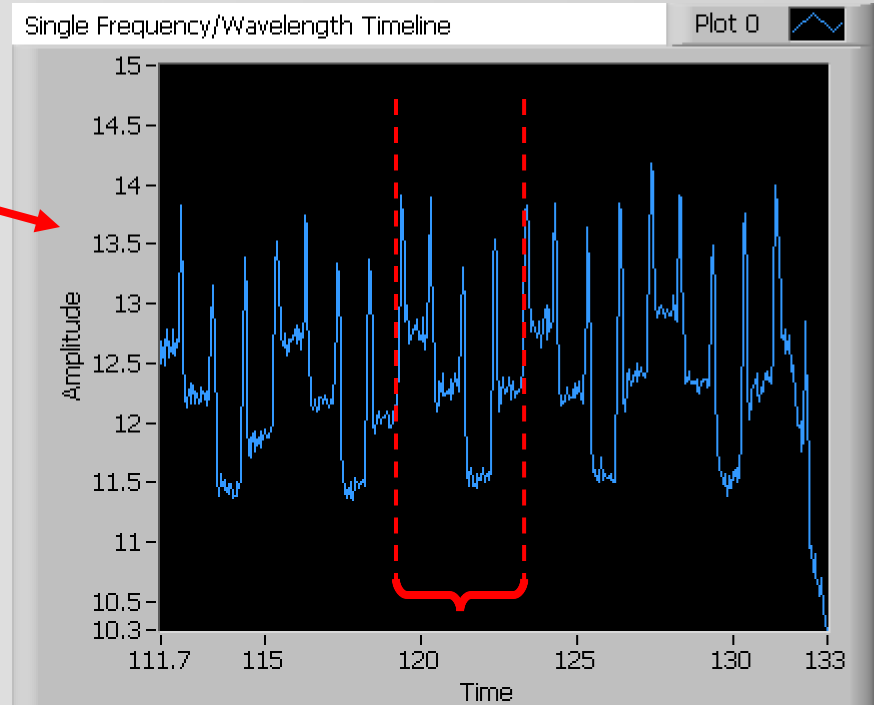
Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Phitell™ Rotating Magnetic Field





Time signal at 8MHz from OERS spectrum

Rotating Magnetic Field cycle (indicated above) variation captured

Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Phitell+Z™

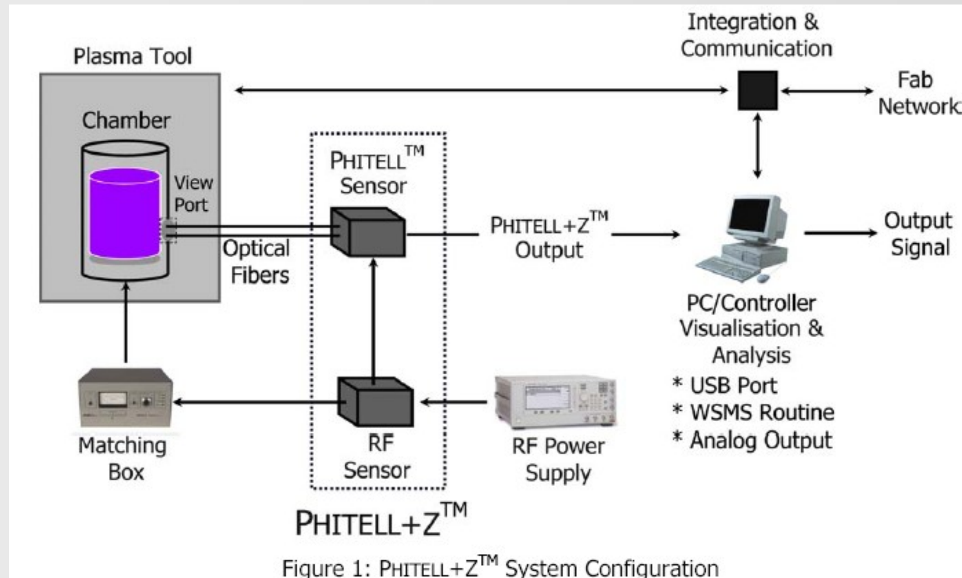


Figure 1: PHITELL+Z™ System Configuration

Employs Electrical Sensor
With Optional Combination With Optical Sensor
Accompanying Visualisation and Analysis Software

Primary Application Area – Arc Detection

Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research

Q & A

?

Lexas Research
Nanotechnology Solutions

This document contains information proprietary and confidential to Lexas Research Ltd. This information may not be used, reproduced, or disclosed without prior consent.

© 2006 Lexas Research