GRID MODERNIZATION INITIATIVE PEER REVIEW 1.4.4 ADVANCED SENSOR DEVELOPMENT

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Advanced Sensor Development
Project Summary

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Sensing and Measurement

Project Description:
Focus on key challenges previously identified in industry roadmaps and DOE programs that are critical to increased visibility throughout the energy system. The proposal is organized around three major segments: end-use, transmission and distribution (T&D), and grid components

Expected Impact:

Increased visibility throughout the future electric delivery system. Demonstrate approaches to data analysis

Objective

End-use: (1) develop low-cost sensors, exploiting additive manufacturing techniques, to monitor the building environment and electrical characteristics of HVAC equipment, and (2) develop algorithms to use building-level data to provide utility-scale visibility of grid reliability and localized weather monitoring.

T&D: extend the resolution of transmission grid visibility orders of magnitude higher than current technologies. Focus is on dynamic response and data resolution as well as innovative ways to estimate electrical parameters from optical transducers.

Asset Monitoring: sensing platforms with attributes for broad applicability across the grid asset monitoring application areas. Focus is on very low cost gas and current sensors for asset monitoring.

Advanced Sensor Development
Project Team

Project Participants and Roles

National Labs: ORNL, PNNL, LBNL, NREL, NETL, SNL
UTK: improve GridEye sensor algorithms
EPRI: demo advanced sensors for monitoring transformer bushings and arresters.
Genscape: develop dynamic line rating approach using wireless monitoring devices
Southern Co., TVA, ComEd: advisory role to ensure the research is aligned with utility needs
EPB: host site for demonstrating advanced sensor technologies
NI: provide hardware platform
SmartSenseCom Inc.: integrate the developed phasor estimation algorithms, GPS timing, and communication module

PROJECT FUNDING			
Lab	**FY16 $K**	**FY17 $K**	**FY18 $K**
ORNL	1,460	1,445	1,165
LBNL	145	145	150
NREL	145	145	150
SNL	250	250	250
NETL	150	150	150
PNNL	75	75	
Non-lab Team	650	550	
Total	**2,875**	**2,760**	**1,865**

