Development of

Advanced Massive Heterogeneous

Sensor Networks

THE Ames Laboratory
Creating Materials & Energy Solutions

Research Team

Ames Laboratory

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U of Maryland

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Power Plant Challenges

- Conflicting goals of reliable low cost energy and climate change mitigation
- Large investment in current infrastructure
- Little implementation of information technologies

Sensors ...

- will be “free”
- will be small (lick ‘n stick)
- will be smart
- will be ubiquitous

Low cost improvements in sensing for control and condition monitoring can result in big improvements in cost and carbon emissions

- “… develop the understandings, algorithms, and control strategies needed to utilize large-scale, high-density sensor networks in advanced power plants.”

- Develop techniques for the “… synchronization of heterogeneous sensors with widely varying capabilities using strategies based on self-organization.”

Efforts

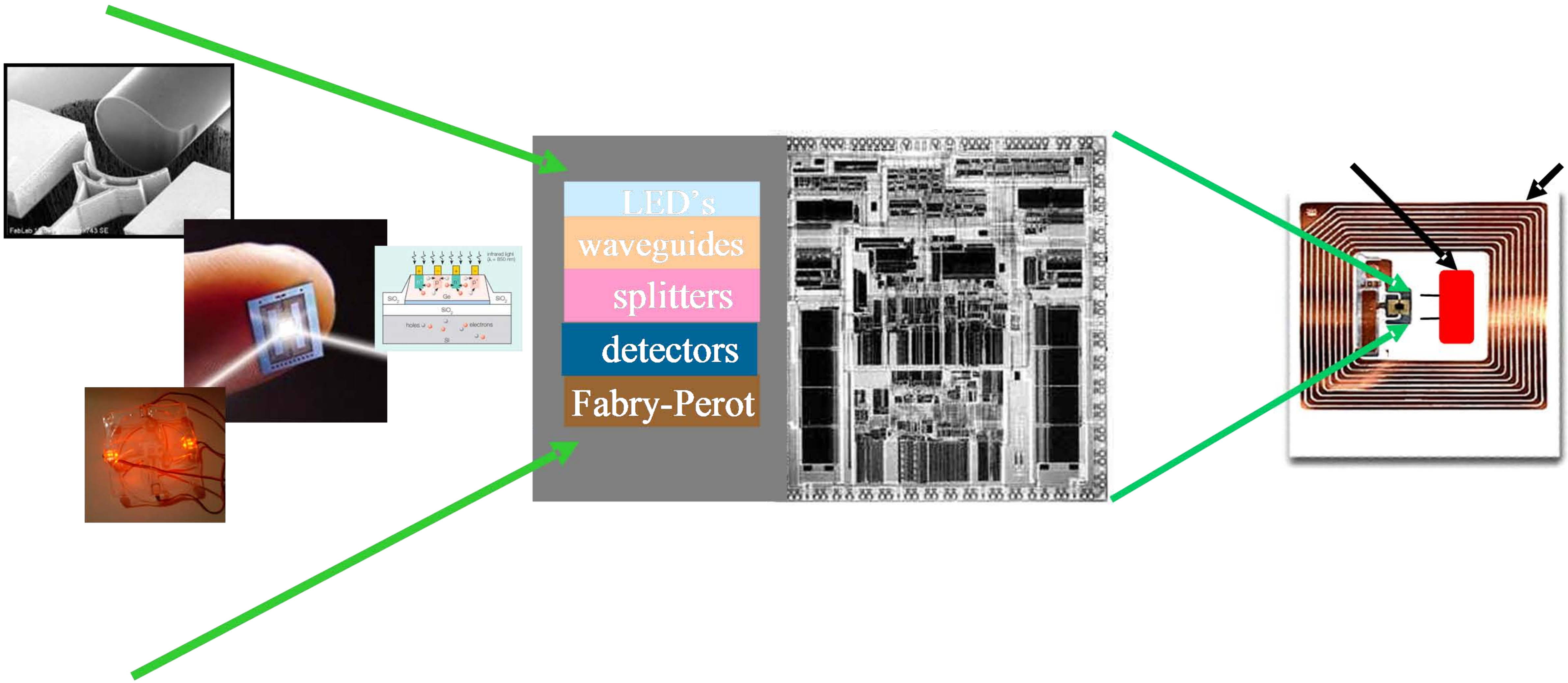
1. Develop smart fiber-based sensors
2. Demonstrate and understand how multiple sensors can improve combustion measurements
3. Develop stigmeric controls for process systems
4. Large scale demonstration of stigmeric controls

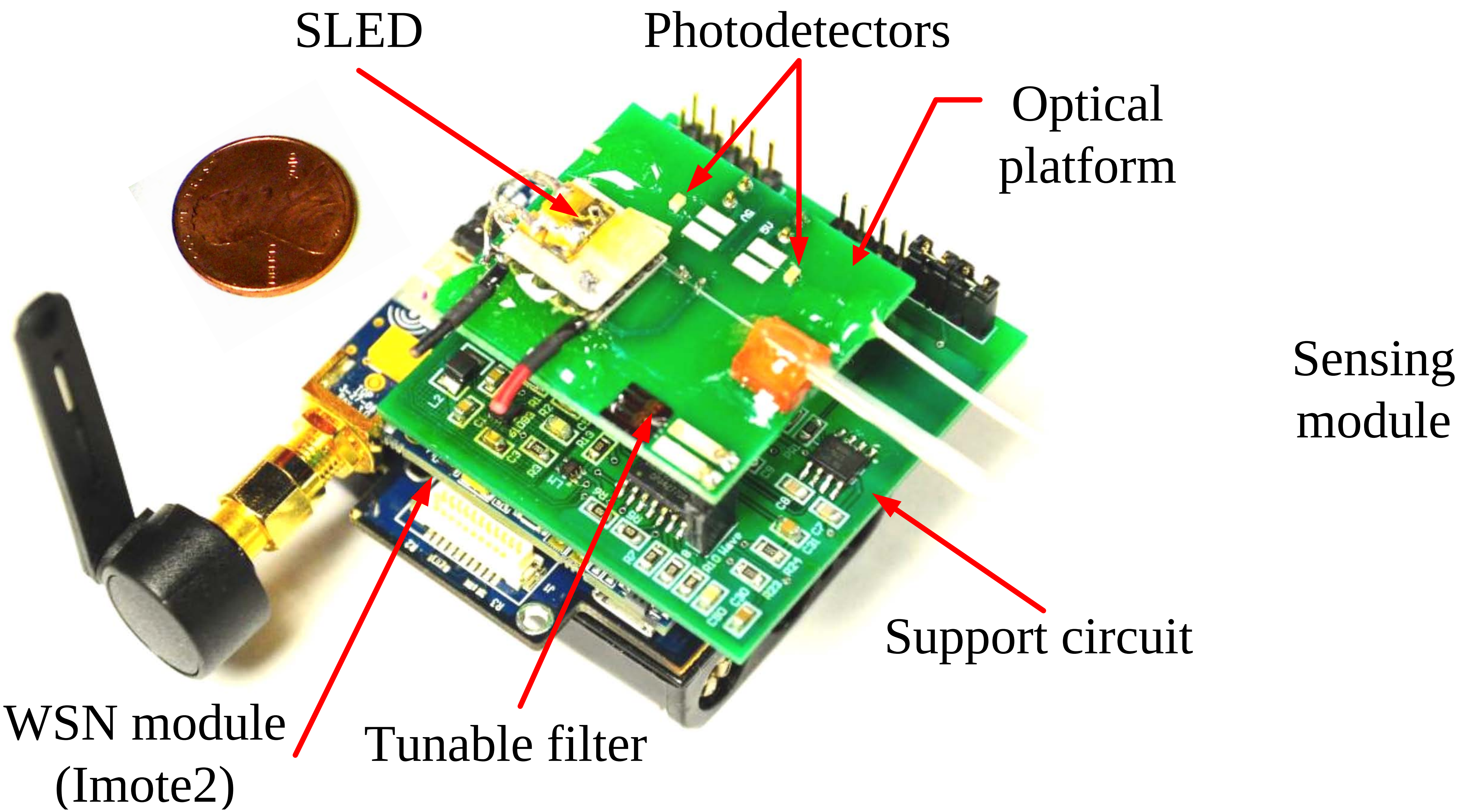
Smart Fiber-based Sensors

1. Optical Wireless Sensor Network (WSN) node developed

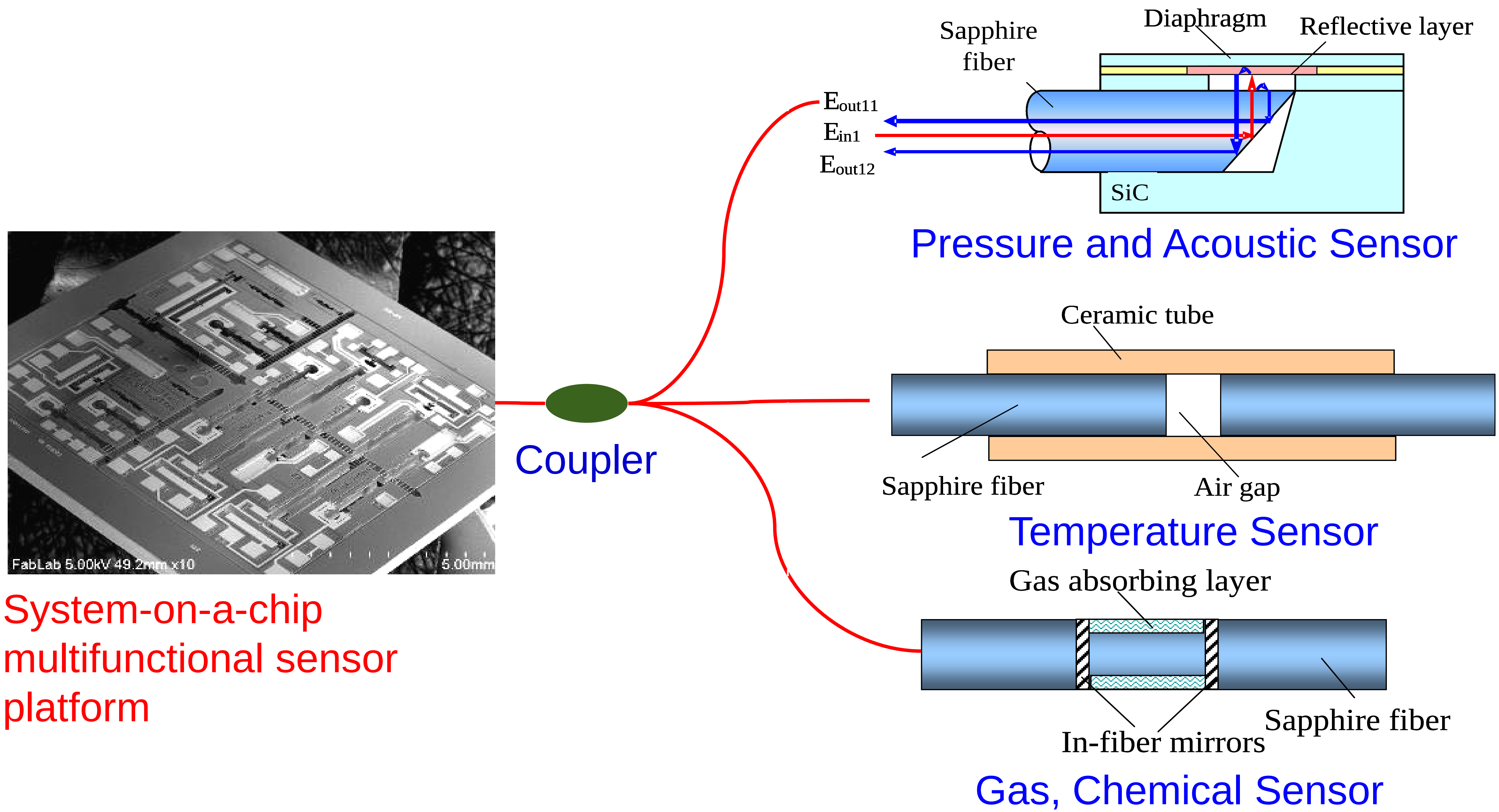
2. Smart system-on-a-chip multifunctional sensor platform demonstrated for pressure, temperature, chemical, and acoustic measurements

3. Smart system-on-a-chip multifunctional sensor demonstrated for multiplexed fiber Bragg grating sensors

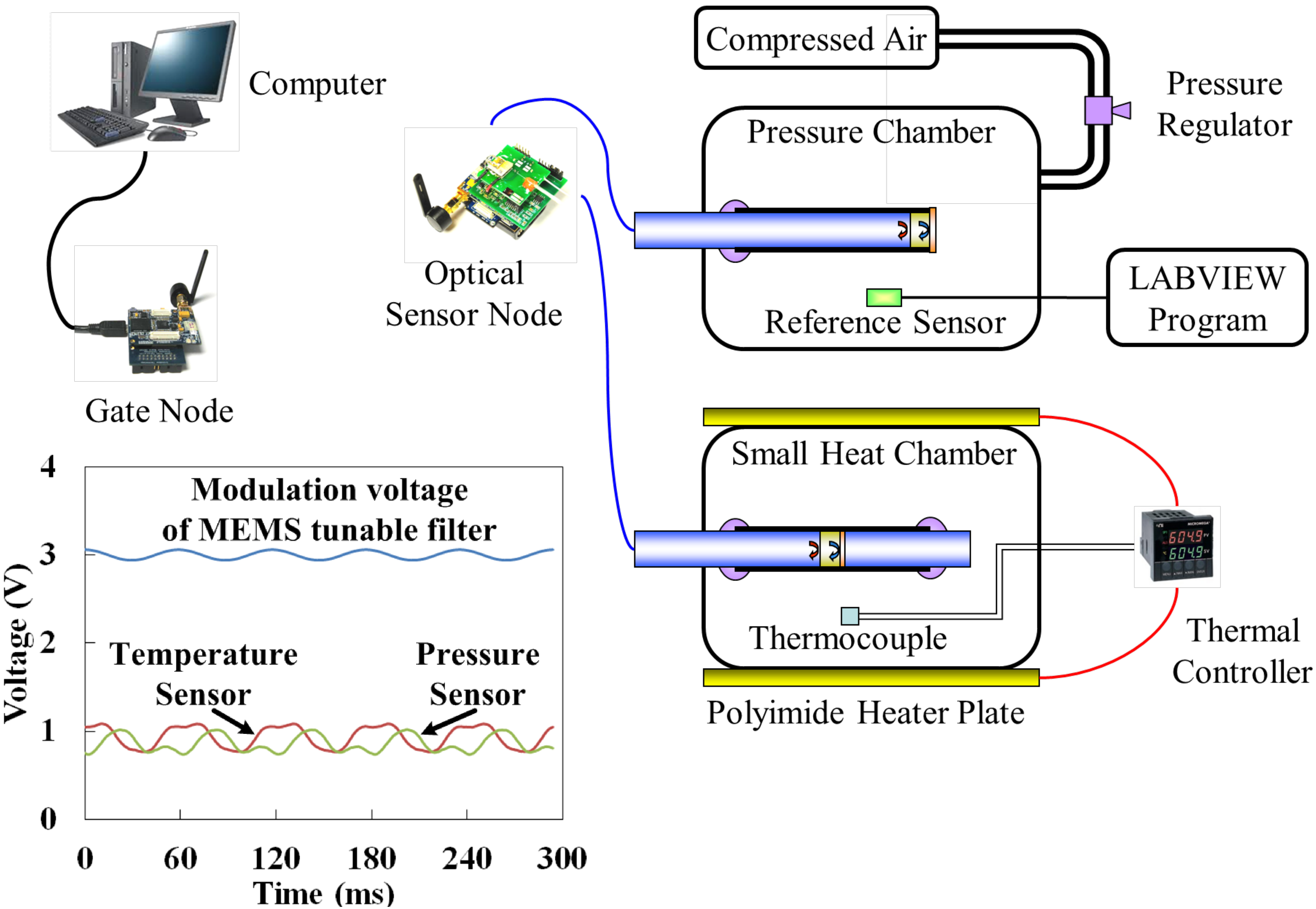

LED's
waveguides
splitters
detectors
Fabry-Perot


SLED
Photodetectors
Optical platform
Sensing module
Support circuit
Tunable filter
WSN module (Imote2)

