National Defense Industrial Association Disruptive Technology Conference

"Self-Powered Autonomous Next Generation Chem-Bio Sensors"

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Systems Center
San Diego

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SSC San Diego … on Point and at the Center of C4ISR

Problem Statement → Solution

Problem Statement:

Potential for Chemical / Biological warfare grows with each passing day as terrorist groups / rogue states gain access to, or develop the ability to fabricate life threatening agents.

DoD Need:
Develop small, inexpensive, highly accurate sensors to detect these life threatening agents. If possible, sensors should be small enough and cheap enough to distribute as needed at potential threat areas, e.g. ports, borders, reconnaissance missions, etc.

Solution:

Develop, prototype and demonstrate CB sensor with warning and reporting capabilities for fixed or handheld wireless nodes using self-powering energy scavenging techniques.

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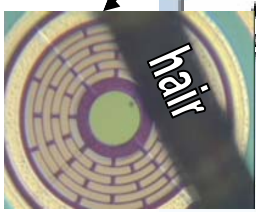
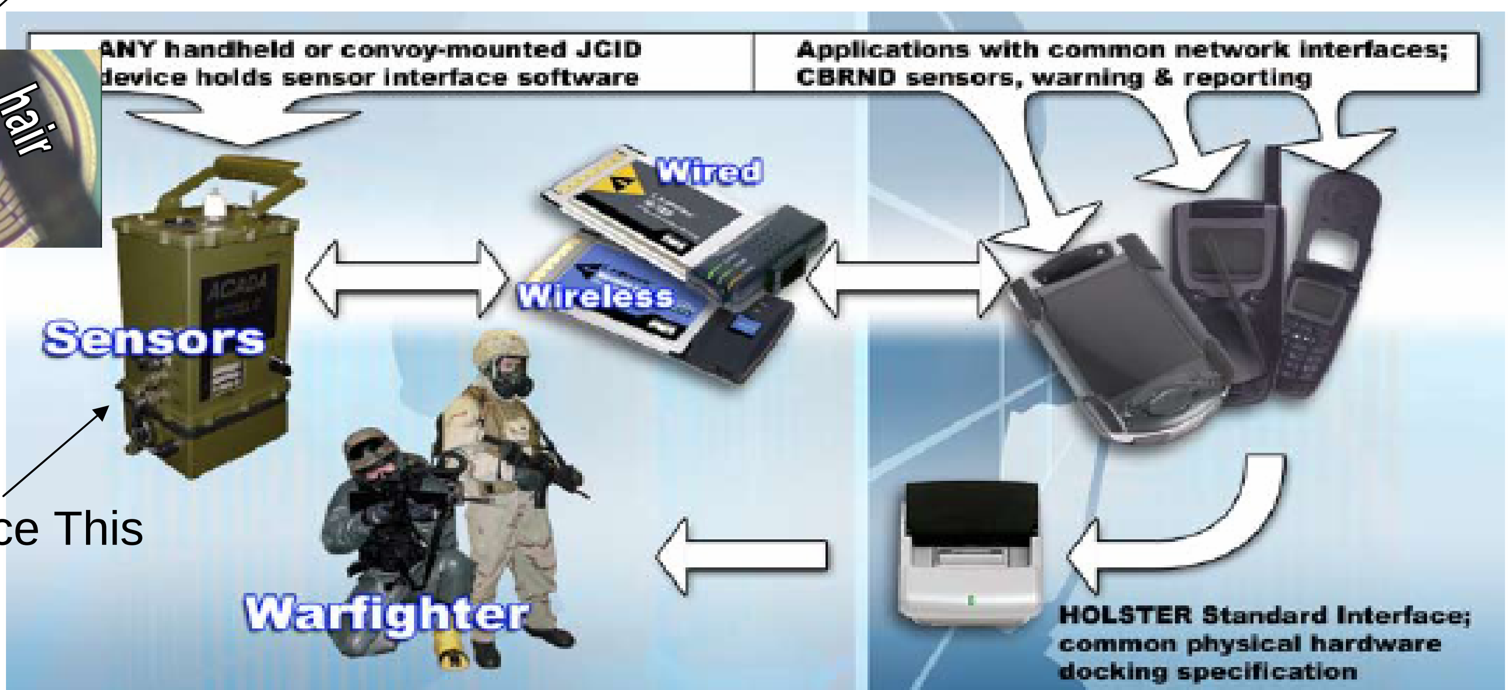
Big Picture

Energy Harvesting – SSC-SD prototyped and patented technology for creating usable energy from vibrational sources using electromagnetic transduction.