Advanced Sensor Development
Relationship to Grid Modernization MYPP

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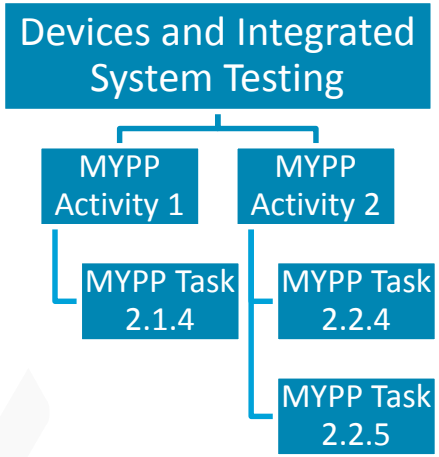
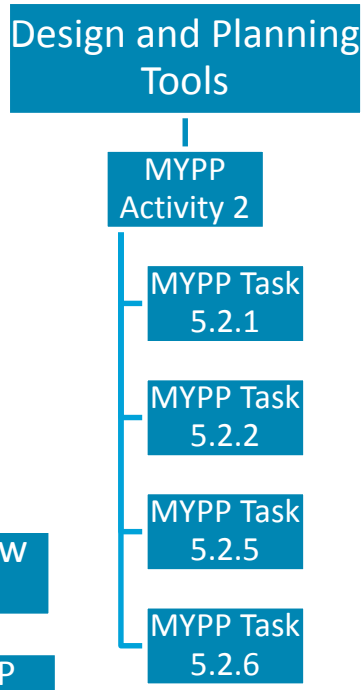
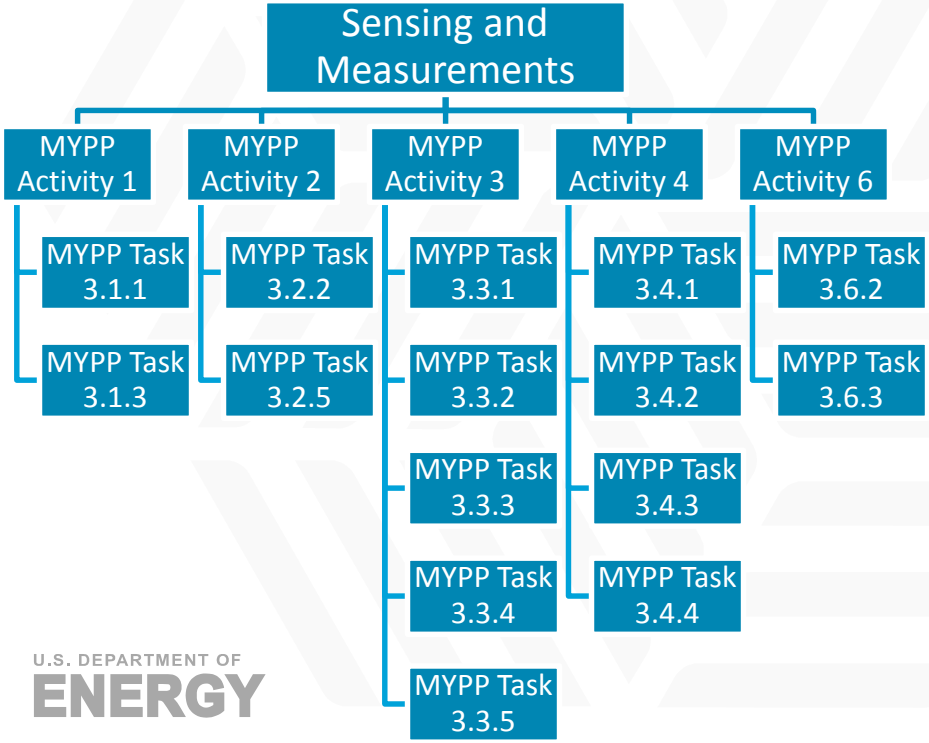
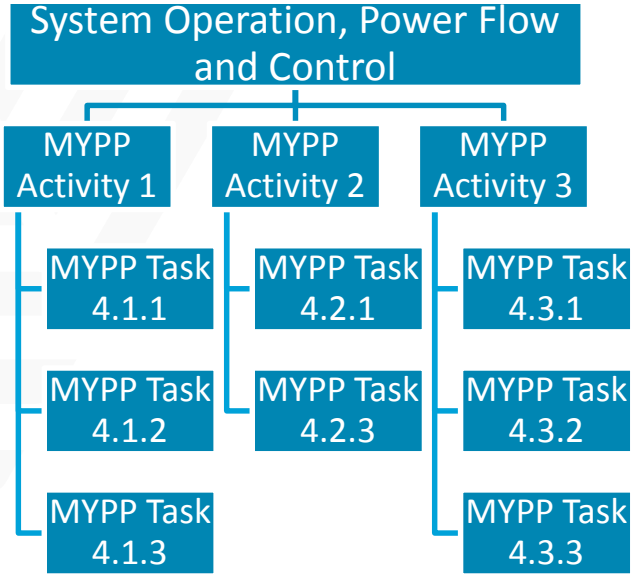
- Sensing & Measurement is a fundamental technical activity with linkages throughout the entire MYPP
- Limited activity in the DOE portfolio prior to the GMI and GMLC









U.S. DEPARTMENT OF ENERGY

Advanced Sensor Development – End Use
Project status

Milestone (FY16-FY18)	Status	Due Date
Draft requirements specification document. The requirements will be harmonized with sensing and measurement strategy developed in 1.2.5 through industry-specific requirements from workshop	Completed	11/30/2016
Draft specification of sensor development to measure airflow at an accuracy > 90% and current at >95% accuracy.	Complete	2/28/2017
Document describing an algorithm to identify power outages based on Internet disconnects. Demonstrate >90% recognition accuracy of power outages based on real streams of Internet communications from typical homes.	Identification algorithm completed	5/31/2017
Draft design document for physical and data-driven sensors incorporating functional and deployment requirements. The document will describe the sensor designs and accuracy taergets.	System integration	8/30/2017
Demonstrate sensors to meet the design targets described in requirement specification document. Evaluate in real building sites and data collected from buildings	Collecting data from field test in building sites	2/28/2018