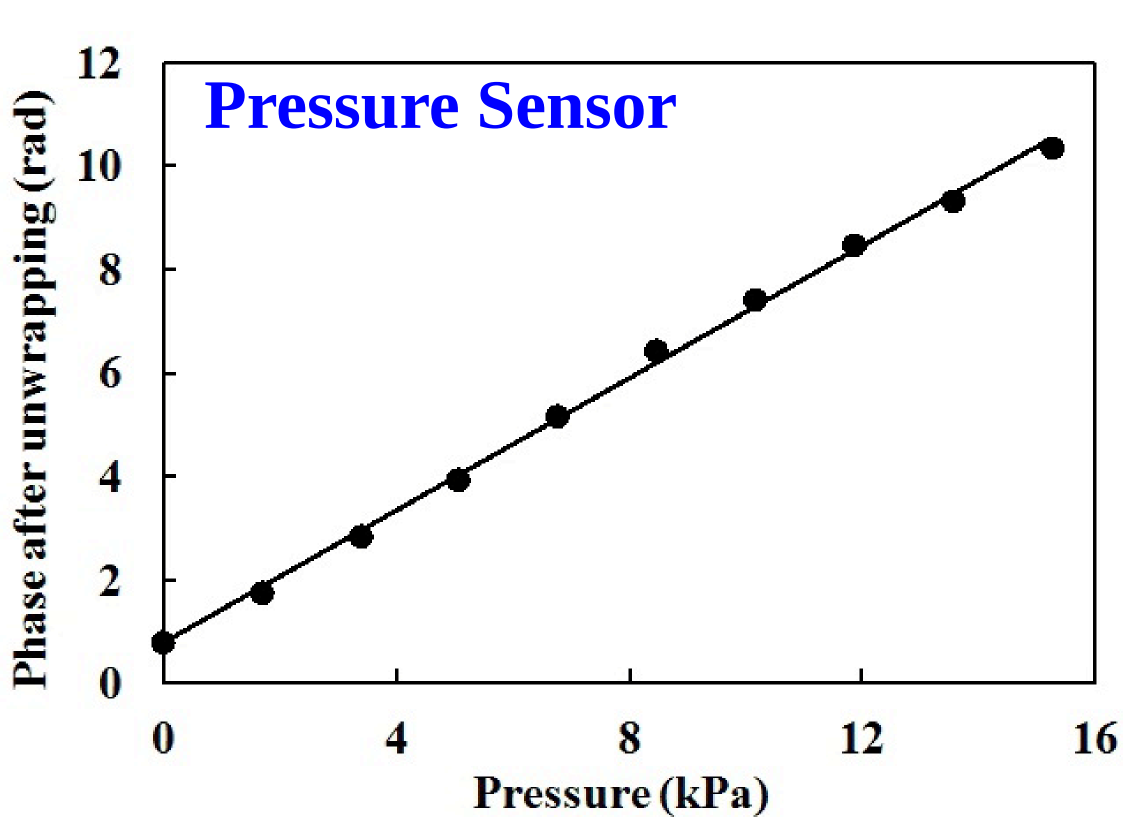
Sensing Strategy ...

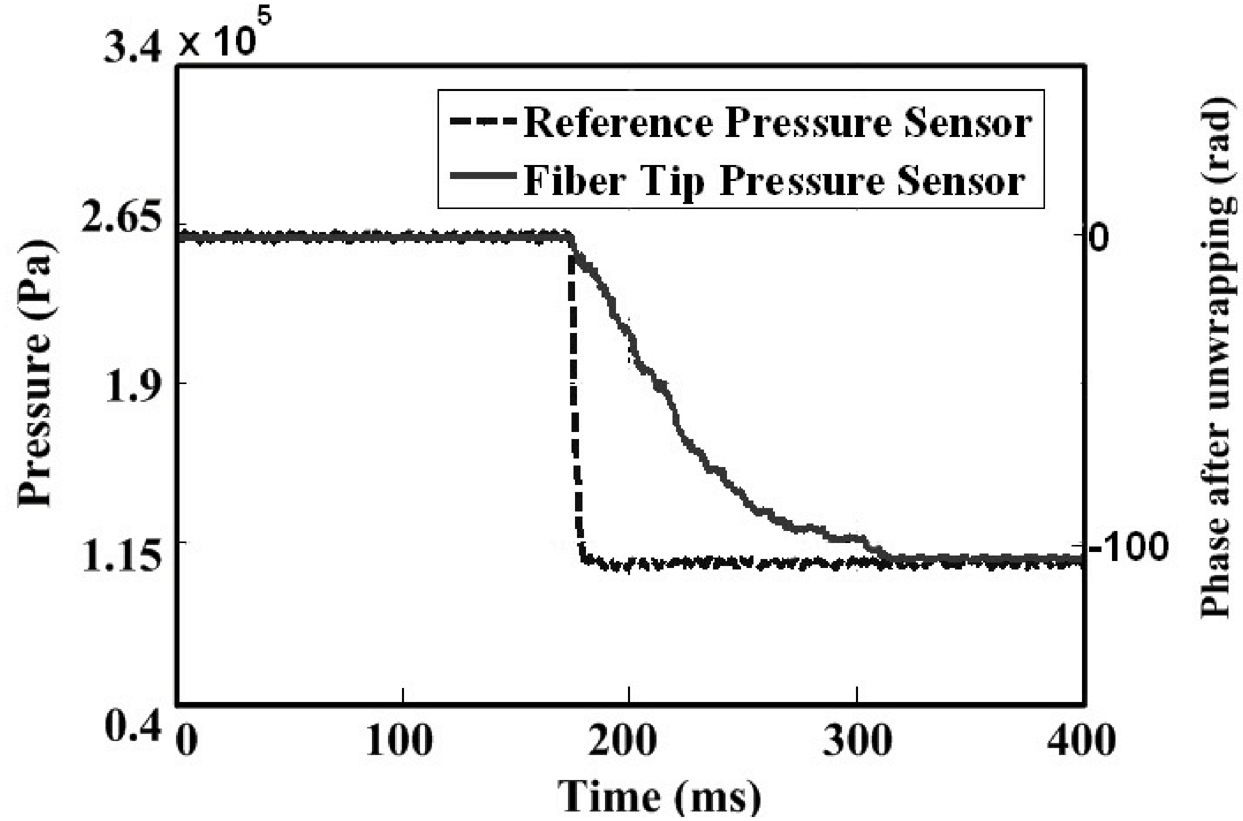


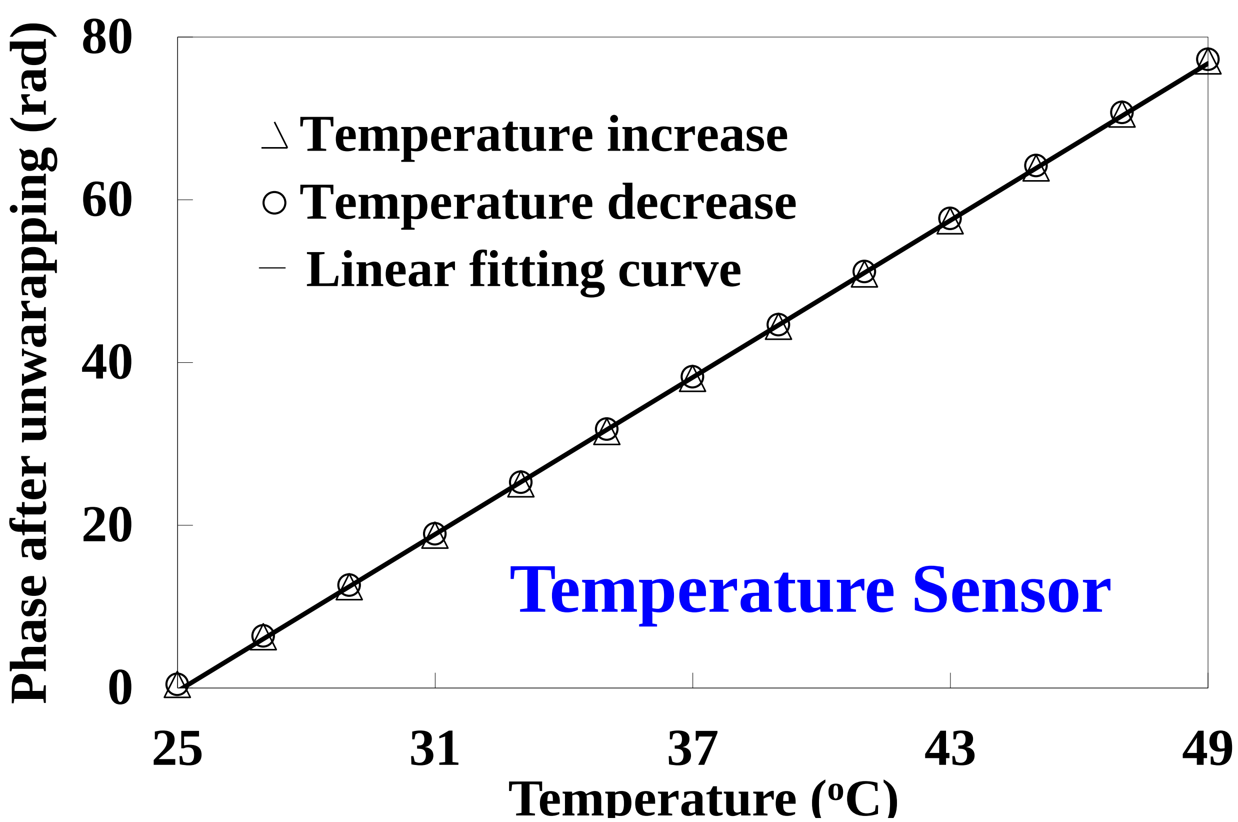
Simultaneous Temperature and Pressure Measurement