Replace This

Existing CBRN Sensors

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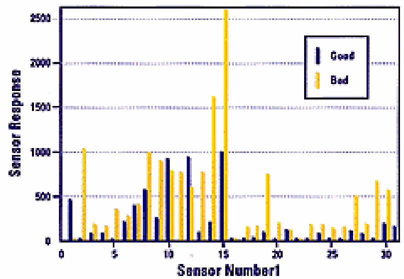
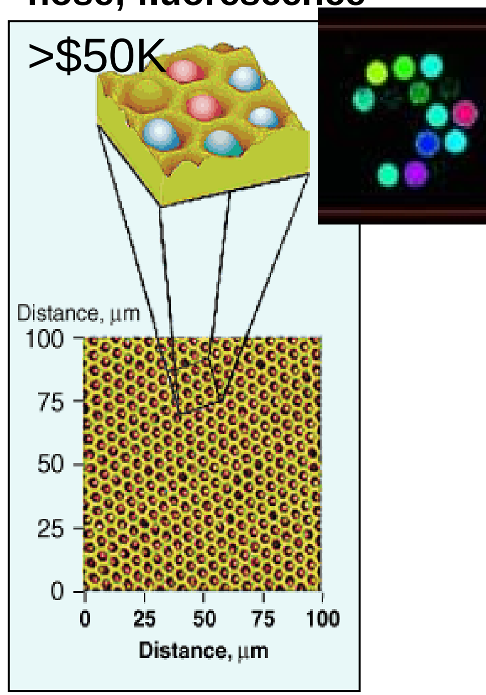
1. Too large
2. Too expensive (particularly for distributed arrays)
3. Consume too much power
4. Require user intervention by a trained technician (not applicable for autonomous operation)
5. Subject to false positives due to technology limitation + single point detection (i.e. lack of multiple sensor redundancy).
6. For positive identification samples must be sent to laboratory for GC/MS or optical spectral analysis.

Examples of Commercially Available, Portable Sensors



Cyranose 320: An electronic nose using chemiresistor sensors

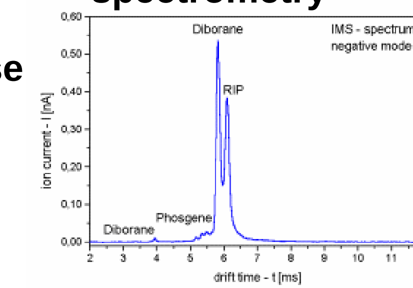
Illumina: artificial nose; fluorescence

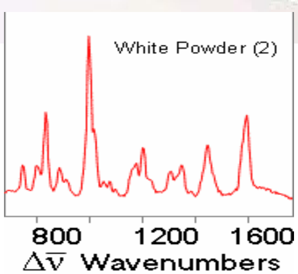


>$5K

HAZMATCAD: electronic nose using SAWs and ECs

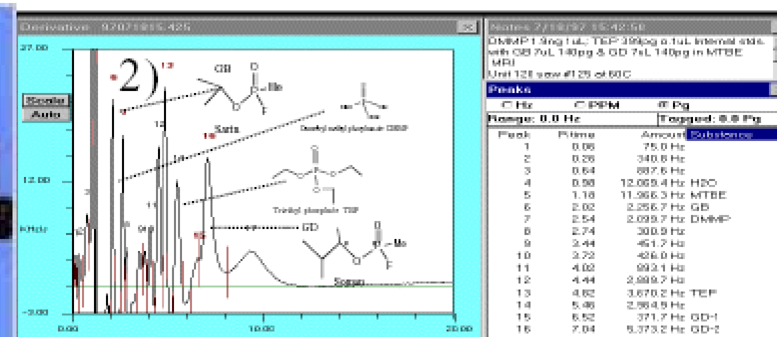
CAM: ion mobility spectrometry





Inspector Raman

ZNOSE 4200: GC/SAW



Sensor Technologies that have been Explored for Use in Disposable CB Sensors

- SAW devices
- CHEMFETs
- Microcantilevers
- Chemoresistors

These sensors use a coating to attract the analyte of interest. In order to detect and positively identify a target, that coating needs to exhibit great selectivity for the target analyte. These devices have no other way of differentiating the target analyte from an interferent.

