Advanced Research Sensor and Controls Project Review Meeting
DOE NETL
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DISTRIBUTED FIBER OPTIC SENSOR FOR ON-LINE MONITORING OF COAL GASIFIER REFRACTORY HEALTH

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Outline

- Motivation, Overview & Objectives
- Background and Fundamentals of Proposed Technology
- Project Scope and Work Plan
- Project Progress

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MOTIVATION AND OBJECTIVES

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Motivation

- Refractory health monitoring in slagging coal gasifiers:
  - Rapid corrosion of refractory materials.
    - High-temperature reducing environment.
  - Difficult to predict remaining refractory life.
    - Localized thinning, spallation, cracking.
  - Expensive to shut down gasifier for repair.

Project Overview & Objectives

- Three-year project beginning 5/1/2011.
- Industrial collaborator Eastman Chemical Co. assists in developing technical requirements.
- Objectives:
  - Develop first-of-a-kind distributed high-temperature sensing platform.
  - Demonstrate potential for coal gasifier refractory health monitoring.
    - Potential operation at the back side of inner-most gasifier refractory wall.
    - Direct mapping of temperature profile.

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Impacts

- Current gasifier operation strategy:
  - Scheduled inspection & replacement of liners.
    - Conservatively short intervals – increased downtime
    - Difficult to predict wear rate.
  - Re-bricking takes up to 3 weeks and $1-2M.

- New technology will enable:
  - Early detection & location of hot-spots.
  - Estimation of remaining lifetime.
  - Allow conditions-based maintenance model.
    - **Reduced downtime & cost savings.**

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BACKGROUND AND FUNDAMENTAL TECHNOLOGY

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Existing Gasifier Monitoring

- Indirect measurements for control systems:
  - Monitor syngas composition to optimize slurry & oxygen feed rates.
- Thermal imaging provides external health assessment:
  - Distributed temperature on outer shell.
  - Heavily insulated – only appropriate as a final safety measure.
- Direct single-point measurements:
  - Cannot monitor entire refractory .
- Distributed fiber optic sensing technologies developed to date generally work below 1000^{o}C.

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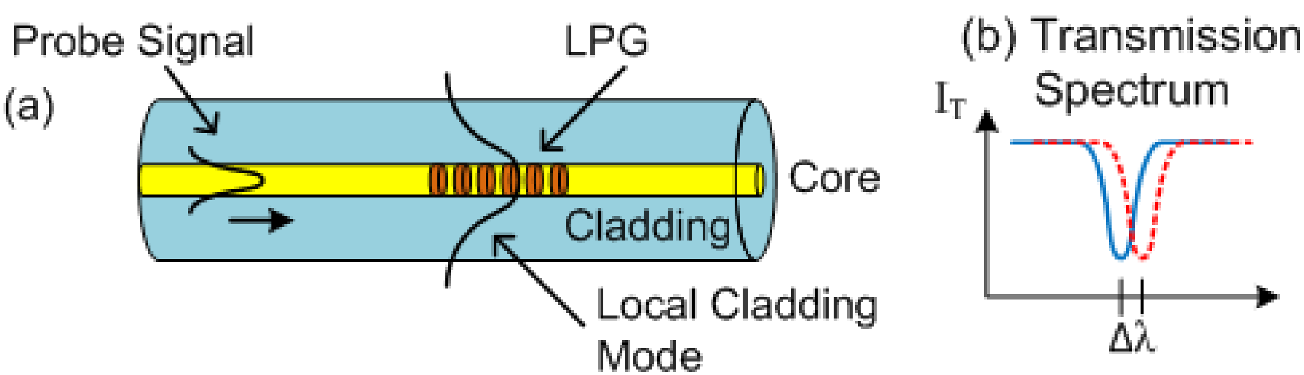
Technical Background: LPG

- Long-period gratings (LPG):
  - Periodic refractive index changes in fiber.
  - Couples confined light into cladding modes.
    - Spectrum shifts with temperature.
  - Traditionally fixed as single-point sensors.
    - Resolution better than 1°C.