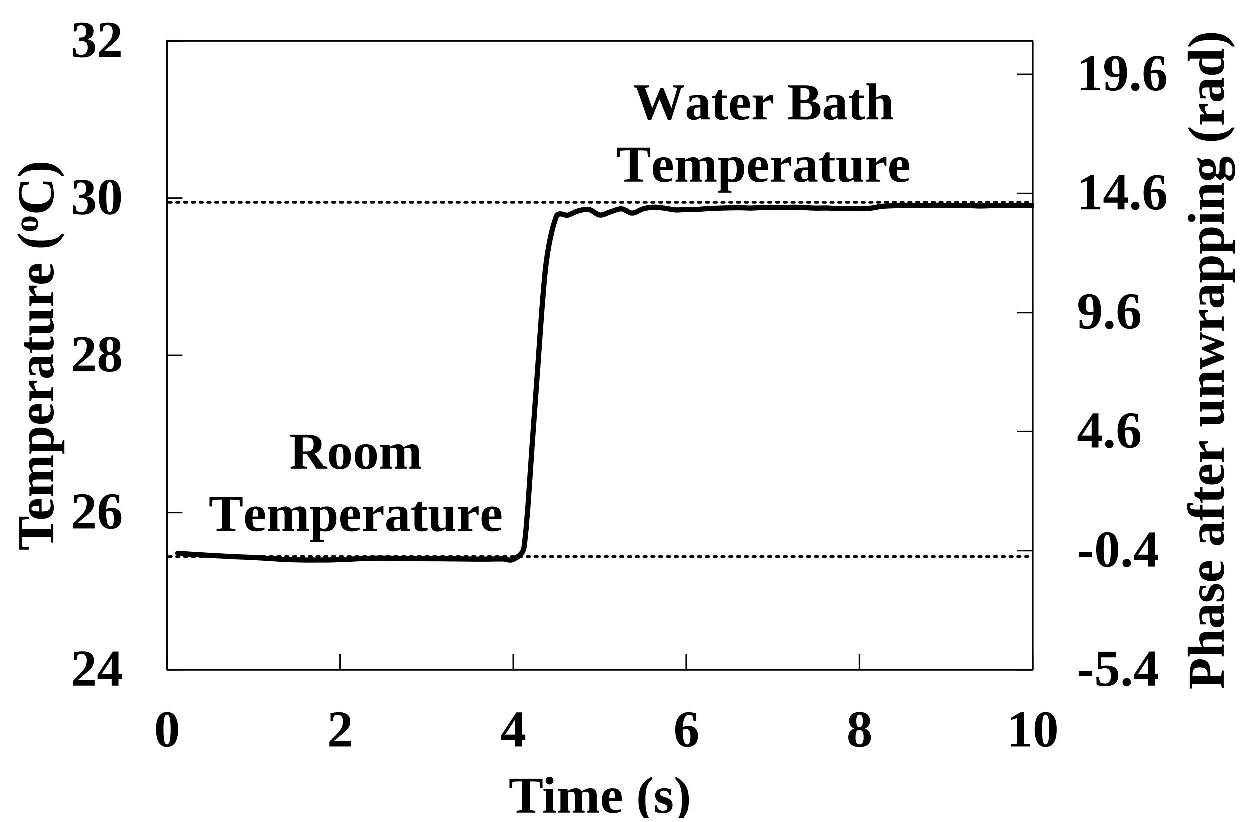


Simultaneous Temperature and Pressure Measurement

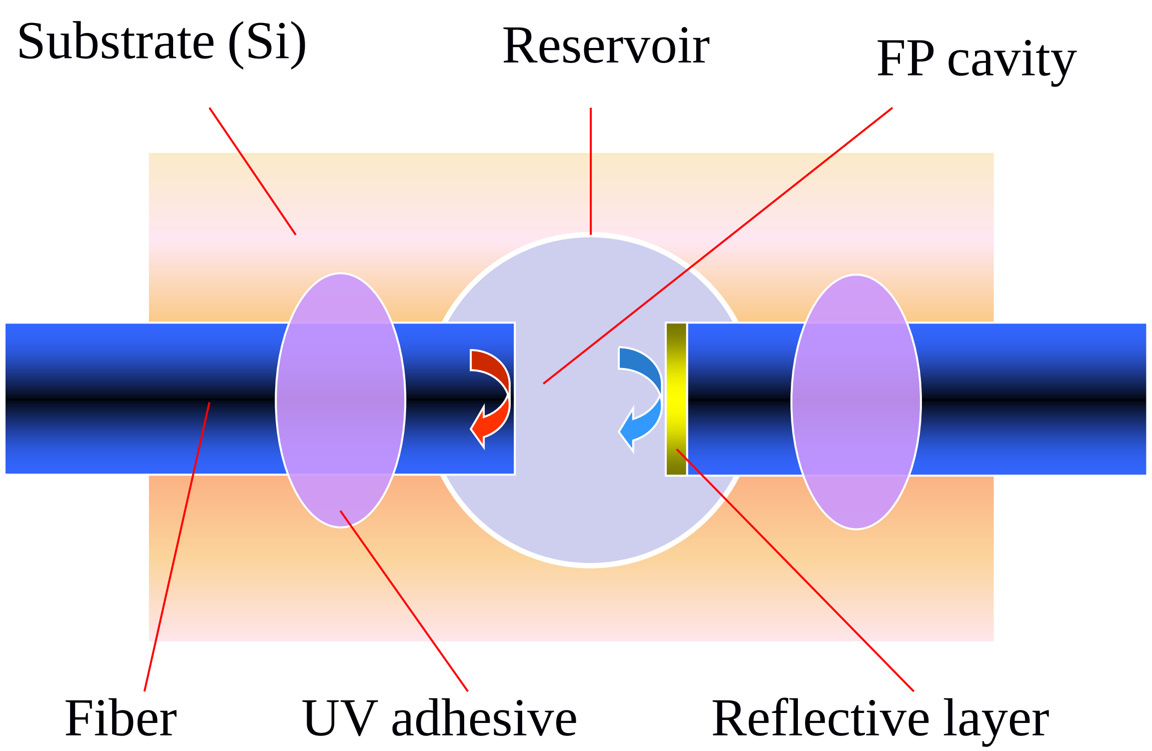


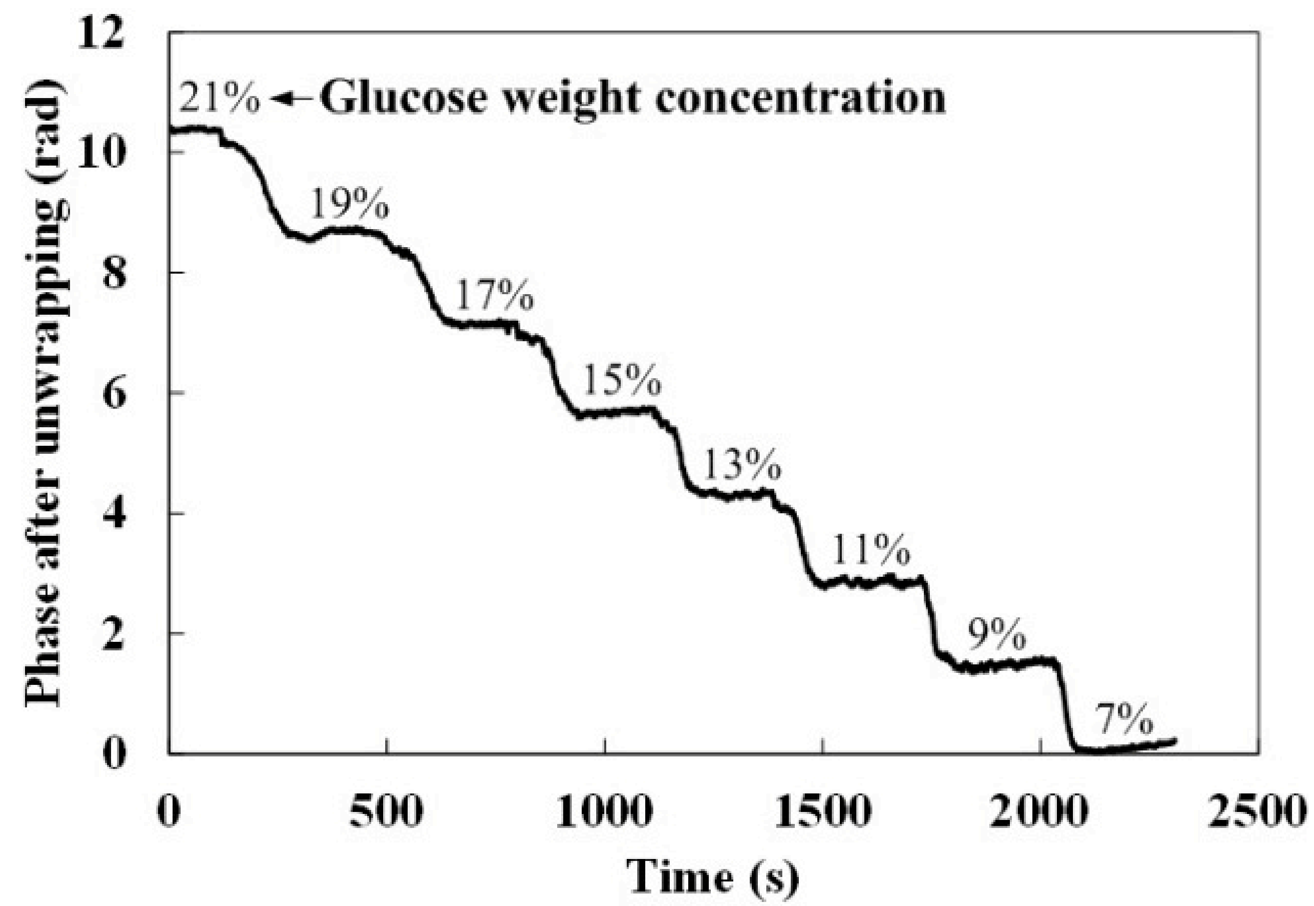


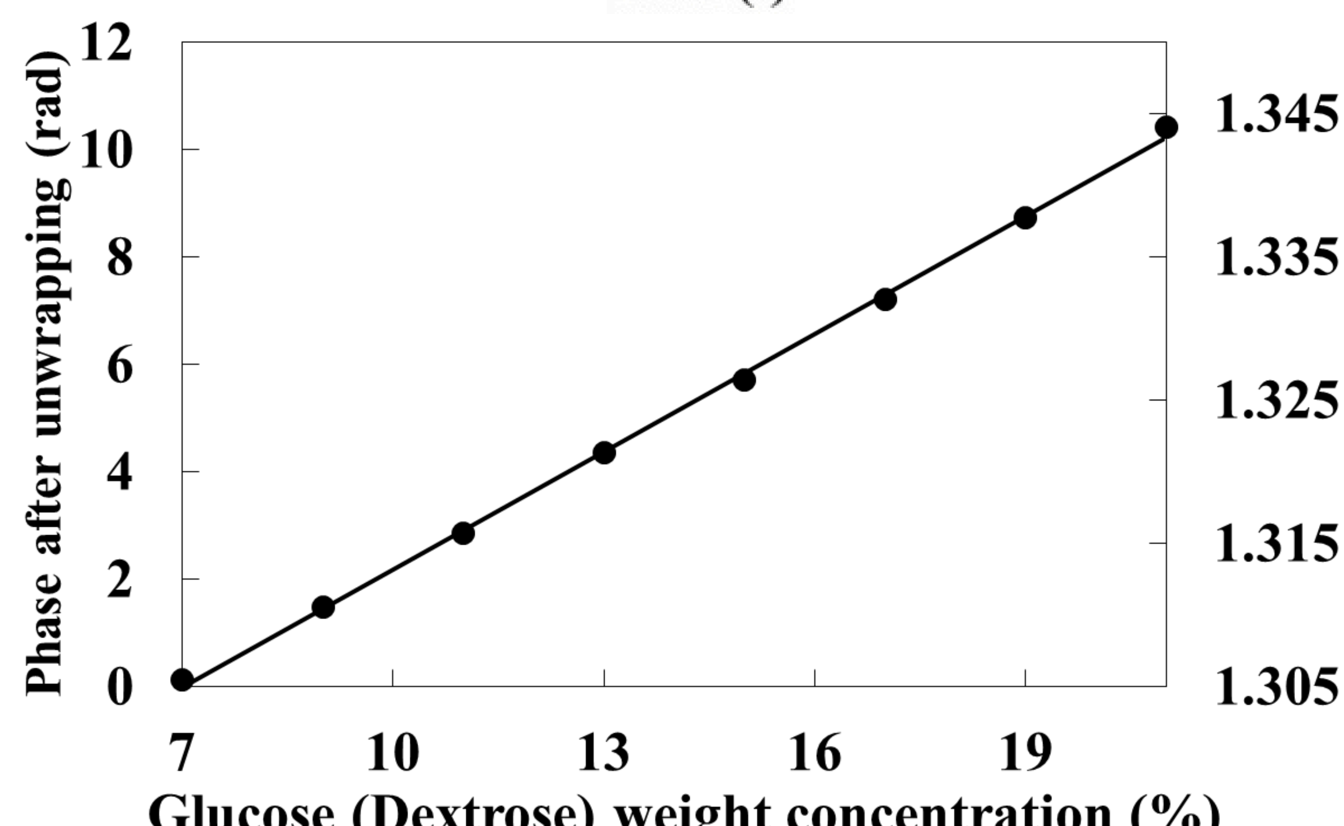




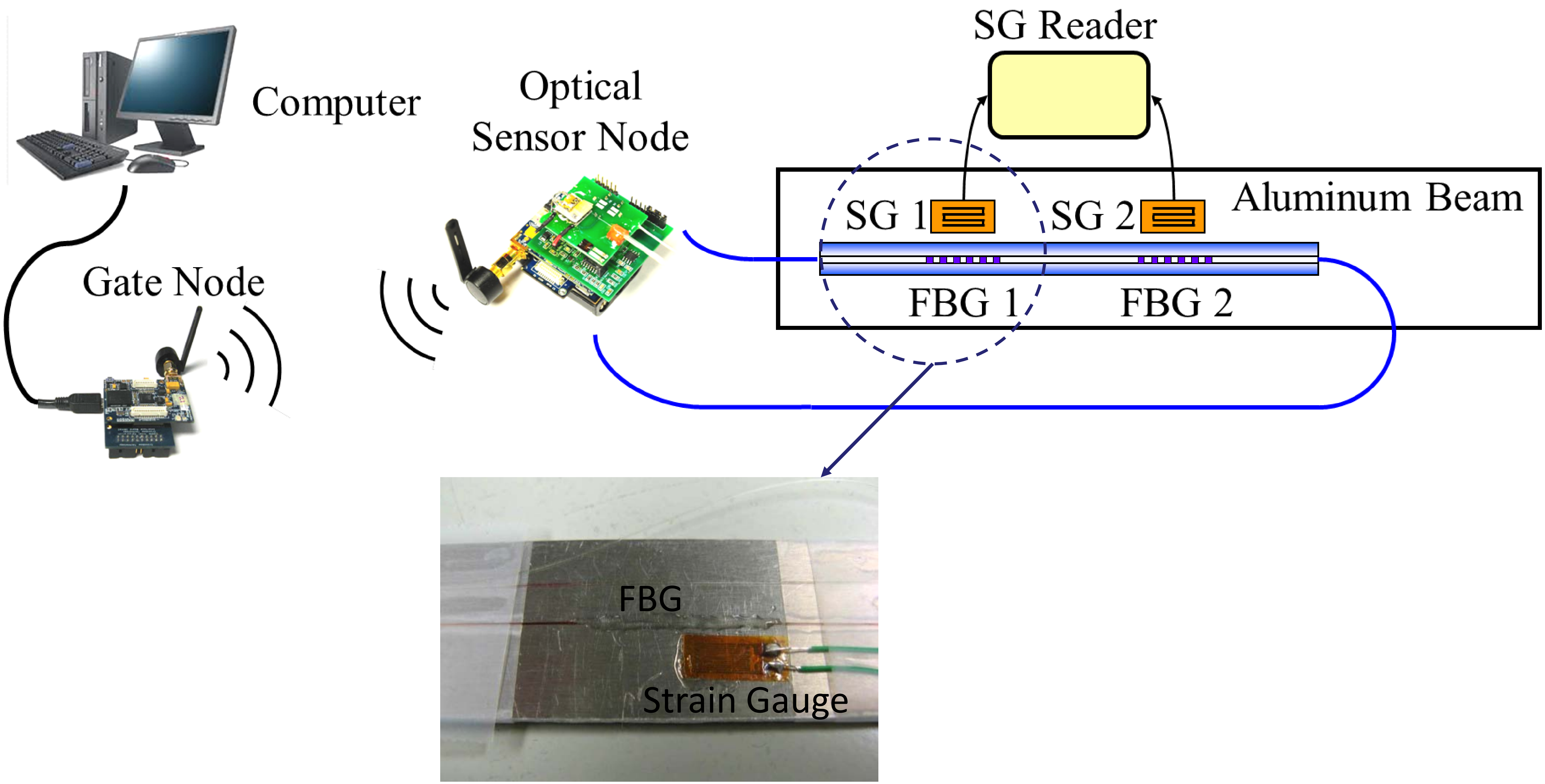
Chemical Sensing with Multifunctional Optical Sensor Platform