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Approach

Reduce CB sensor size

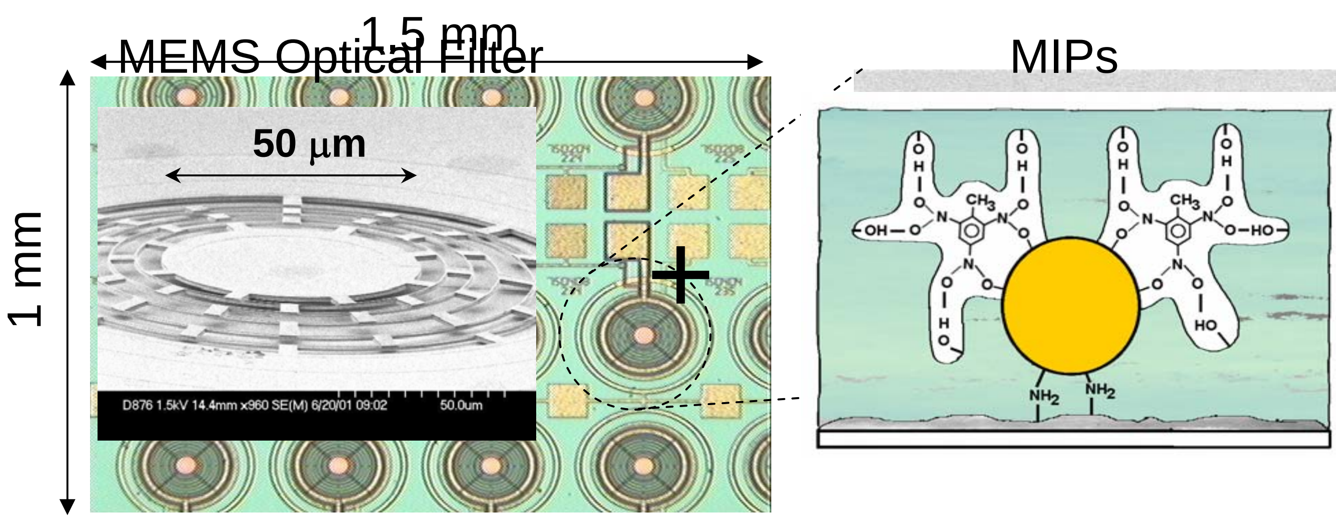
1. Develop micro tunable spectrometer arrays (Reduce an expensive state-of-the-art laboratory system to an inexpensive and small autonomous device which requires little to no user intervention.)

    a) Surface Enhanced Raman Spectroscopy (SERS) – Laboratory experiments have shown single molecule detection using SERS.

    ➢ Couple with SERS active Molecularly Imprinted Polymers (MIPS)

    b) Absorption Spectroscopy

    c) Fluorescence Spectroscopy



Approach

Utilize Energy Scavenging Techniques for self-powering remote nodes

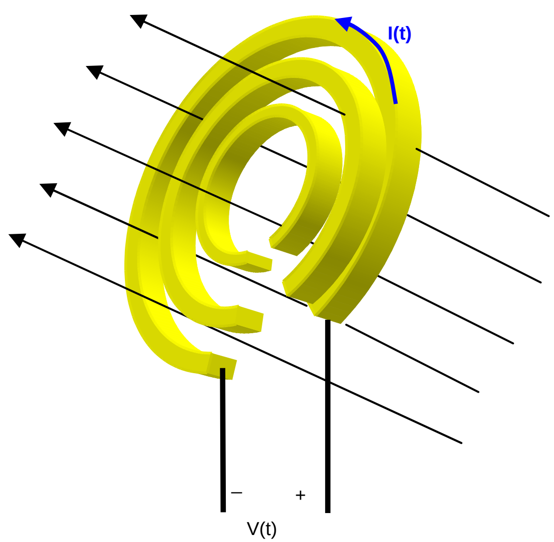
1. Develop vibrational energy harvesting device based on electro-magnetics.
2. Couple energy harvesting device to existing wireless sensor nodes.
3. Integrate other energy harvesting technologies to platform .