↑ Traditional LPG: **a**. principle and **b**. spectrum

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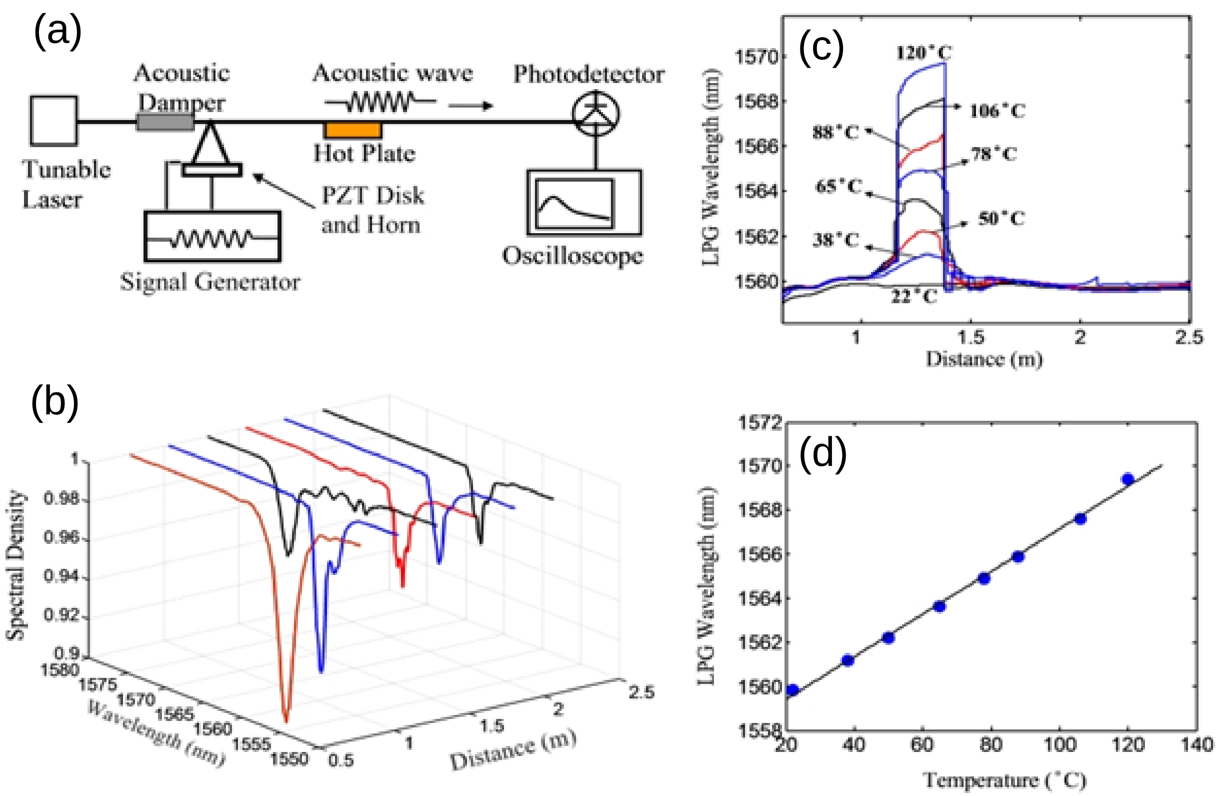
Proposed Approach: T-LPG (I)

- Traveling-LPG (T-LPG):
  - Preliminary results have used acoustic pulses to generate T-LPG for distributed sensing.



← (a) Experimental setup;
(b) Evolution of LPG spectrum
(c) Spatial temperature response
(d) Resonant wavelength vs. temperature

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Proposed Approach: T-LPG (II)

- Light-induced T-LPG:
  - Two light pulses (pump) are injected into the sensing link, counter propagating.
  - The beat note of the pump induces a transient LPG at a location predetermined by the delay between the pump pulses.
  - The signal light probes the T-LPG and translates the local temperature to a spectral shift.

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PROJECT SCOPE AND WORK PLAN

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Scope of Work

- Design & construct novel high-temperature distributed sensing system.
- Construct test environment to simulate gasifier refractory.
  - Based on input from Eastman.
  - Develop computational model to describe thermal signature of refractory breakdown.
- Lab test of sensor to verify:
  - Operation at over 1000^{o}C.
  - Performances meet the technical requirements.