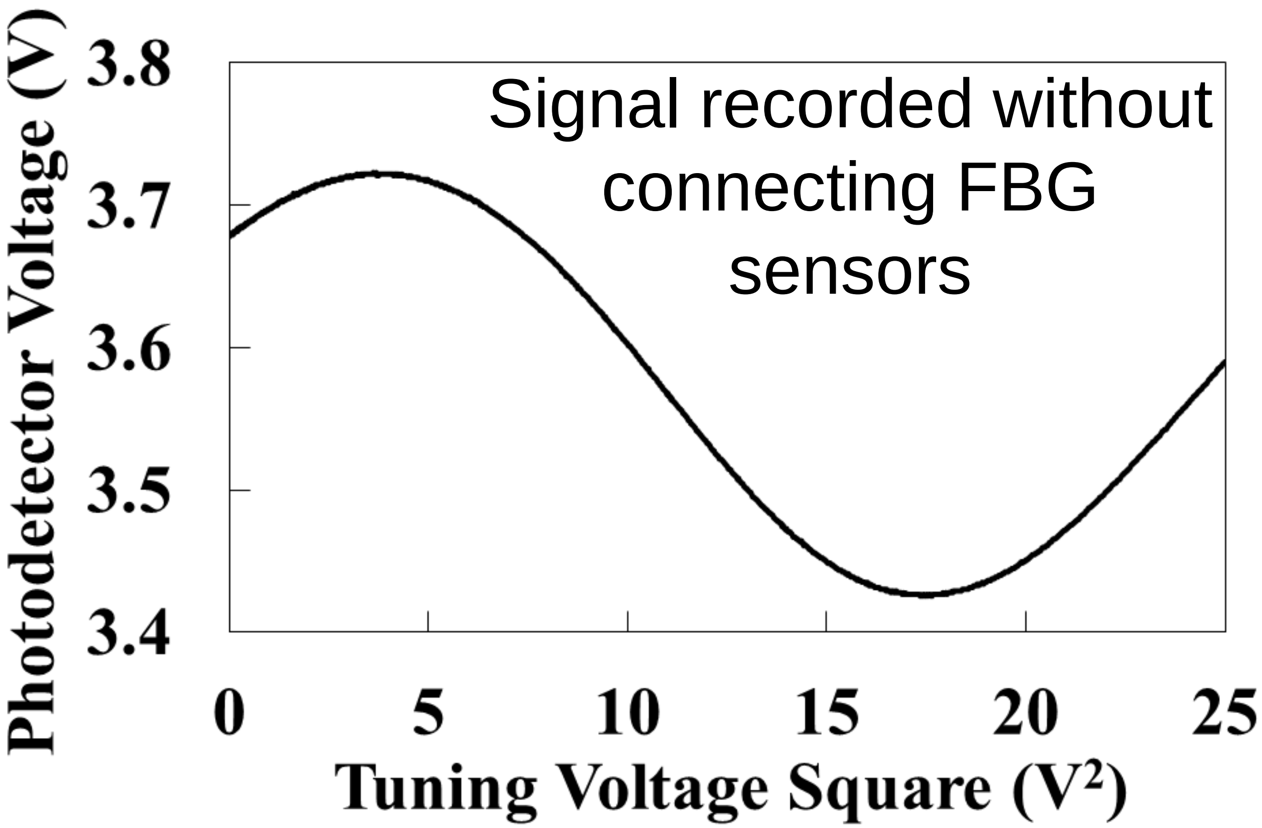


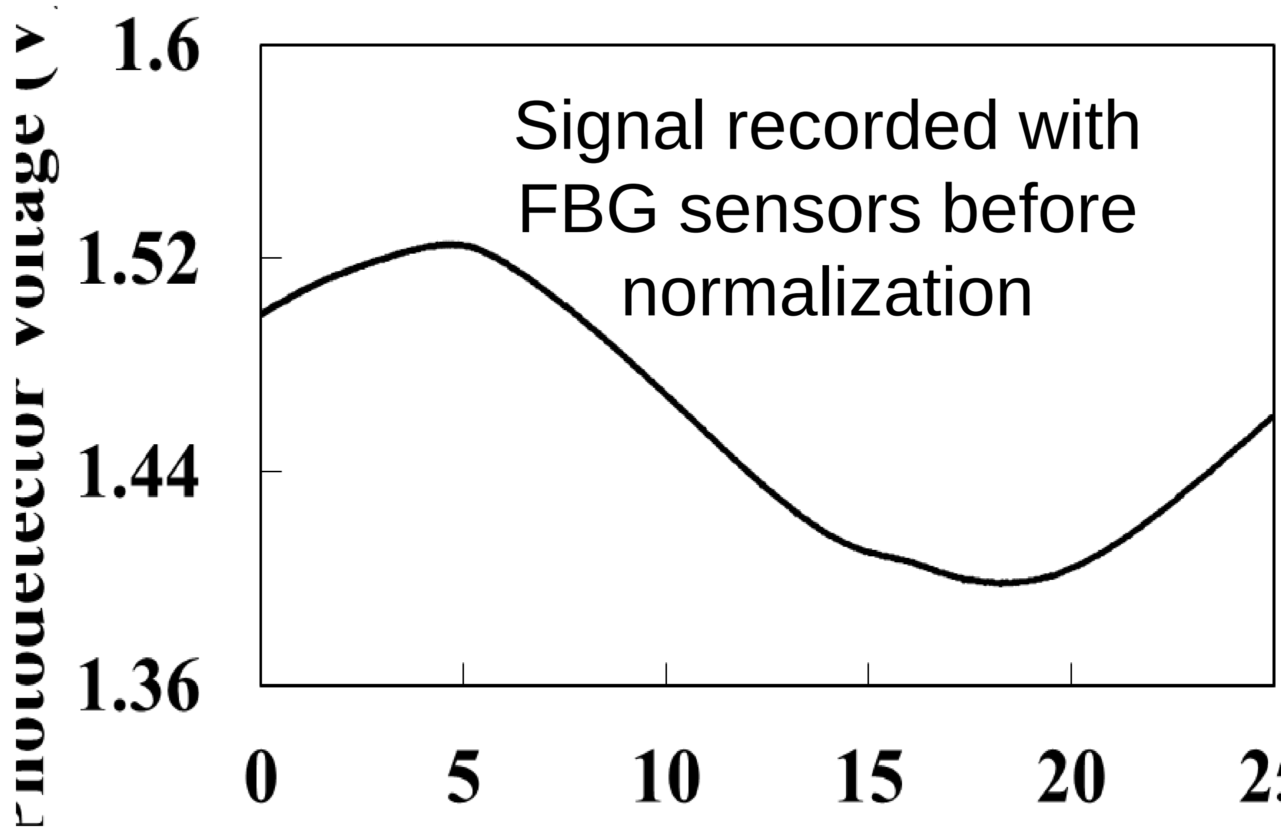


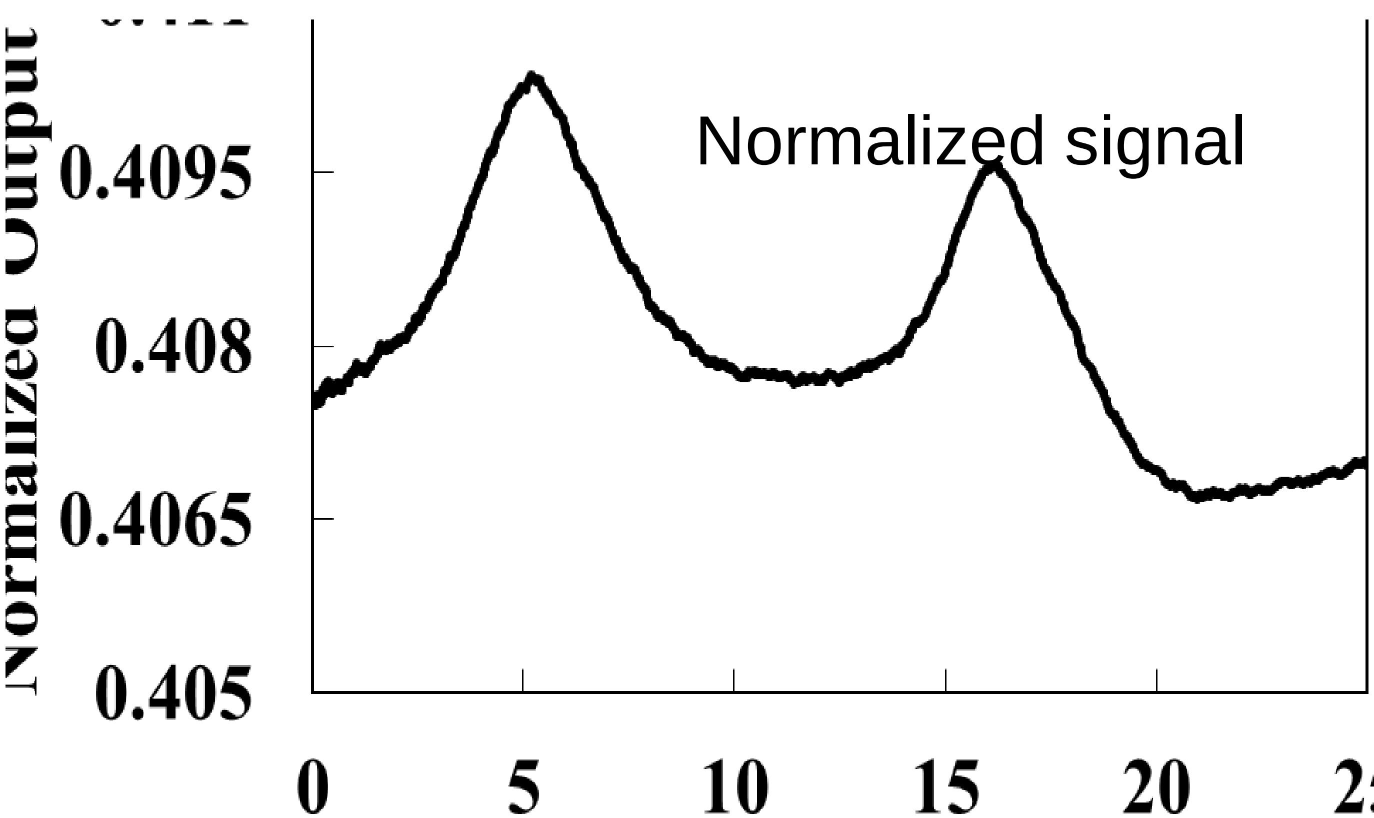
Multiplexed FBG Sensors



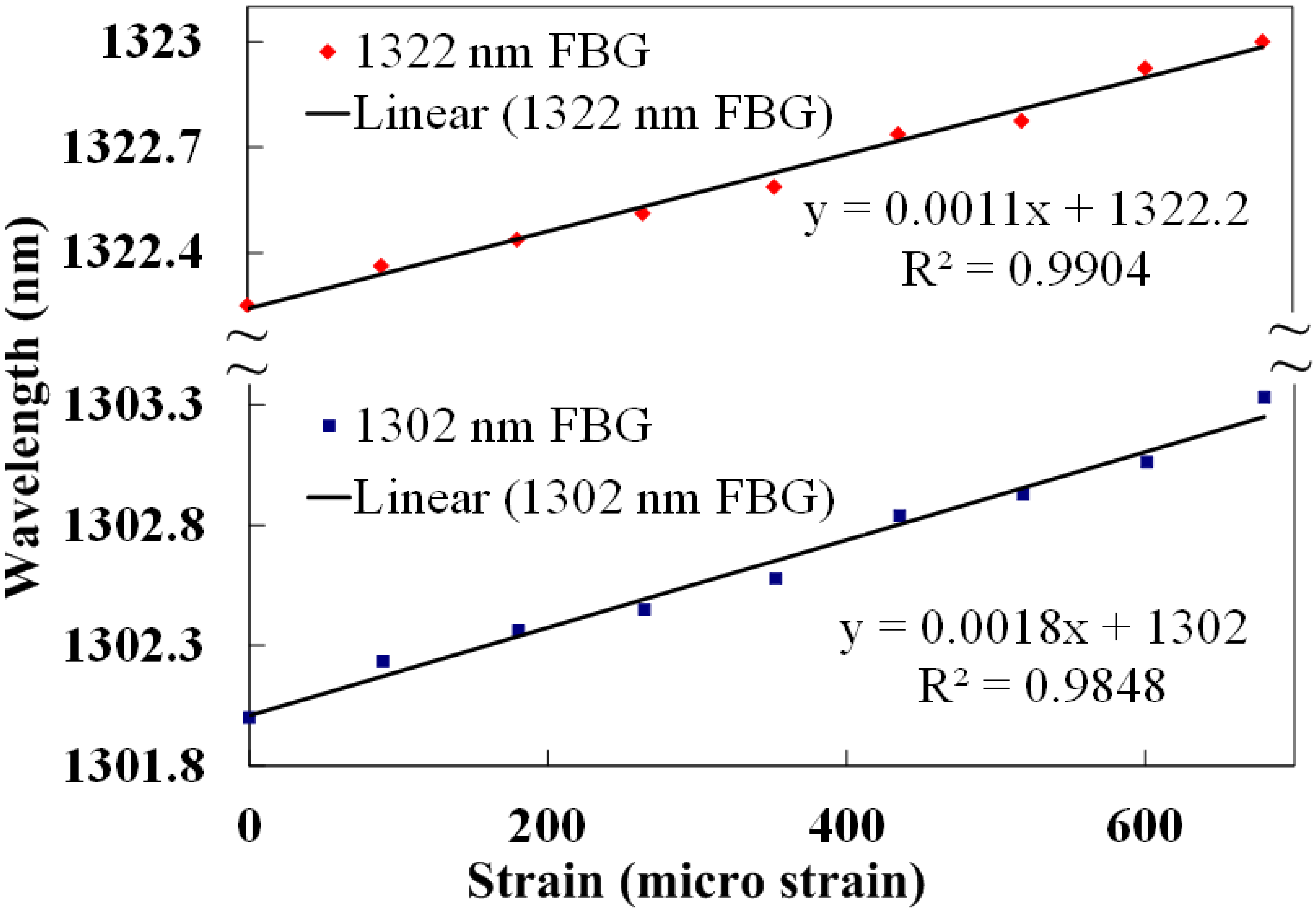
Multiplexed FBG Sensors







Bragg wavelength shift versus strain



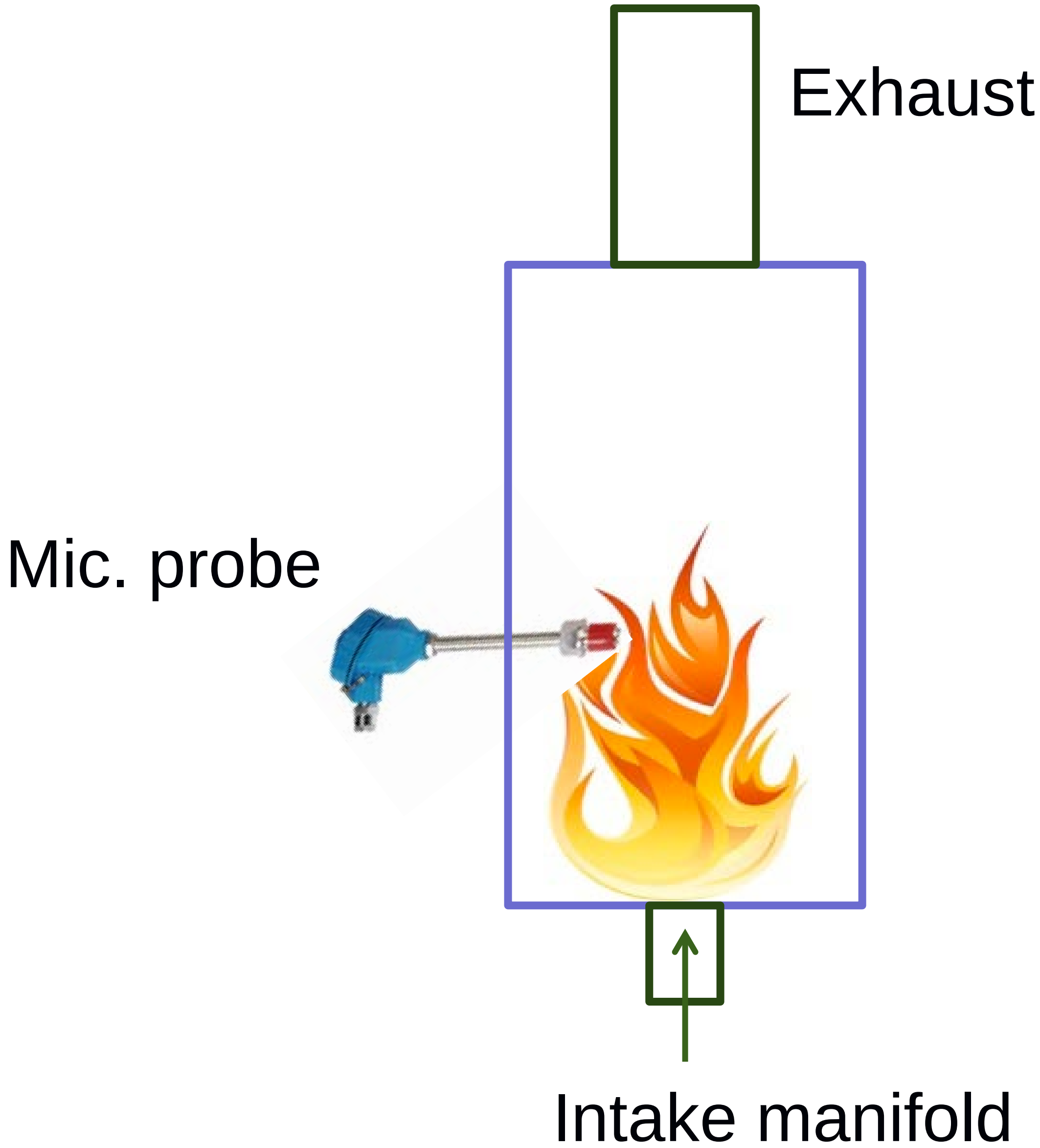
Multiple Sensor Demonstration

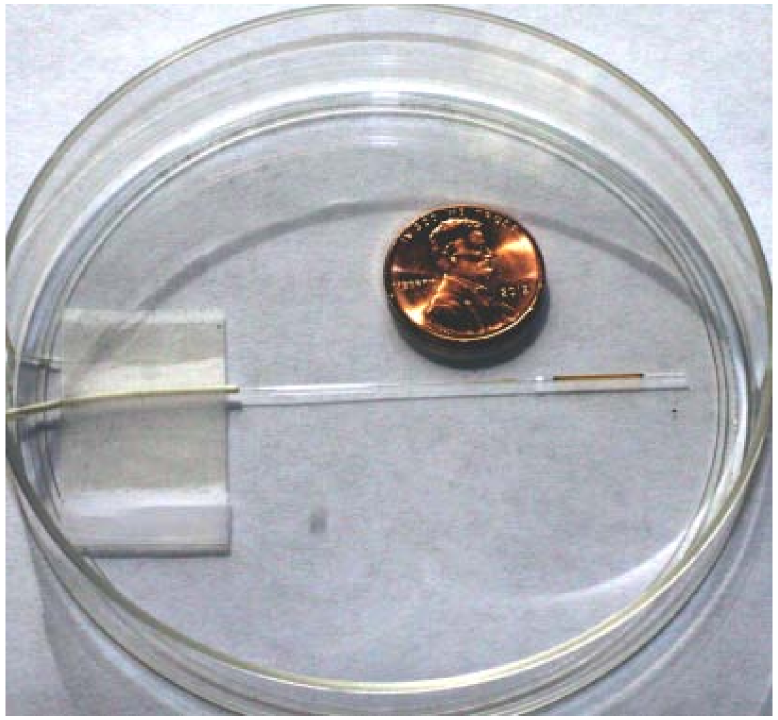
1. Studied multiple homogeneous sensors for source identification