$$\oint_{\ell} E \cdot d\ell = -\frac{d}{dt}\int_S B \cdot ds = -\frac{d\psi_m}{dt}$$

$$\vec{B} = B + B_0 \cos(\omega t)$$

$$\frac{d}{dt}\int_S B \cdot ds = \frac{d}{dt} A(B + B_0 \cos(\omega t))$$

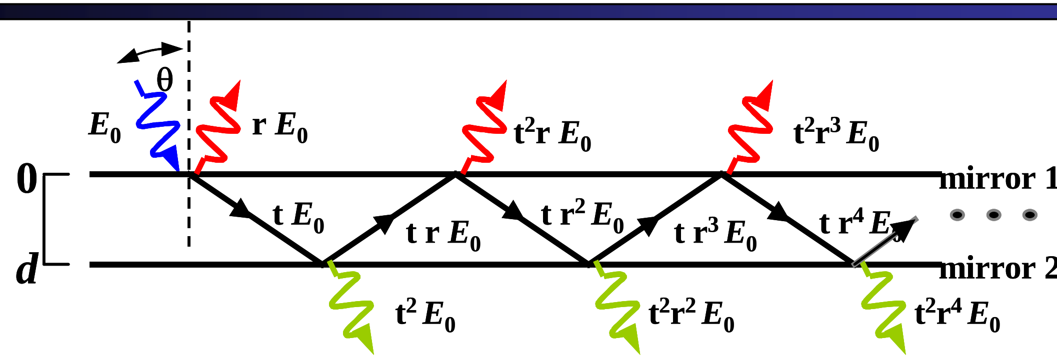
$$V = N(2\pi f B_0 A) = N(2\pi^2 r^2 f B_0)$$



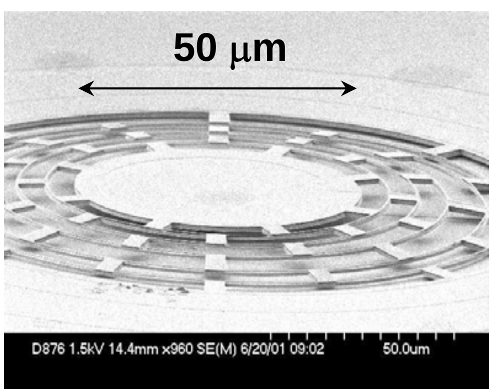
Advantages of Concept

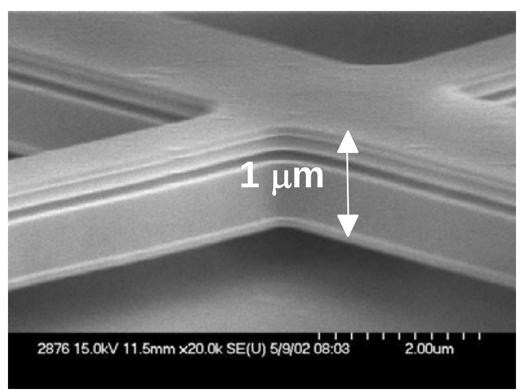
- **<u>Three optical techniques in one device:</u>**
  - **SERS Analysis**
  - Fluorescence Detection
  - Change in Absorption
- **<u>Sensitive</u>** (single molecule detection has been reported for SERS)
- **<u>Specific</u>** (Binding + optical detection greatly reduces false positives)
- **<u>Easily expandable / adjustable</u> to meet emerging threat conditions**
- **<u>Capable of detecting CW, BW & TICs</u>** (multiple agents can be detected in a parallel fashion)
- **<u>Can either be used to detect a single agent or arrayed for simultaneous detection of multiple agents</u>**
- **<u>Low-power</u>** (Each sensor < 10 mW)
- **<u>Compact</u>** (<1 in^3 – includes light source, sensor, comms, and battery).
- **<u>Low-cost</u>** (sensor fabrication utilizes batch fabrication of existing IC infrastructure). $50-$100.
- **<u>Anticipate small temperature / humidity sensitivity</u>**