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Tasks

1. Project management and planning
2. Determine sensor technical requirements
3. Sensor design and refractory performance modeling
4. Demonstrate the chosen mechanism
5. Develop distributed sensor prototype
6. Design and build test environment
7. Test sensor and evaluate performance
8. Prepare final report

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PROJECT PROGRESS

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Progress (I)

- Project management and planning (completed).
- Determine Technical Specifications.
  - Based on input from Eastman Chemical Co..

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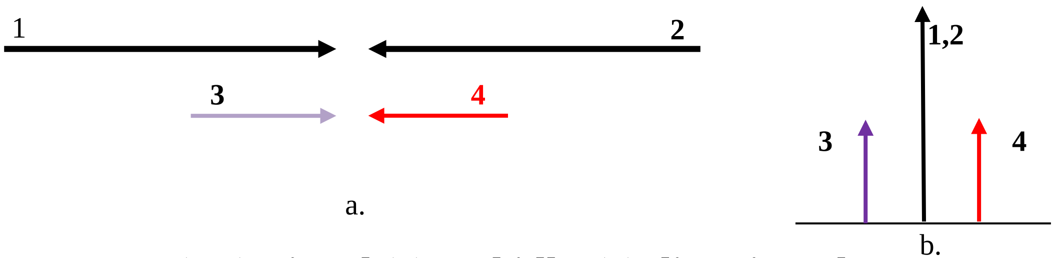
Progress (II)

- Theoretical analysis and system design:
  - A special four-wave-mixing (FWM) process:



a. Pump (1,2), signal (3) and idler(4) directions. b. Energy diagram.

  - The coupled-mode equation of the process:

$$\frac{dA_1}{dz} = i\gamma\left[\left(|A_1|^2 + 2\left(|A_2|^2 + |A_3|^2 + f_2|A_4|^2\right)\right)A_1 + 2f_1A_2^*A_3A_4e^{i\Delta\beta z}\right]$$

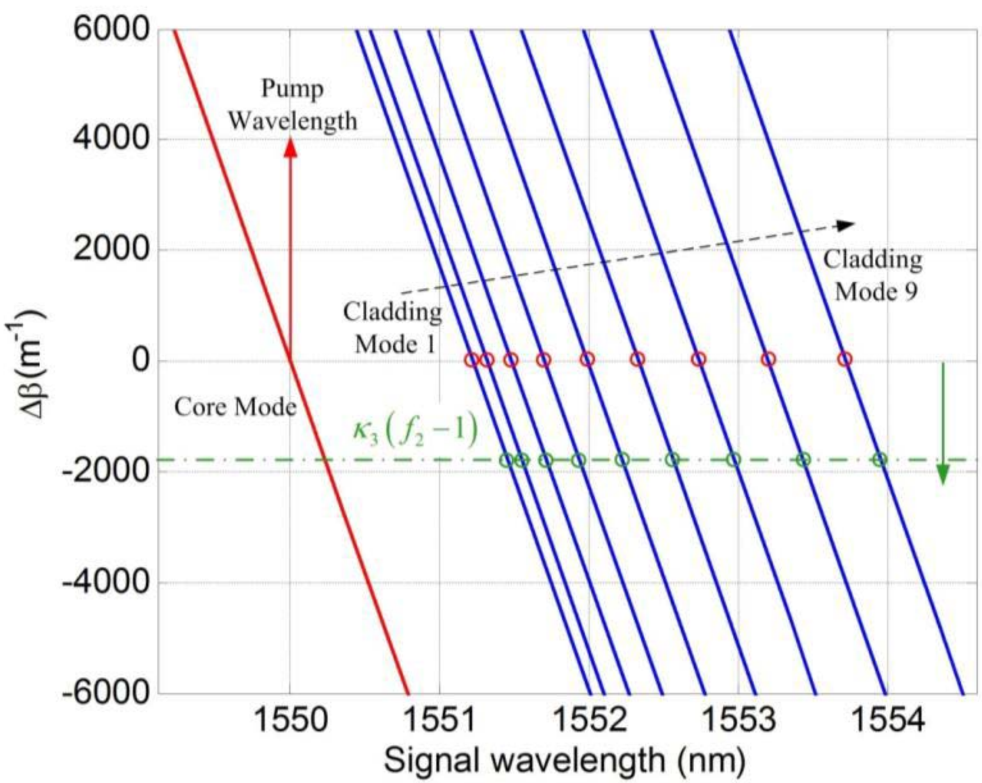
$$\frac{dA_2}{dz} = -i\gamma\left[\left(|A_2|^2 + 2\left(|A_1|^2 + |A_3|^2 + f_2|A_4|^2\right)\right)A_2 + 2f_1A_1^*A_3A_4e^{i\Delta\beta z}\right]$$