Advanced Sensor Development – End Use
Project status

Milestone (FY16-FY18)	Status	Due Date
Develop Ultra-PMU Algorithms for transient capture in noisy conditions, including adaptive zero-cross algorithm and phase-locked loop algorithm.	complete	11/30/2016
Develop Optical CT/PT Integrated PMU Monitoring System: Tailor ORNL high-accuracy phasor and frequency measurement algorithms for optical CT/PT.	complete	11/30/2016
Develop Ultra-PMU Algorithms for Transient Capture: Experiment with adaptive window size for optimal performance. Ensure the algorithms be able to detect the transients in one cycle or less.	The performance of the Ultra-PMU algorithms are being tested under the power system transients	5/31/2017
Develop Optical CT/PT Integrated PMU monitoring System: Algorithm should achieve accuracy of 0.001 degrees for phase angle and 0.2 mHz for frequency which is the state-of-the-art accuracy of the commercial PMUs. Develop data pre-processing and signal conditioning functions. Design GPS synchronization scheme and interface. Design high precision timing functions and data flow functions	Conduct a test at SmartSenseCom and the results show good PMU accuracy from optical sensor data	5/31/2017

Advanced Sensor – Asset Monitoring
Project status (cont)

Milestone (FY16-FY18)	Status	Due Date
Demonstrate chemically treated 3D nanostructured sensing scaffold with characterized gas interactions. Gas concentration levels of 50 ppm (for CH4) and 500 ppm (for H2) will be used for the characterization for the proof of concept. (Abnormal concentration of CH4 is typically ~80ppm, H2 is ~1000ppm.)	Completed	5/31/2017
Develop CoFe electrodeposition process for integrated biasing magnets.	Completed	11/30/2016
Validation of repeatable electrodeposition process which is capable of providing repeatable material stack of required thickness (variable thickness range for detecting currents in the 1A - 1000A range , while current state-of-the-art solutions detect currents on the order of 10A).	Building testing platform for 1A - 1000A current detection	5/31/2017
Completed investigation of several different potential H2 sensing materials with some exploration of CO and CH4 sensitivity (to be reported in the annual report)	Investigating the potential of H2 sensing materials	11/30/2017

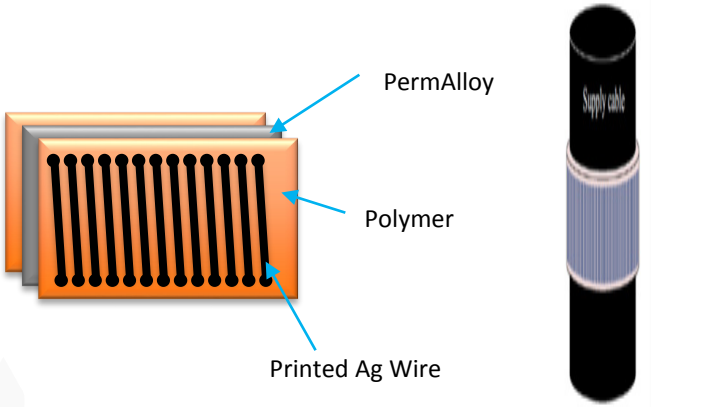
End-use Sensors
Physical Sensors

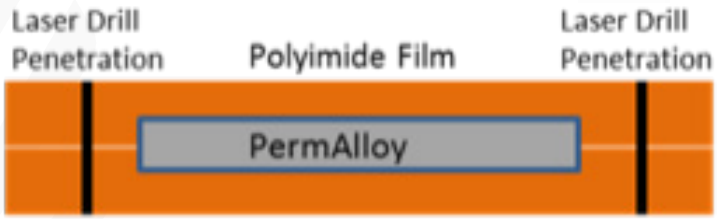
Background

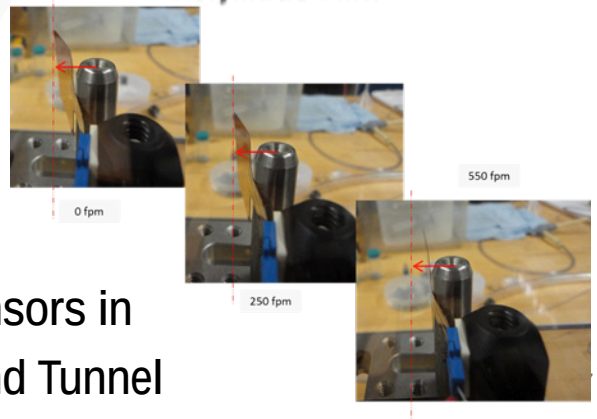
- Buildings consume 74% of electricity. Low-cost sensing that can observe end use state and improve energy efficiency are needed.
- Economical electric current measurements are necessary to enable building loads as grid resources facilitating high-resolution end-use state observability