2. Simulations of geometry arrangement and source identification performed

3. Experimental studies of geometry arrangement and source identification performed

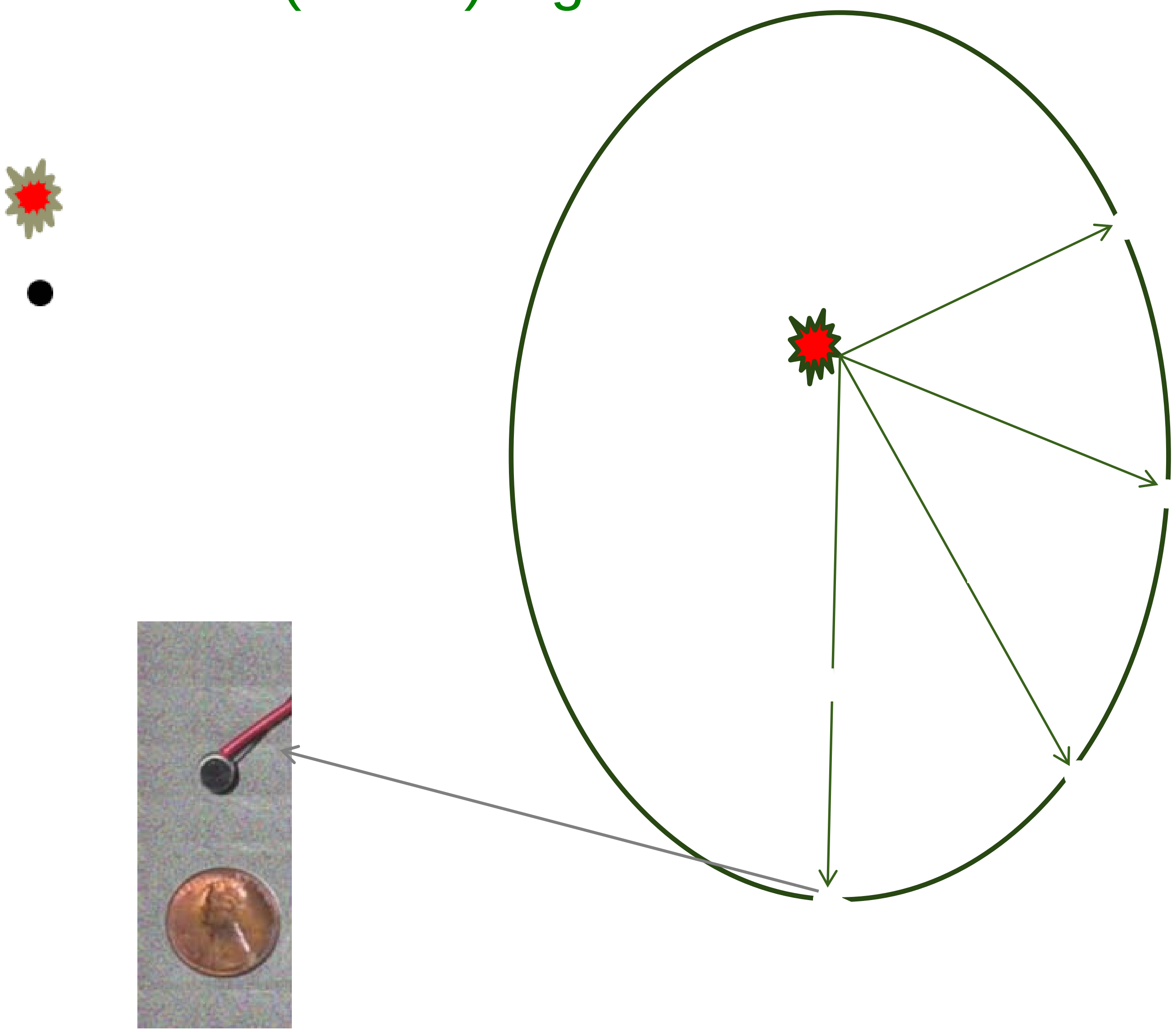
Acoustic Measurements of Combustor

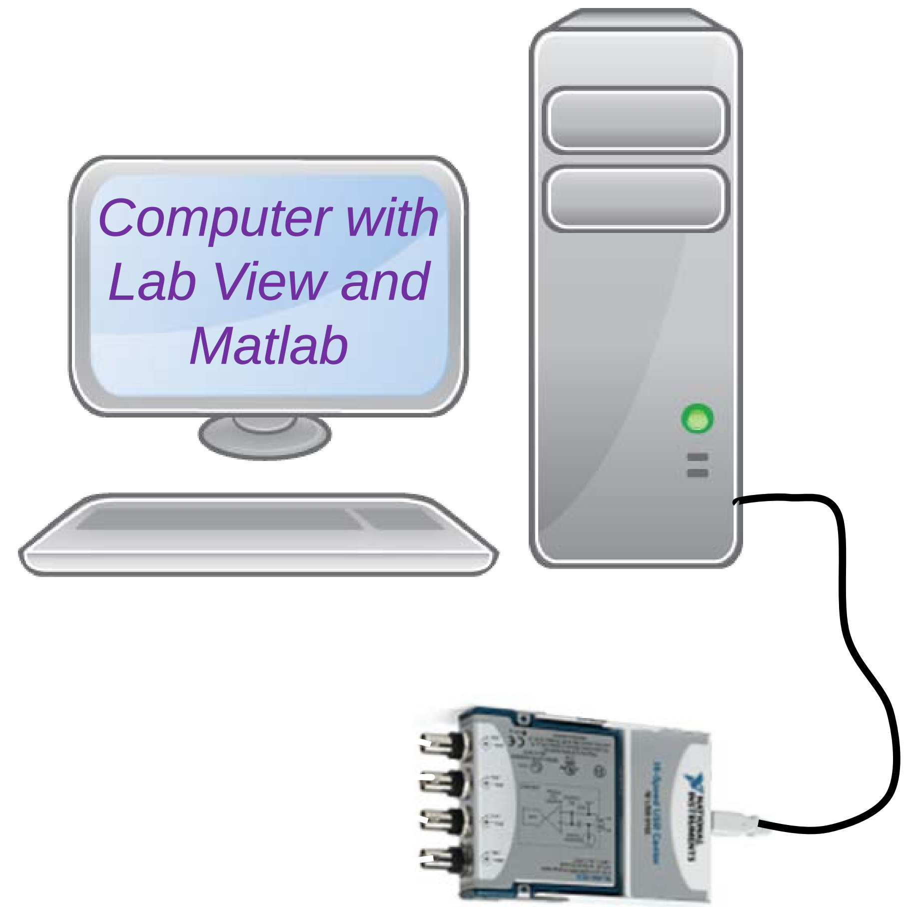




Methods Based on Time Delay of Arrival

Step 1: Time Delay Estimation (TDE) between a given pair of microphones using cross correlation (CC) or phase transform (PHAT) algorithm





Step 2: Solutions sought from nonlinear hyperbolic position equations and optimization using Matlab

Time Delay Estimation with Defined Sensor Positions

- Signals received at 2 microphones separated at known distance is:

$$r_1(t) = s(t) + n_1(t), \qquad 0 \le t \le T ....(1)$$
$$r_2(t) = s(t-\tau) + n_2(t),$$

where, $r_1(t)$ and $r_2(t)$ outputs from two microphones

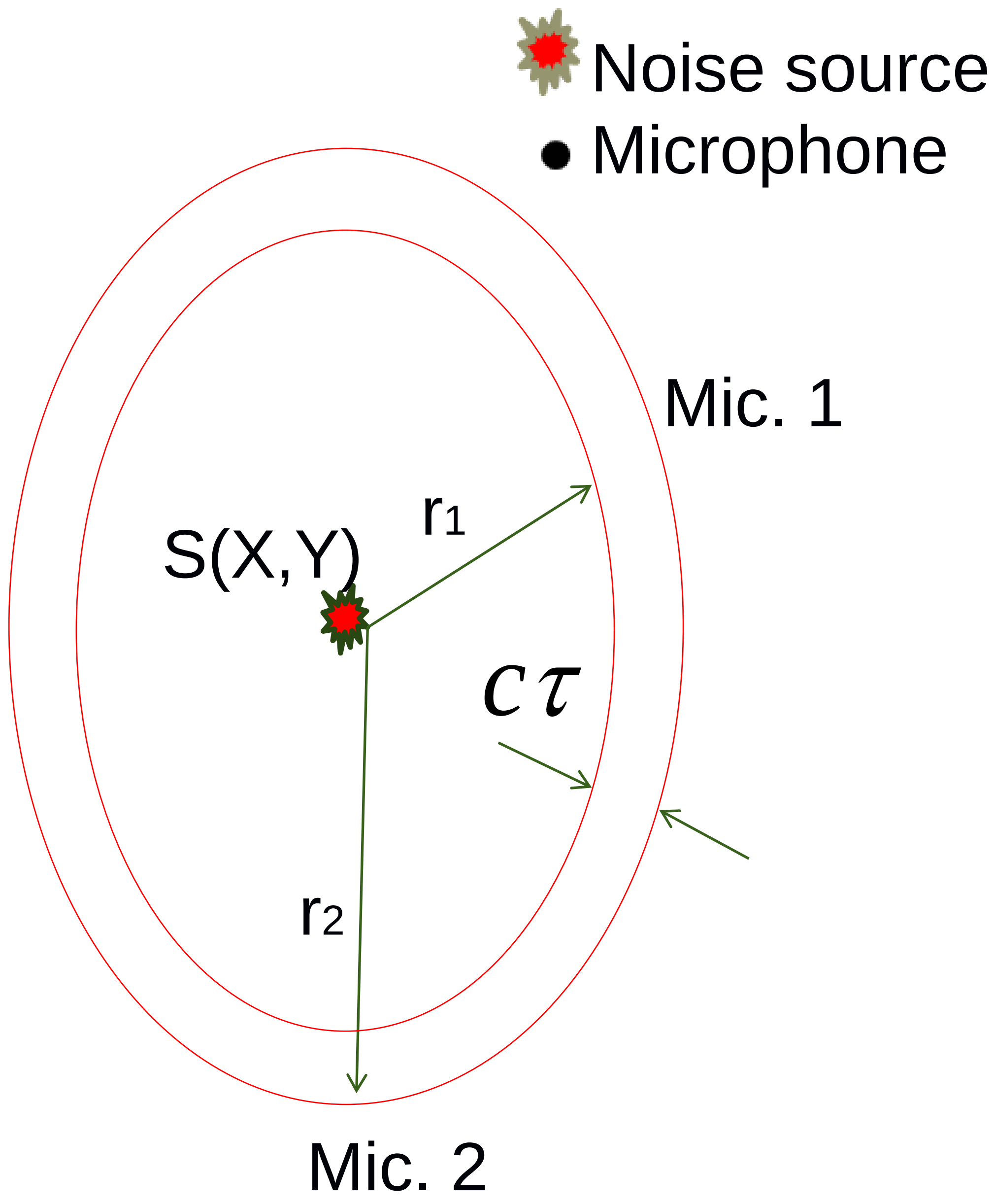
$s(t)$: source signal

$n_1(t)$, $n_2(t)$: additive noises

T : observation interval

τ : time delay between the two received signals

C: speed of sound



Hyperbolic Position Estimation From Time Delays

- Relationship between range difference (R_{ij}) and the time delay between sensors i and j is given by:

$$R_{ij} = c\,\tau_{ij} = R_i - R_j$$

c : Speed of sound

τ_{ij} : Time delay between sensor i and j

- In a 2-D system, the hyperbolas that describe the range difference R_{ij} , between sensors are given by:

$$R_{ij} = \sqrt{(X - x_i)^2 + (Y - y_i)^2} - \sqrt{(X - x_j)^2 + (Y - y_j)^2}$$

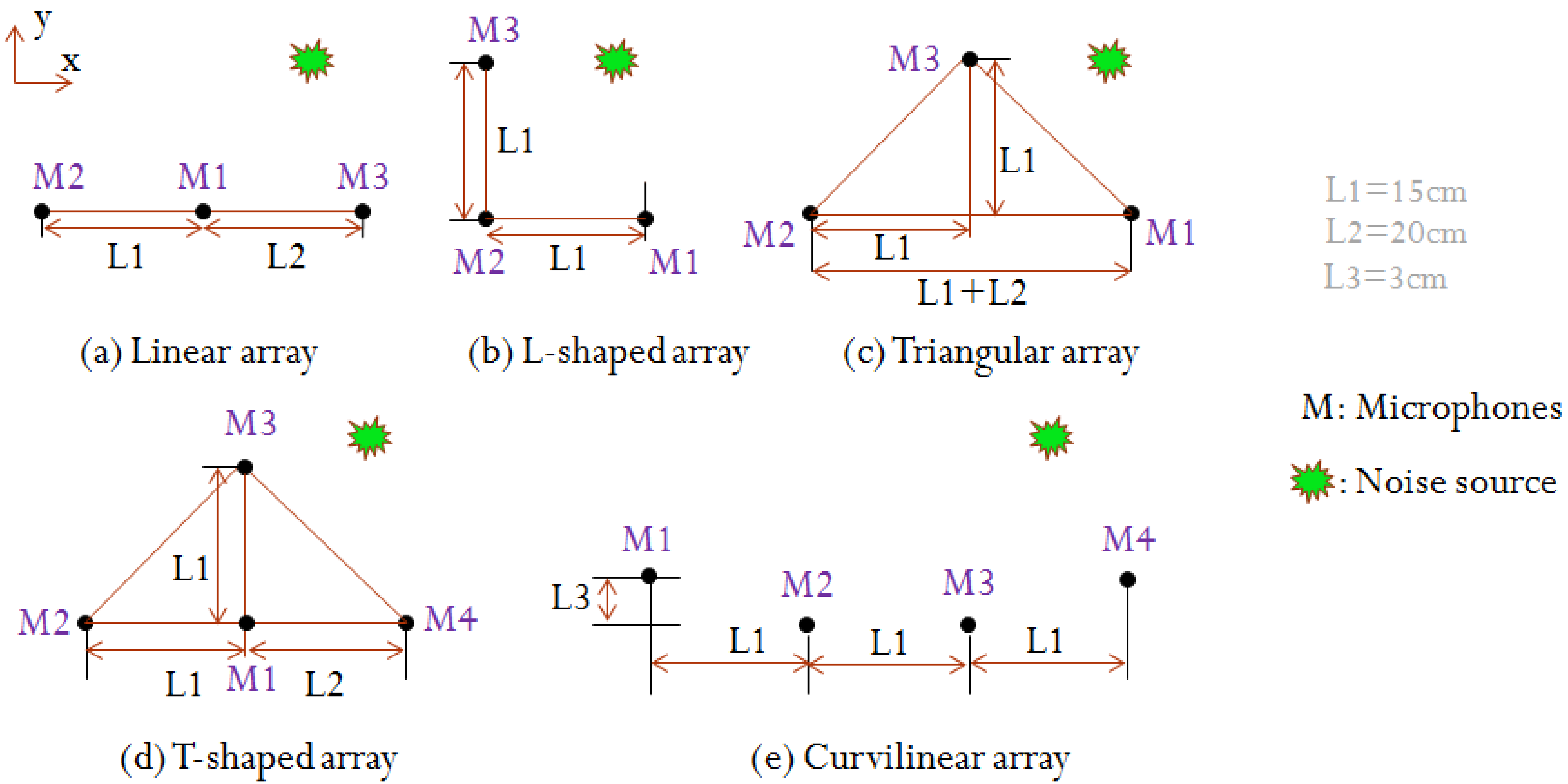
R_i R_j

(x_i, y_i): Location of sensor i

(x_j, y_j): Location of sensor j

(X, Y): Unknown coordinates of noise source

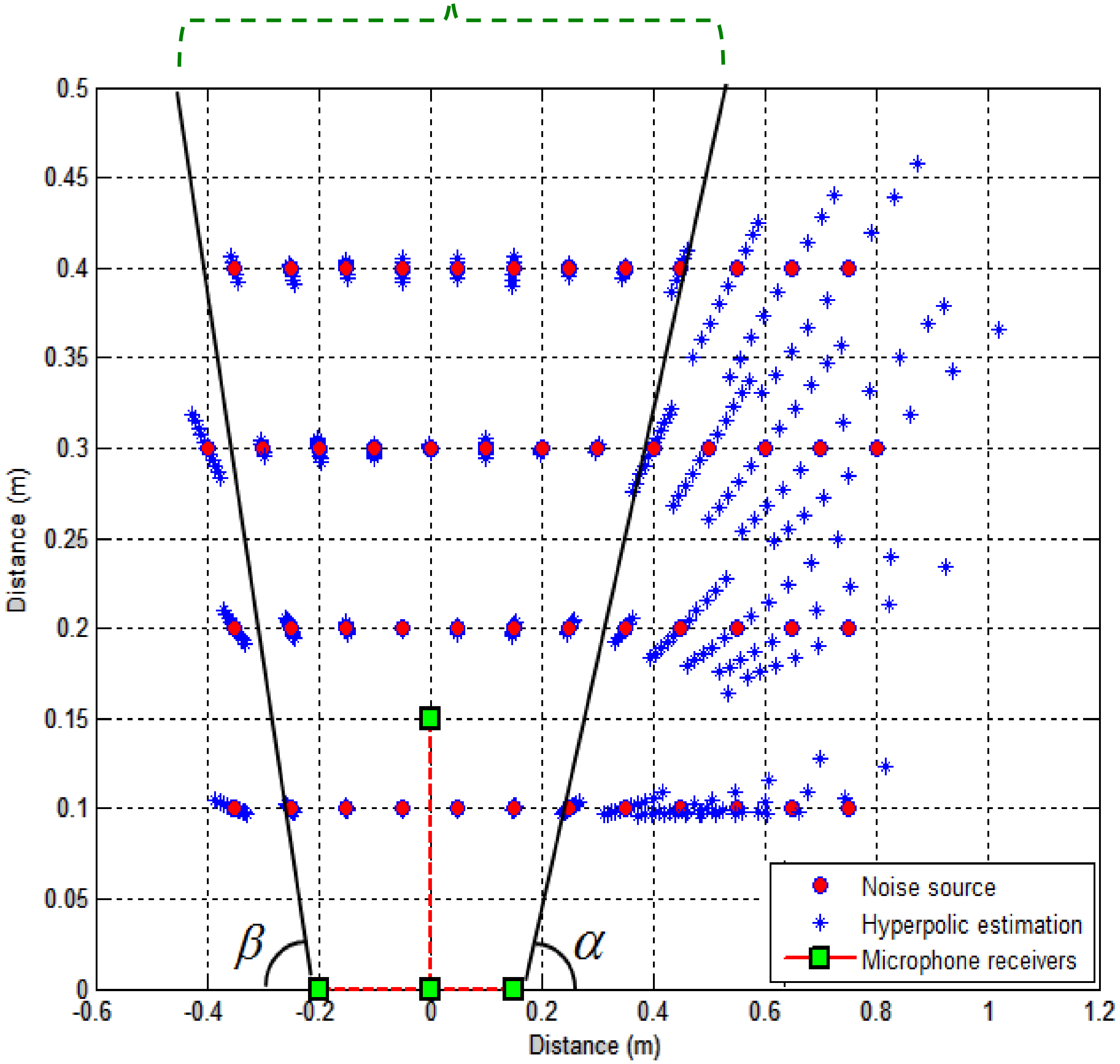
Number of sensors and arrangement (Simulations)

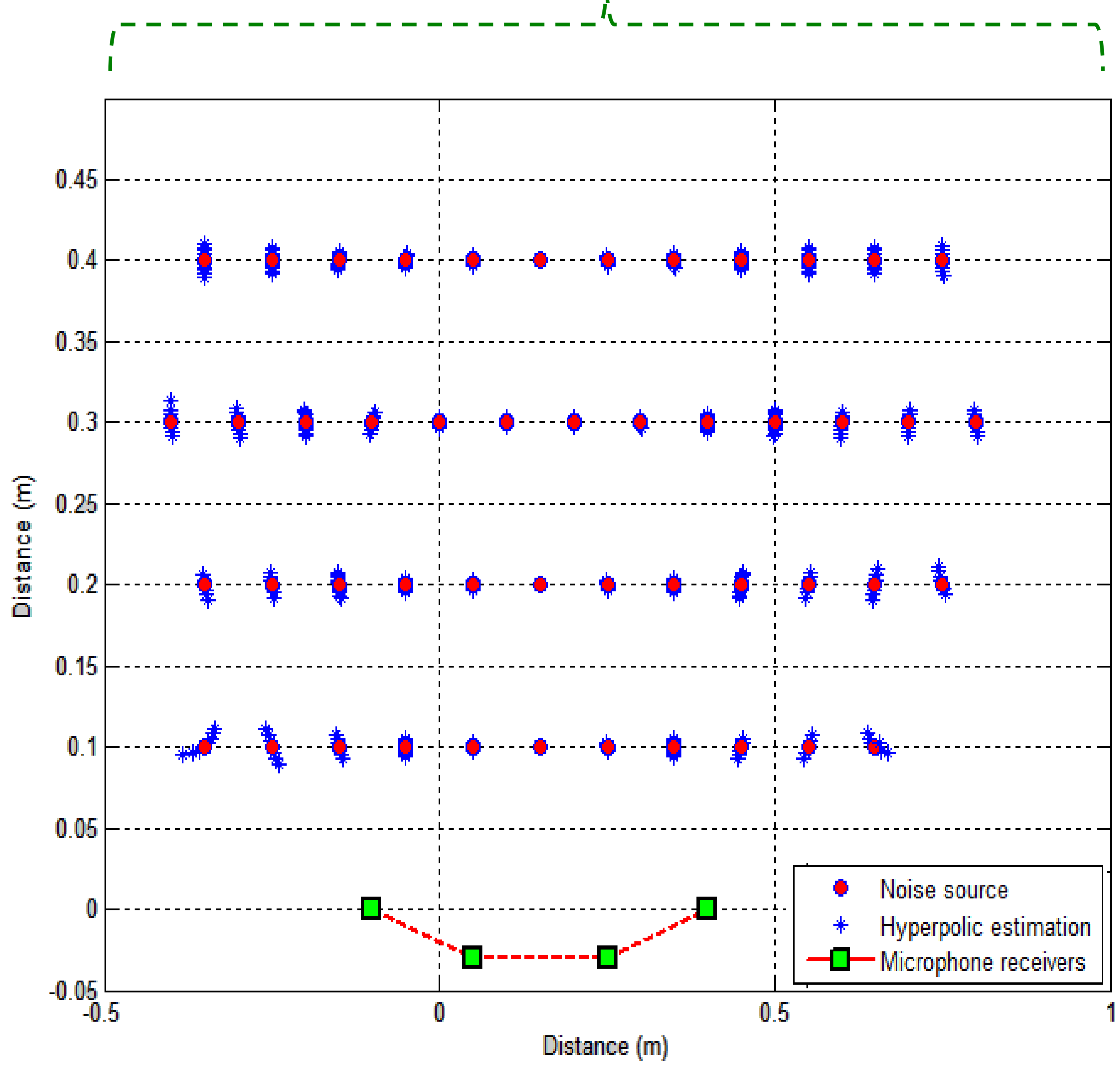


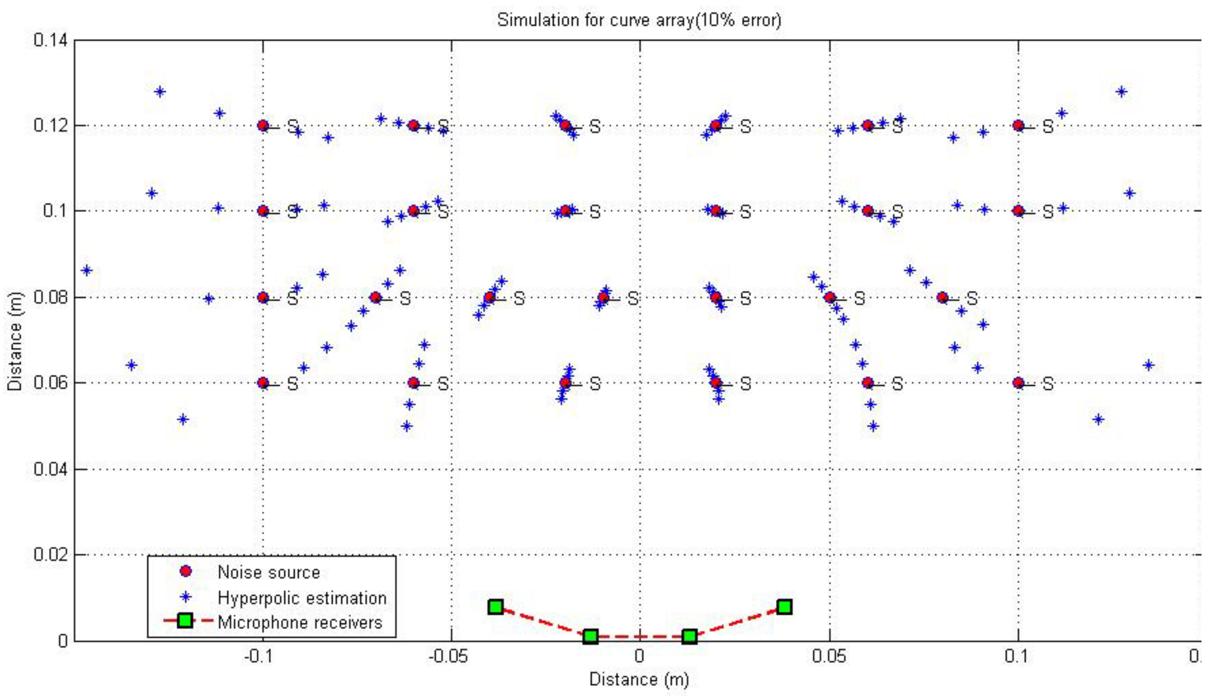
Simulation results : Hyperbolic estimation of noise source in a 2-D plane using T-shaped and Curvilinear array

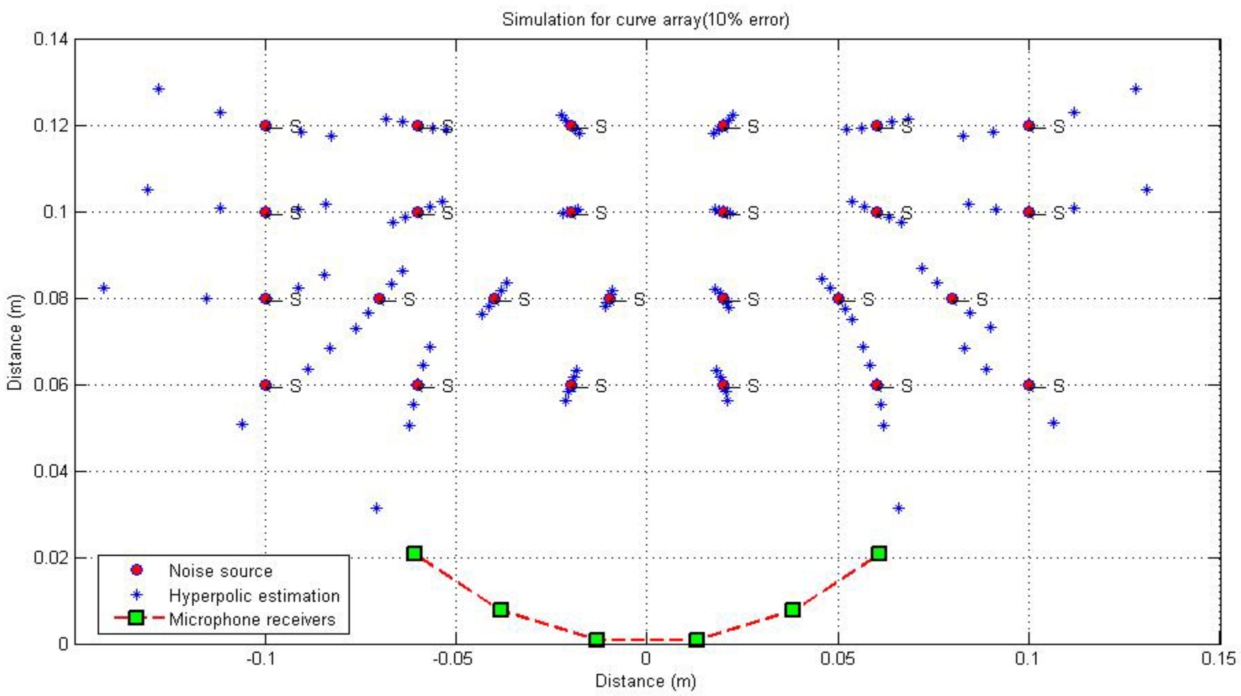
Estimated position error = 5%
(in bounded regime)