$$\frac{dA_3}{dz} = i\gamma\left[\left(|A_3|^2 + 2\left(|A_1|^2 + |A_2|^2 + f_2|A_4|^2\right)\right)A_3 + 2f_1A_1A_2A_4^*e^{-i\Delta\beta z}\right]$$

$$\frac{dA_4}{dz} = -i\gamma\left[\left(|A_4|^2 + 2f_2\left(|A_1|^2 + |A_2|^2 + |A_3|^2\right)\right)A_4 + 2f_1A_1A_2A_3^*e^{-i\Delta\beta z}\right]$$

Progress (II): *contd.*

- Theoretical analysis and system design:
  - A special four-wave-mixing (FWM) process:
    - Phase matching required $\omega_s n_s - \omega_i n_i = c\kappa_3 \left(f_2 - 1 \right)$



← Numerical result shows the possibility of achieving phase matching in standard fibers.

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Progress (III)

- Alternative single pump configuration.
- The scheme is based on a T-LPG induced by cross phase modulation (Kerr-effect).
- No phase matching requirement.

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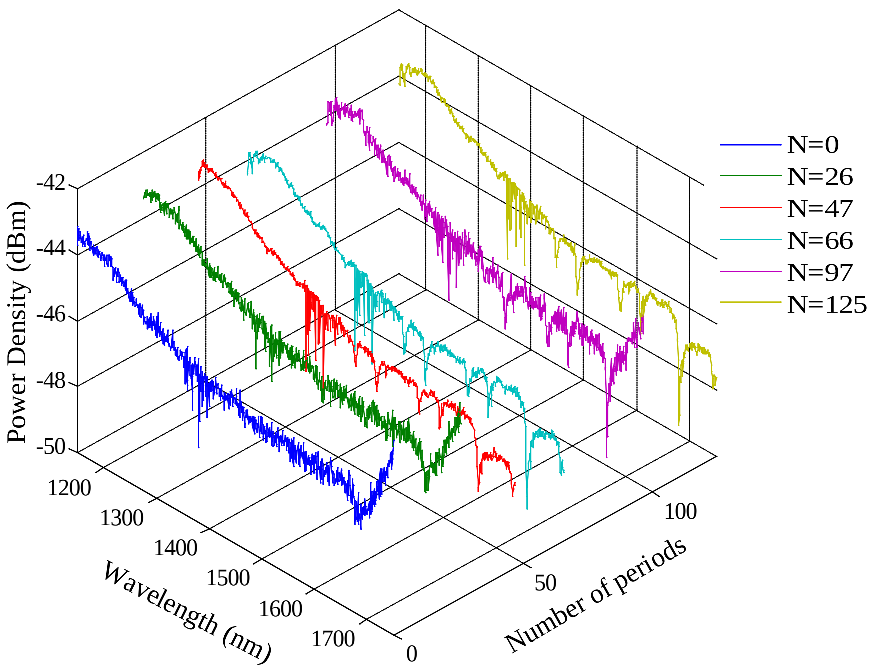
Progress (III)

- Theoretical analysis and system design:
  - Kerr-induced T-LPG by single pump modulation:
    - No phase matching requirement.
    - Preliminary experimental investigation with static gratings.



← Experimental results showing the spectral evolution of a static LPG (with a period of 3mm) with increasing number of periods.