Accomplishments

- During FY17, a current transformer approach was determined that is compatible with low cost manufacturing techniques.
- During FY16, a Piezo electric/resistive material-based thin- film sensor is developed with additive manufacturing to measure flow. Device enables fault detection and improve efficiency (20-30%)
- Platform technology for signal conditioning and communication aspects are currently underway for ubiquitous deployment
- Outcome:
  - A retrofit compatible thin film low-cost sensors for improving energy efficiency in forced air cooled/heated buildings and enabling sub-metered end-use observability
  - Three Invention Disclosures filed and one underway on flexible current clamp sensor







Sensors in Wind Tunnel

End-use Sensors
Virtual Sensors

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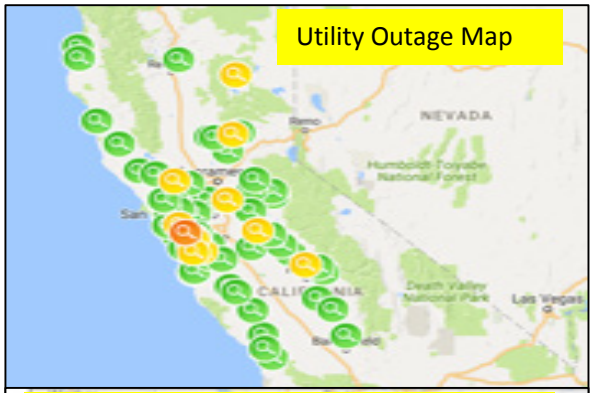
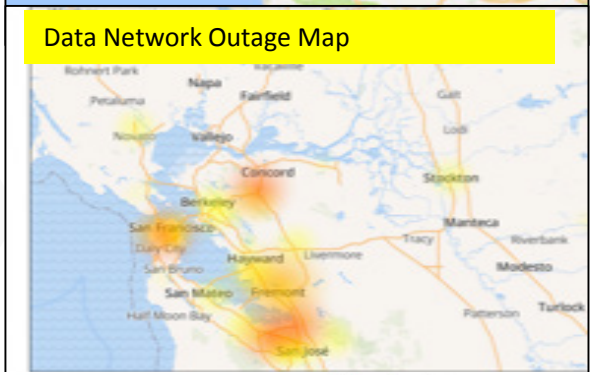
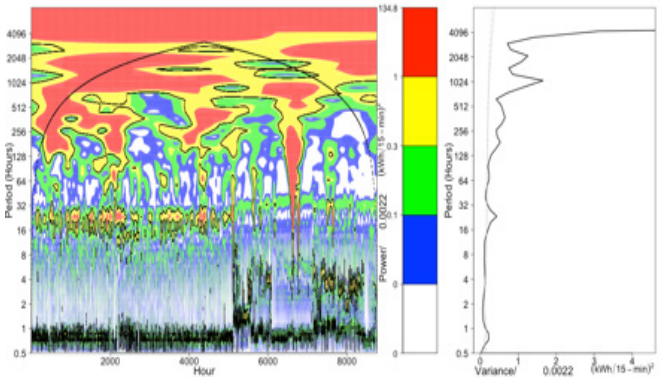
Data-driven sensor development