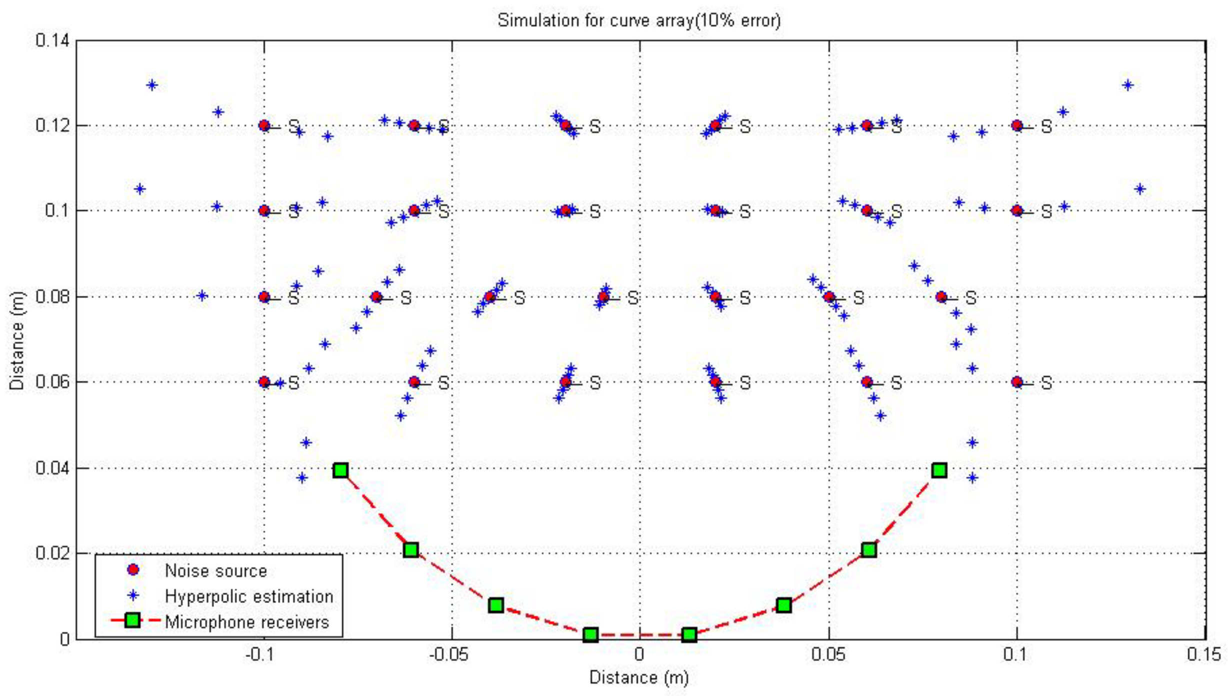
Estimated position error = 5%



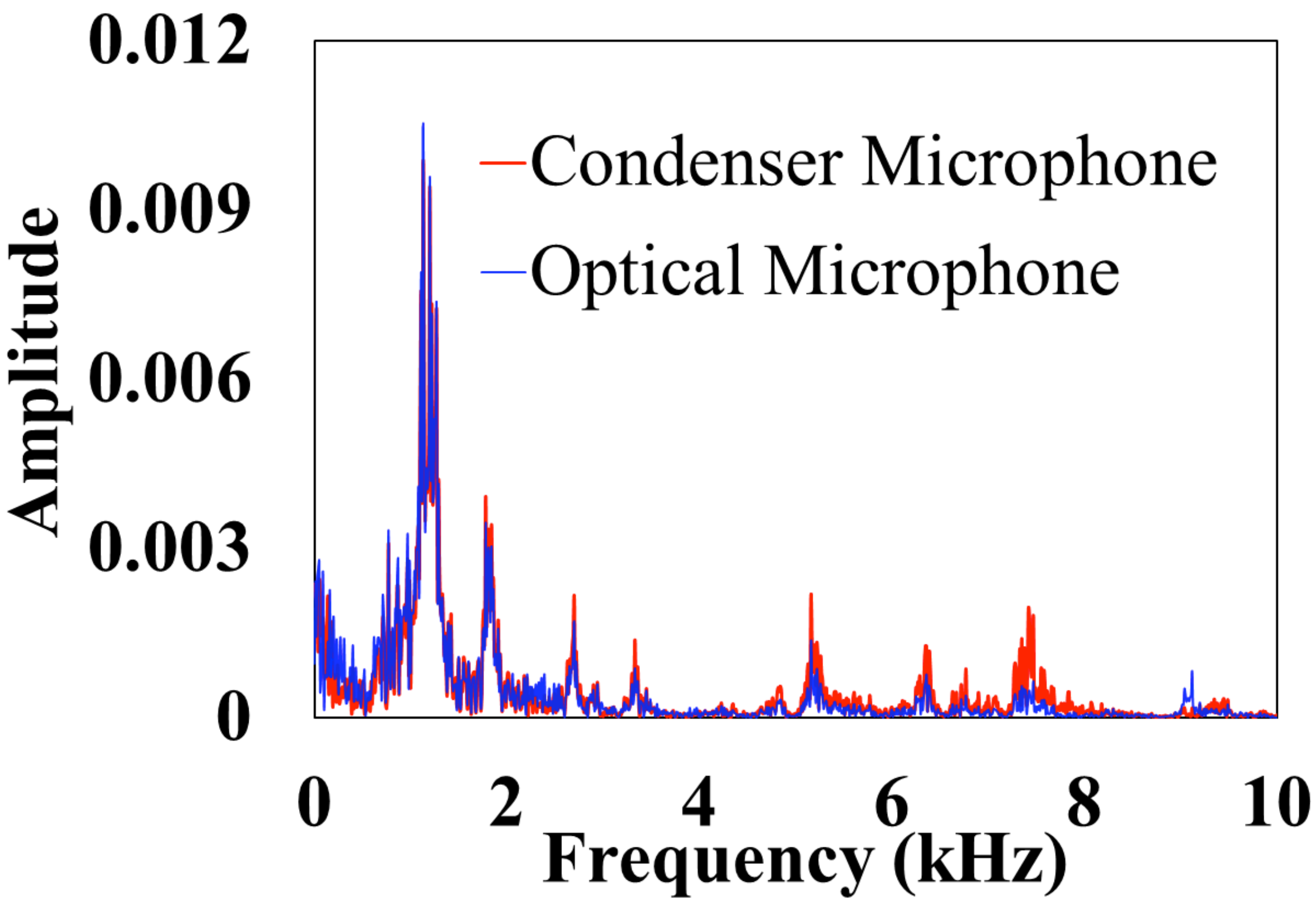




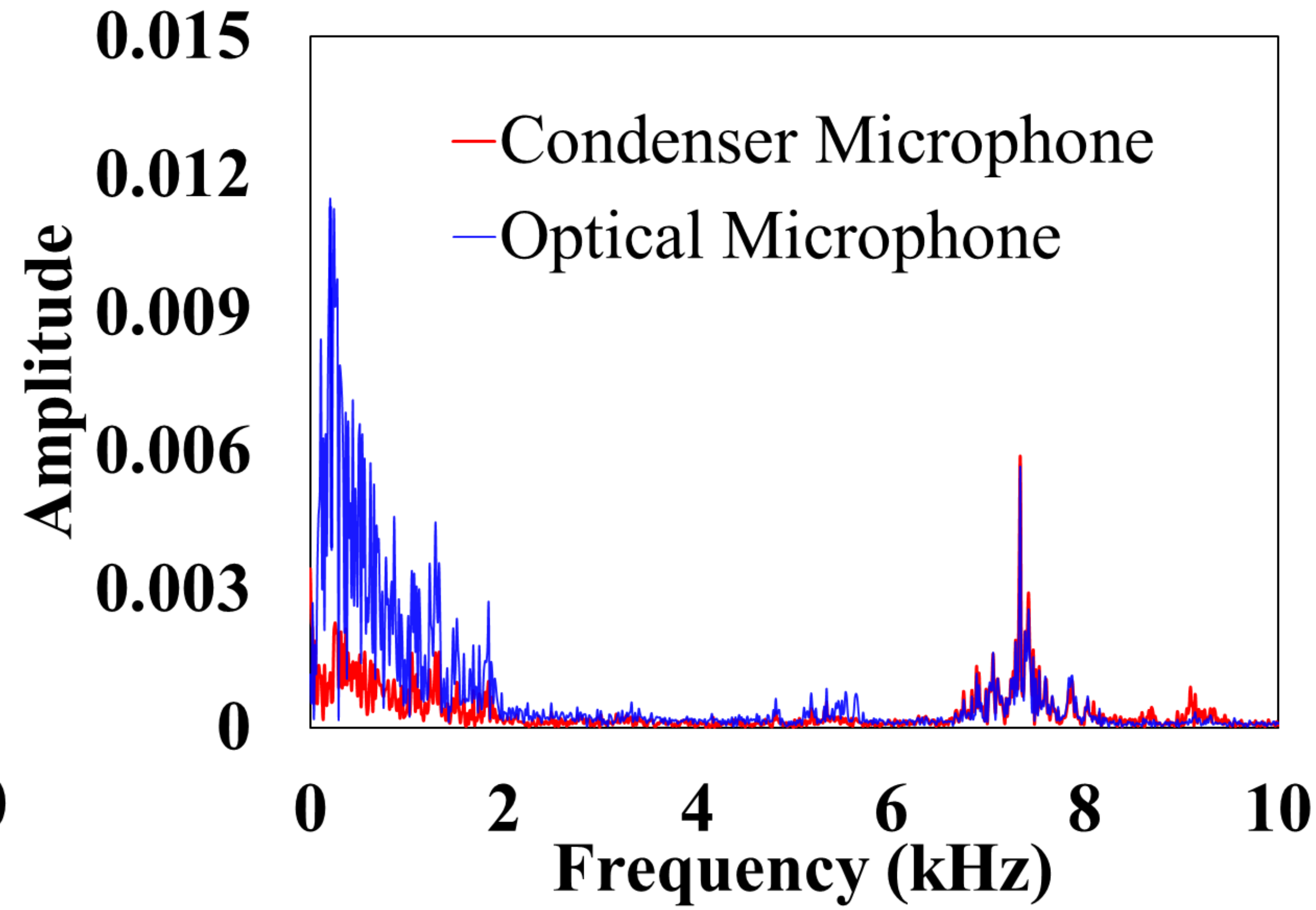




Estimated position error with time delay error of -10 to +10%

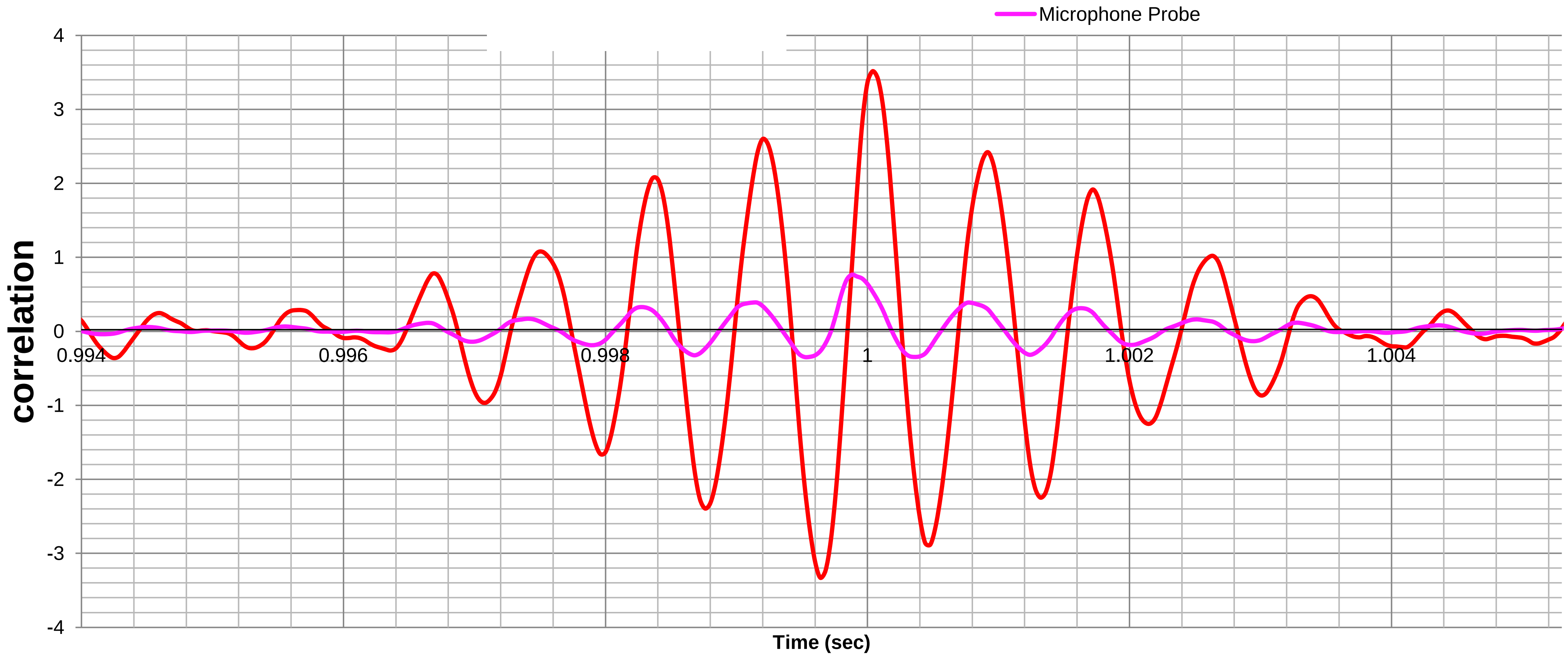


Cold air flow



Gas ignited

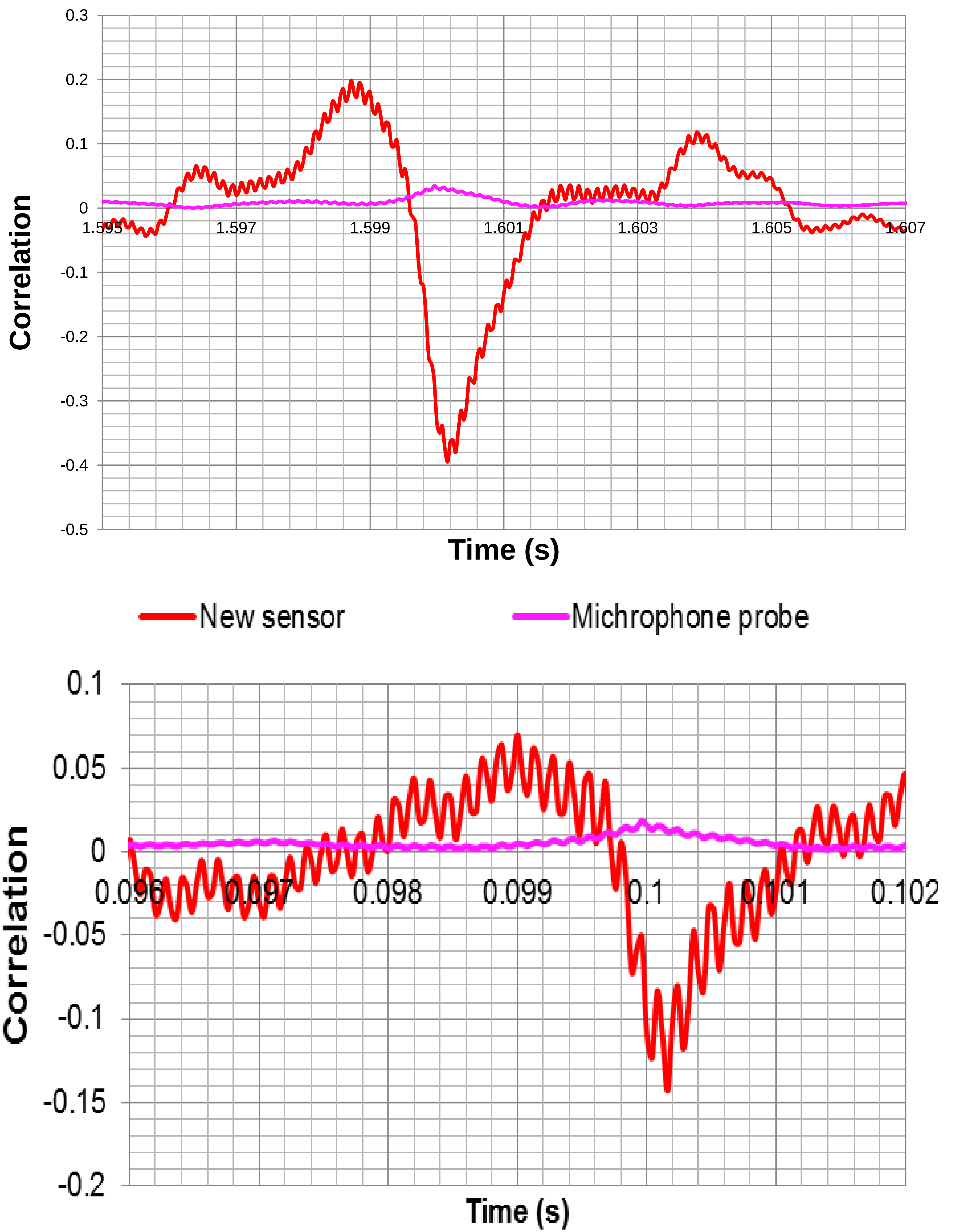
Air Flow Tests



Premixed swirl flame

Φ = 1.0

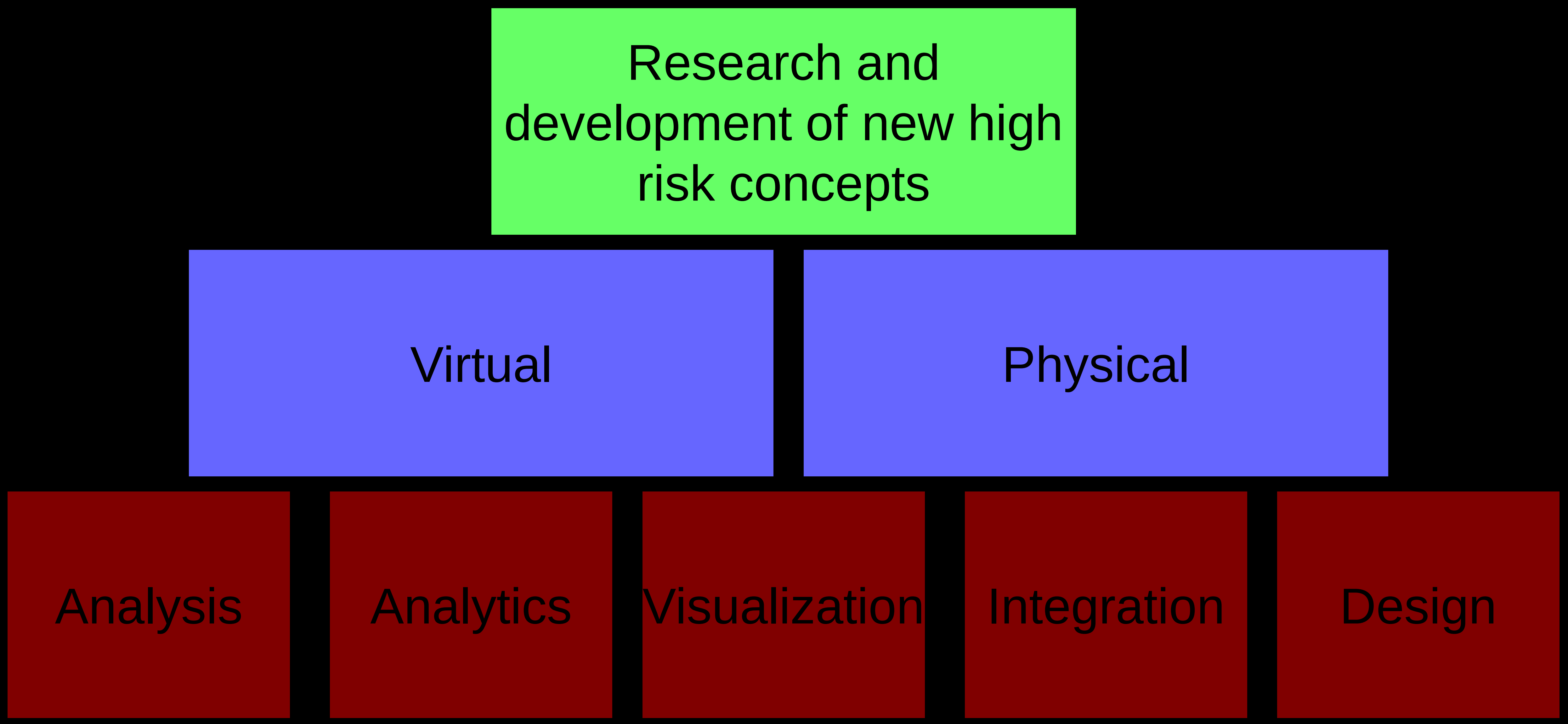
Φ = 0.6



Stigmeric Controls

1. MESA Energy Studio completed
2. Testing ready to begin on the small scale stigmergy control experiment
3. Paper on qualitative stigmergy published