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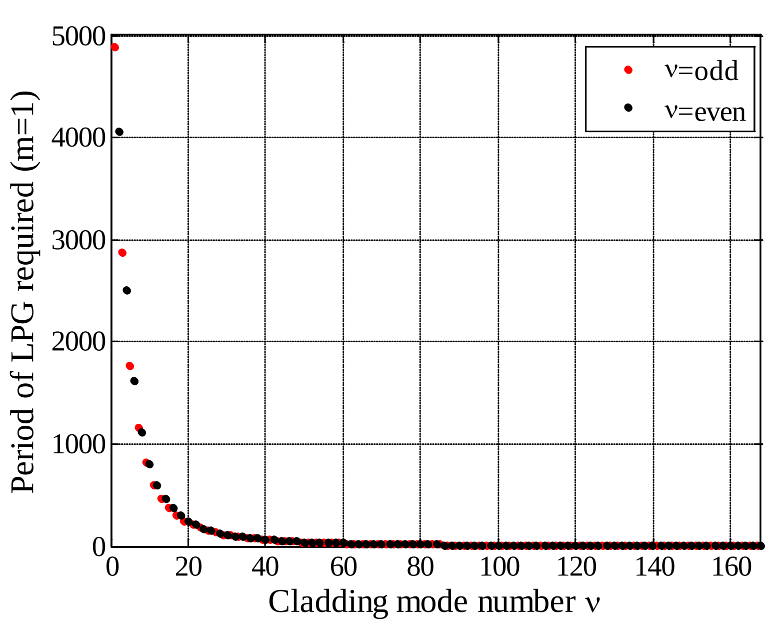
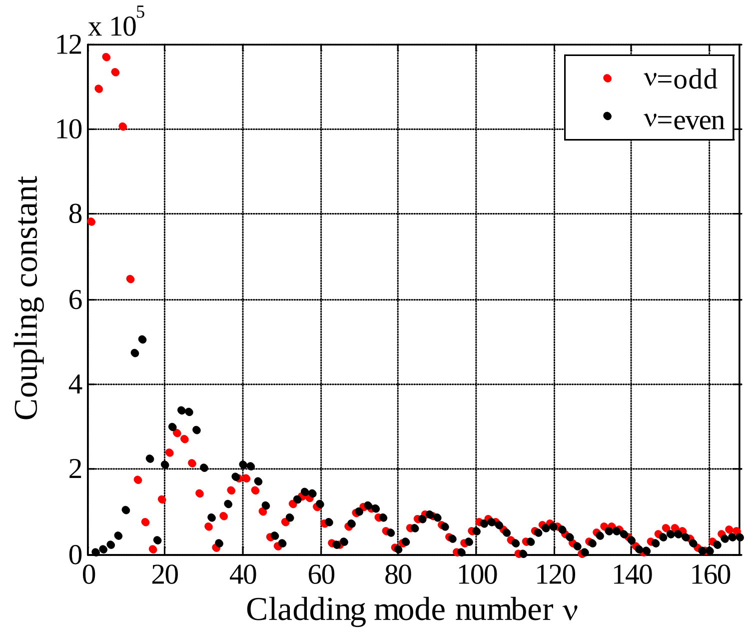
Progress (III): *contd.*

- Kerr-induced T-LPG by single pump modulation.
  - Theoretical study on the grating period and coupling efficiency.





↑ Analytical results showing the dependences of the grating period and the coupling constant on the corresponding cladding mode number.

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Progress (Summary)

Project Start Date: 5/1/2011
Project End Date: 4/30/2014

Task	Description	Budget Period 1						Budget Period 2						Start Date	End Date
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12		
1	Project Management & Planning													5/1/2011	9/30/2011
2	Determine Technical Specifications													5/1/2011	3/31/2012
3	Sensor Design & Refractory Model													10/1/2011	3/31/2014
3.1	Investigate various sensing mechanism													10/1/2011	9/30/2012
3.2	Develop sensor design													10/1/2011	9/30/2012
3.2	Develp refractory model													10/1/2011	9/30/2012
4	Demonstrate the Choson Mechanism													10/1/2011	12/31/2012
5	Develop Sensor Prototype													1/1/2013	9/30/2013
5.1	Construct prototype sensor													1/1/2013	6/30/2013
5.2	Calibrate & verify basic operation													4/1/2013	9/30/2013
6	Design & Build Test Environment													11/1/2012	12/31/2013
7	Test & Evaluate Sensor													10/1/2013	3/31/2014
8	Prepare Final Report													4/1/2014	4/30/2014
	Technical Progress Reports	Q	Q	Q	Q	Q	Q/T	Q	Q	Q	Q	Q	F		

Project Milestone — Umbrella Task — Budget Period
Linked Tasks: Application Info. — Task Continuation

Reports: Q - Quarterly A - Annual T - Topical F - Final

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