- Develop utility-scale power outage maps using data from internet-connected device data to enable utilities with regions affected by power outage in a timely fashion
- Technology – Collect status data from internet-connected devices to act as sensors for power outages.
- Partnership with Comcast NBC Universal to utilize Comcast internet-connected device information and obtain data sets
- Data analysis and processing algorithms were developed and are currently being tested.
- Utilize weather-correlated building load activity to facilitate utility-scale load shape estimation and demand forecasting
- Developed R-code for extracting and post processing 15-minute interval kWh data over 28-months for 101 homes in NEEA RBSA* data set, including whole building electric and ~25 submetered loads per house.
- Outcome
  - Developed data-driven outage map creation in partnership with a major network connectivity company. Established NDA and data agreement with Comcast NBC
  - Open-source package in R for residential-level load shape estimation and forecasting
  - One conference publication accepted and one journal publication in review for method to generate data-driven load shape
  - Partnership with University of Colorado and Elevate Energy, Chicago Illinois







T&D Sensors

Fast Algorithm Development

Objective: Improve dynamic responses to capture fast transients in the grids.

Methodology: Modified Phase-Lock Loop (MPLL) Algorithm

- No data window or filter
- Fast gradient descent method and variable step
- Recursive structure

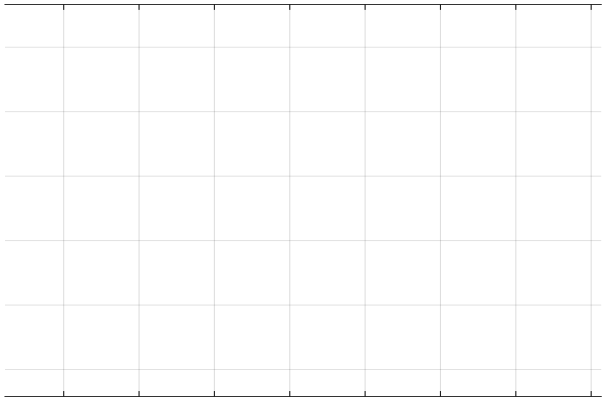


Fig. 1 Frequency ramp test

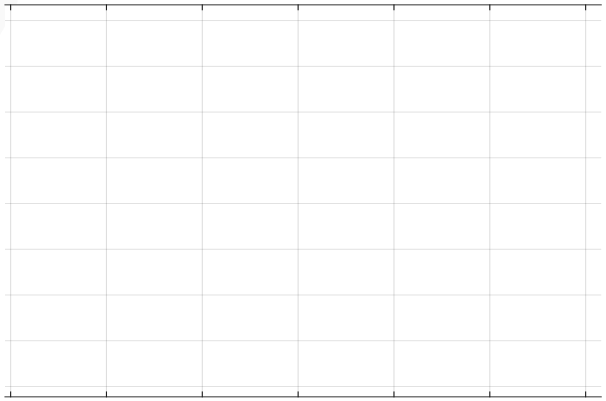


Fig. 2 Phase modulation test

T&D Sensors

Test setup and work completed

- PMU testing system has been built.
- Multiple ultra fast PMU algorithms for phasor estimations have been developed.
- Dynamic response tests including frequency step change and frequency ramp tests demonstrated the fast response capability of **one cycle** (compared to 6 cycles DFT based algorithms).
- Steady-state tests verified feasible steady state measurement accuracy.
- Response time of a commercial PMU has been tested to provide a benchmark for the proposed algorithms

T&D Sensors
Optical PMU

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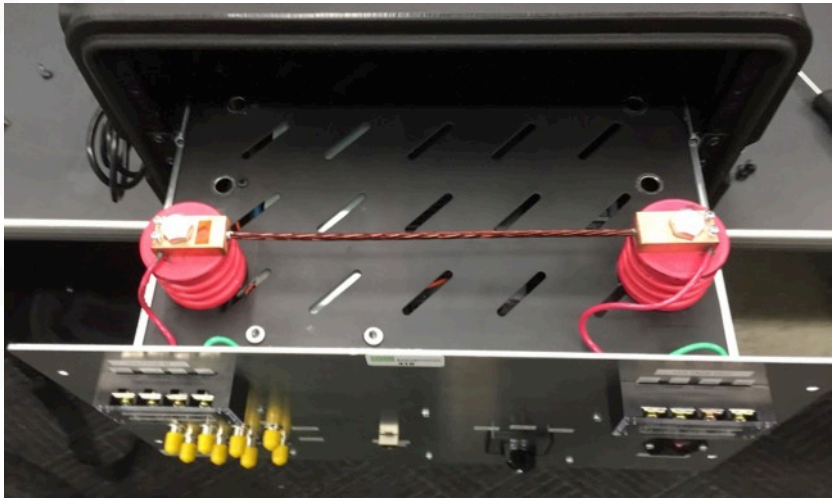
Objective:
To achieve better dynamic range, high linearity, and cost competitive measurement technology.