MESA Energy Studio



Stigmergy

Agents interact with each other through the structure under construction (modifying their local environment)

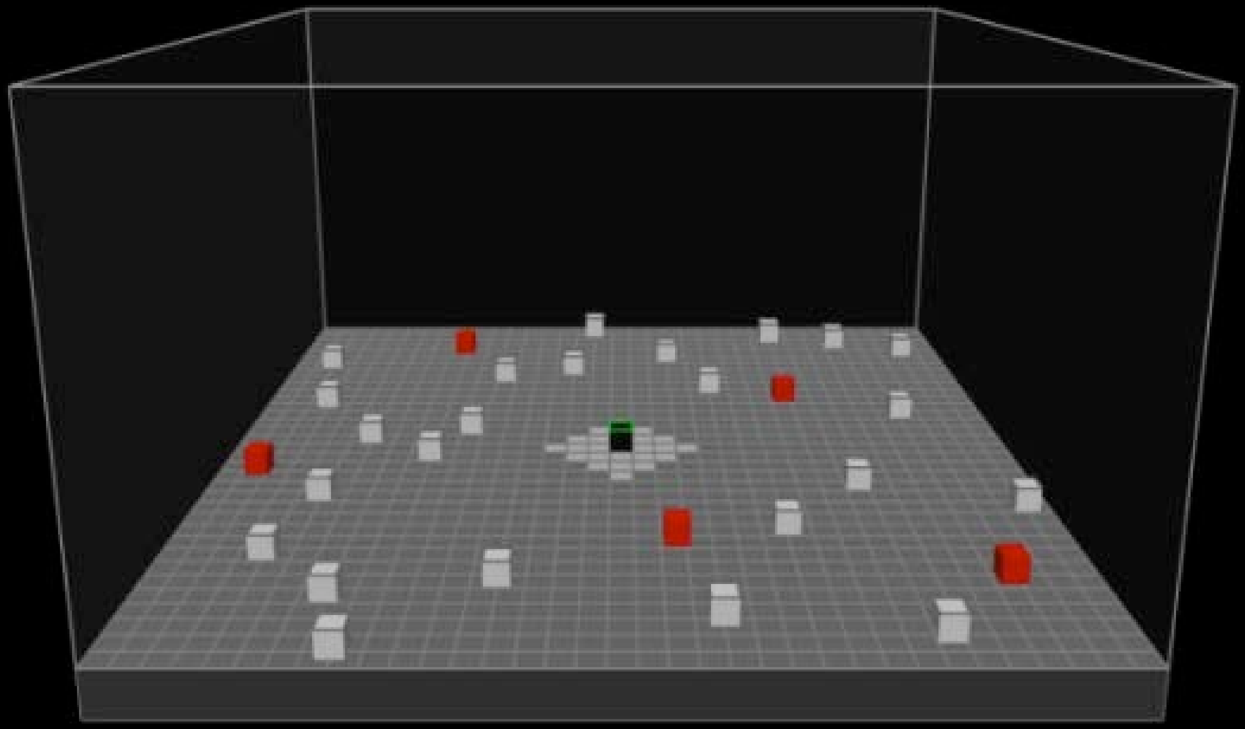
Previous Work

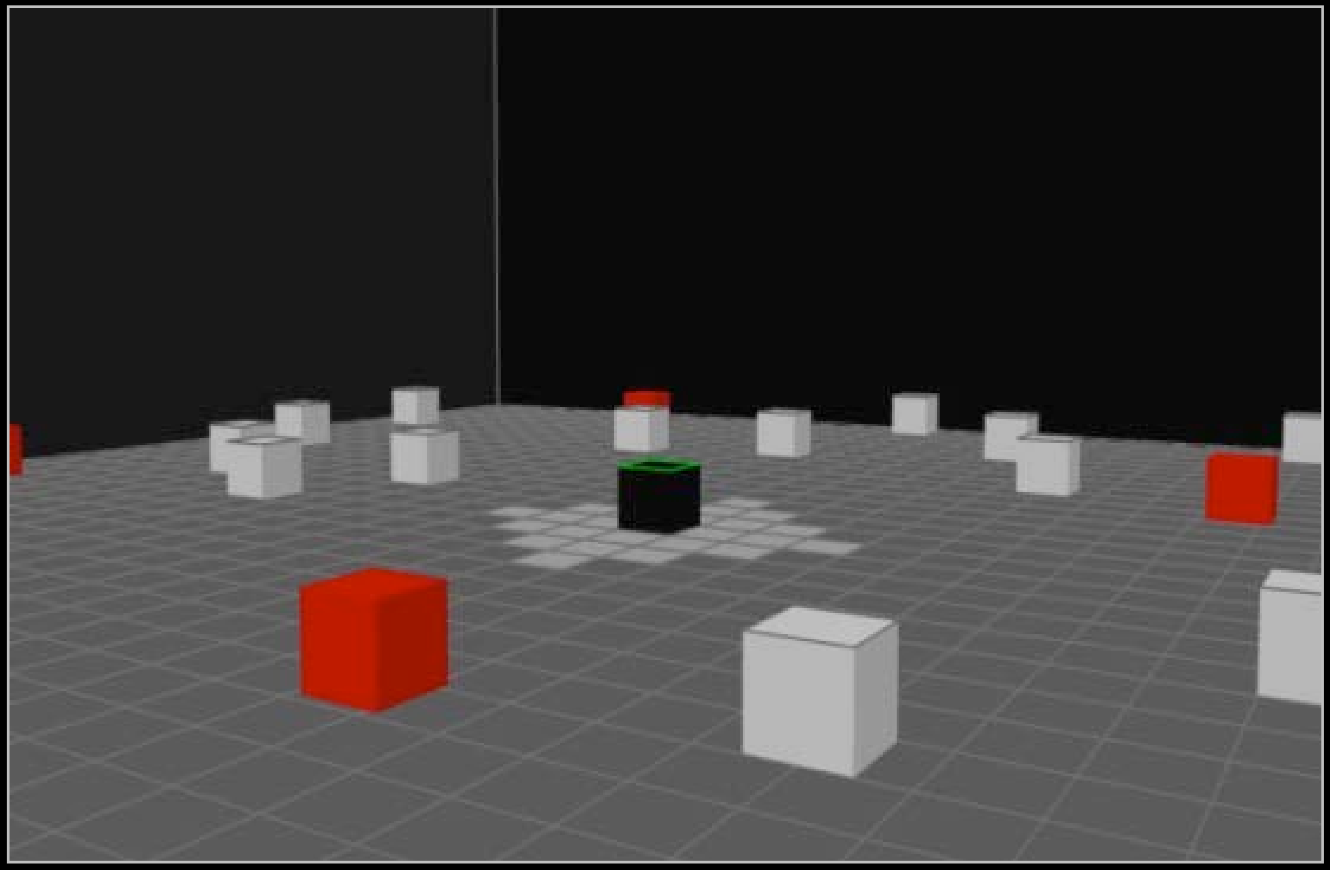
Most efforts have focused on sign-based stigmeric methods such as the ant colony optimization algorithm

- network optimization
- scheduling problems

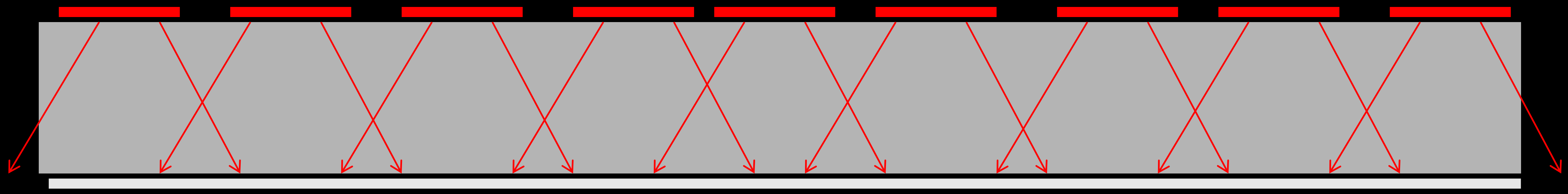
	Sign-based	Sematectonic
Quantitative	Ant colony	Worn down trails
Qualitative		Collective construction

Collective construction problem





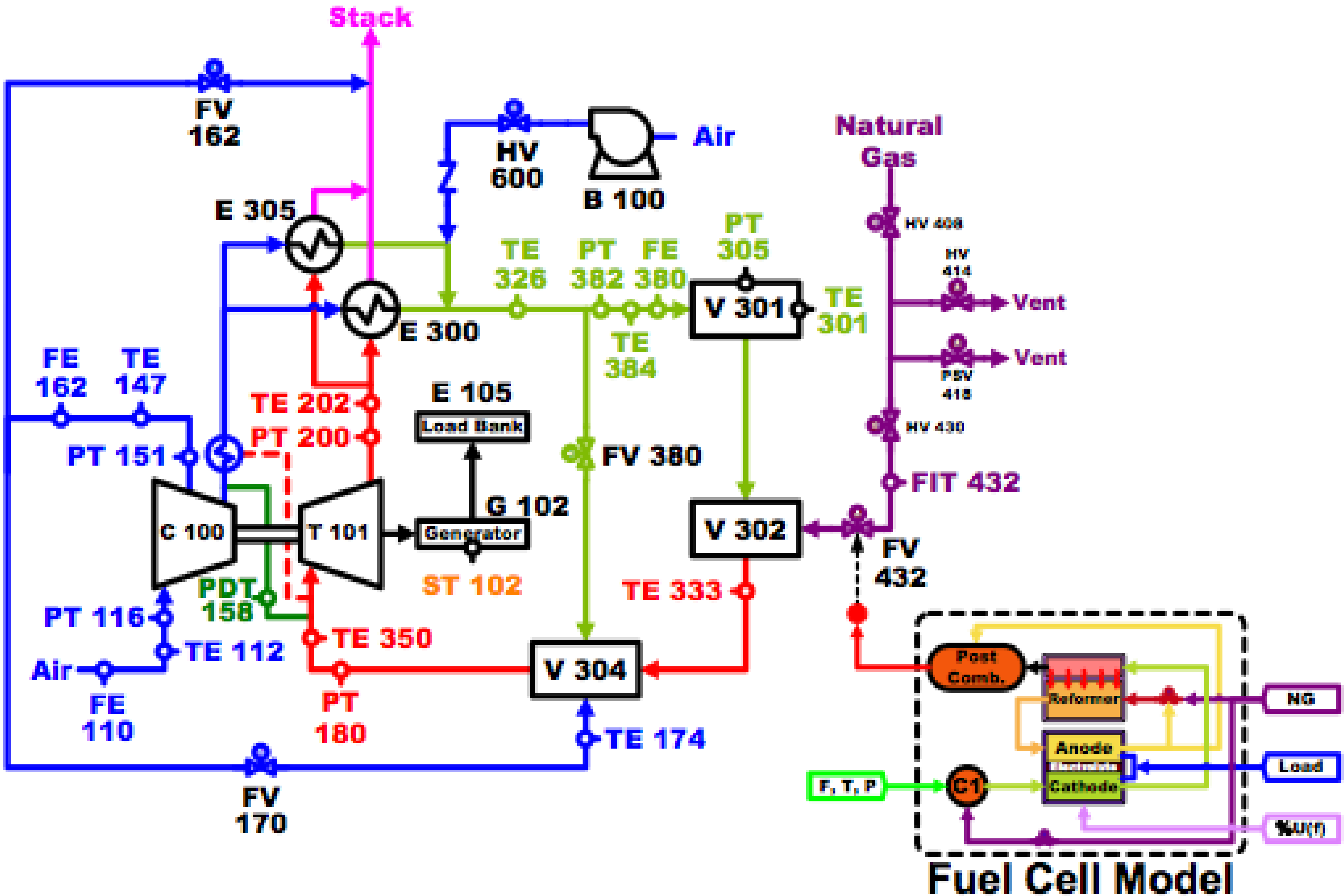
Collective construction problem



Large scale demonstration

1. Finalized the new inferface for VE-Suite
2. Scan of Hyper complete
3. Virtual framework nearly complete

High Performance Project


Stack
FV 162
HV 600
B 100
Air
Natural Gas
HV 408
HV 414
Vent
Vent
PSV 418
HV 430
E 305
E 300
TE 326
PT 382
FE 380
PT 305
V 301
TE 301
TE 384
FE 162
TE 147
TE 202
PT 200
E 105
Load Bank
PT 151
FV 380
FIT 432
C 100
T 101
G 102
Generator
V 302
FV 432
PDT 158
ST 102
TE 333
PT 116
TE 350
TE 112
Air
FE 110
V 304
PT 180
TE 174
FV 170
Post Comb.
Reformer
NG
Anode
Load
F, T, P
C1
Cathode
%U(f)
Fuel Cell Model

Three Steps

FY 2012 ICE can mimic and follow Hyper

FY 2013 ICE controls Hyper

Sensor and Control Strategies tested on ICE

FY 2014 Testing of new sensor and control strategies in the Hyper-ICE facility

FY 2012

- Design/build the Hyper ICE Studio
- VE-Suite connection to current data
- VE-Suite linkage to Hyper models in realtime
- VE-Suite linkage to Hyper realtime
- Demonstrate linkage

FY 2013

- Compare model/sensor output with plant ops
- Test protocols approved
- Determine control strategies to be tested
- Establish baseline data
- Transfer machine controls to ICE
- Test control strategies in ICE
- Run Hyper from ICE

FY 2014

- Establish testing program for various controls strategies
- Test protocols approved
- Realtime optimization testing
- Self-adapting, self-organizing systems
- Two six-week test runs