- Optical sensor test system designed and built for 110V-480V voltage and 0A-20A current measurements
- GPS-Synchronized measurement system set up for acquisition of analog output from optical sensor system
- Additional system designed and built for 24V operation
- Safety analysis of test unit performed
- Plan created for modification of test unit to meet ORNL safety standards



Asset Health Monitoring

Magneto-elastic Sensor (MagSense)

- A -first-of-its-kind electrochemically deposited (ECD) cobalt ion (CoFe) alloy with a high degree of magnetostriction was developed.

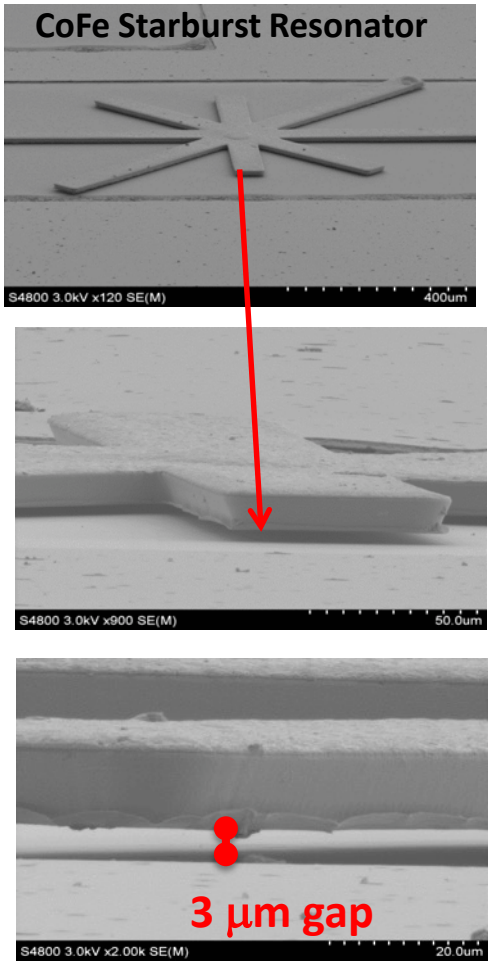
- Fine-tuning process parameters to result in higher magnetic sensitivity parameters (increase resistivity, lower coercivity, and increased magnetic softness).

Two patent applications:

- US Appl. 14/876,652 “Electrodeposition processes for magnetostrictive resonators”.
- Passive Magnetoelastic Smart Sensors For A Resilient Energy Infrastructure

- When commercialized, this sensor will drastically reduce the costs associated with sensors manufacturing and deployment

2.4 mm long freestanding resonator



Asset Health Monitoring
SAW sensor

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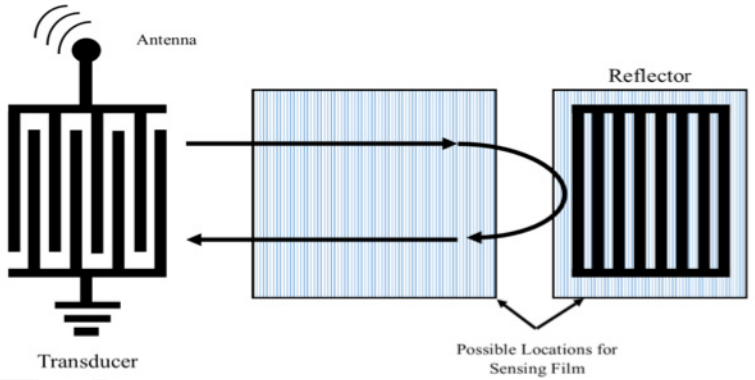
Sensing and Measurement

- Have developed high-surface area porous nanostructured silica and phase-separated metal-oxide films, coated with cryptophane-A, on QCM substrates for methane detection. Selectivity and sensitivity are promising.
- Hydrogen-sensitive chemical coating is used on nanostructured QCM surfaces for hydrogen detection.
- Successfully transferred the nanostructured coating technology on $LiNbO_3$ SAW devices for further characterization. Will pursue to achieve selectivity and sensitivity at the target levels.

- Patent disclosure is filed (DOE S-Number: S-138,412): *"Innovative three dimensional nanostructured thin film scaffolds for gas sensors"*
- When commercialized, our sensor platform will ***reduce the cost of online gas analysis of power transformer (incipient) failures by an order of magnitude***



Surface –Acoustic Wave (SAW) sensor

Asset Health Monitoring

Nano-Enabled Optical Fiber Sensor

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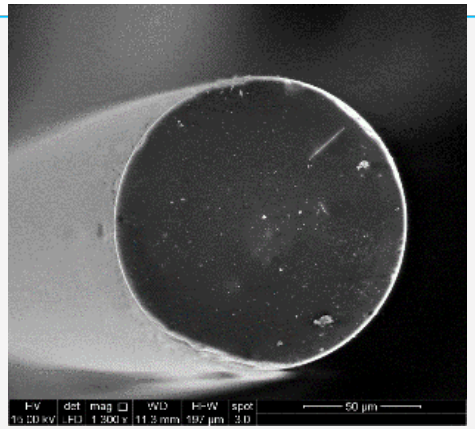
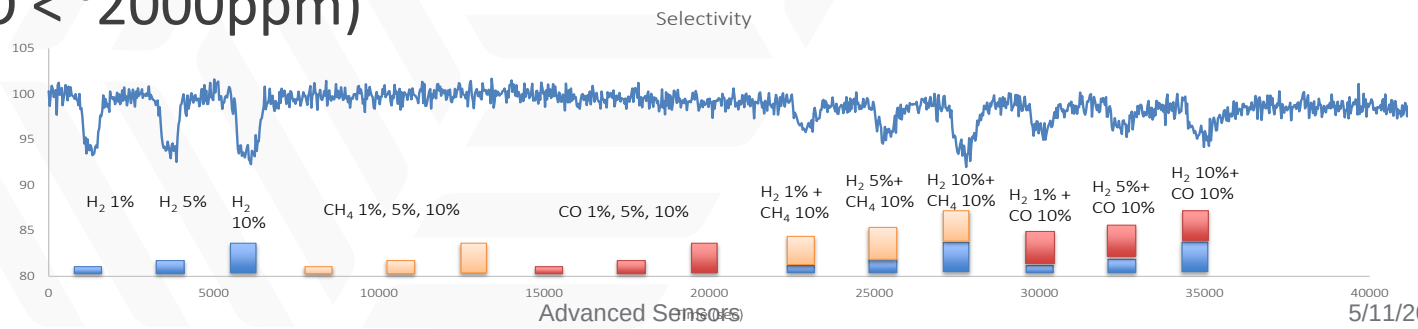
Sensing and Measurement

- Integrated nanomaterial with optical fiber platform for selective H_2 chemical sensing;
- Demonstrated real-time temperature monitoring for operational transformer core;
- Will pursue sensing materials to achieve improved selectivity and sensitivity at relevant levels (H_2, CH_4, CO <~2000ppm)





Advanced Sensor Development
Response to December 2016 Program Review

Recommendation	Response
Please make a strong case for why airflow sensors are important for grid modernization	**Detection of equipment malfunction, quick demonstration, 3D printing technology developed here has a broader applications.**
Please work with DOE program manager Charlton Clark and INL on any work in dynamic line rating to ensure there is no duplication of effort	**Followed up with DOE Wind Program Manager. No duplication since our focus is low-cost, wireless, current measurement technology**
Please be prepared to provide more detailed information on the "buildings as sensors" effort at the Peer Review in April	**Our approach is to use information at building level to project the sum at grid level**

Advanced Sensor Development
Relationship to other projects

Advanced Sensor Development project relates to other GMLC projects, in both Foundational and Program-Specific.

Program Specific Areas include:

- GM0072 Suite of Open-Source Applications and Models for Advanced Synchrophasor Analysis
- GM0073 HVDC and Load Modulation for Improved
- Dynamic Response Using Phasor Measurements
- GM0077 Advanced Machine Learning for Synchrophasor Technology