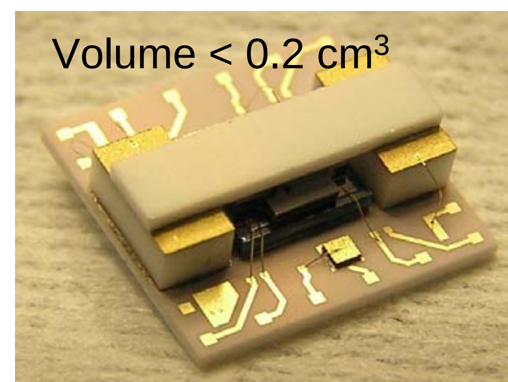
Fabry-Perot Etalon / Interferometer



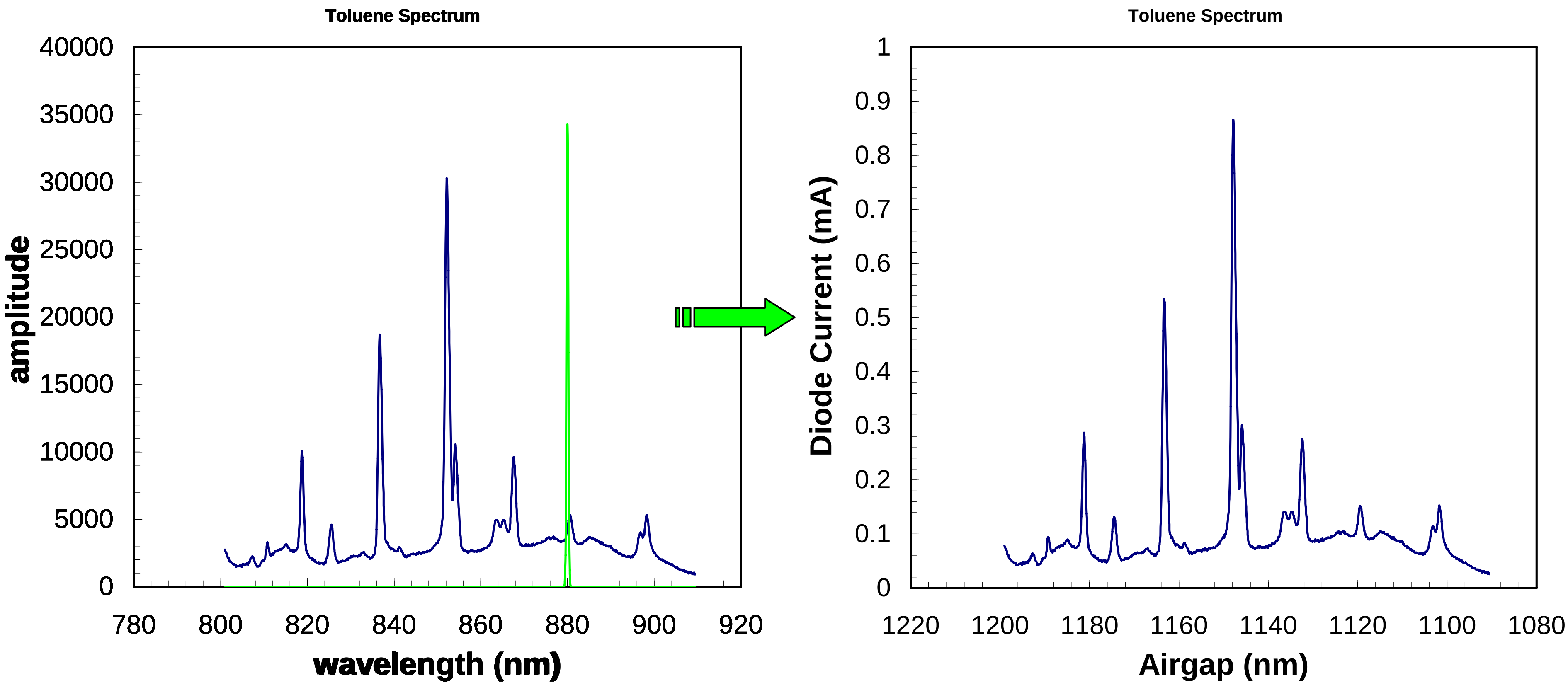
Fabry-Perot Interferometer is comprised of two optically flat parallel mirrors where one of the two mirrors is allowed to move thereby adjusting the spacing between the mirrors. If the spacing is a integral multiple of half wavelengths, a resonance occurs with a corresponding peak in transmission.







Spectrometer: Ideal Operation



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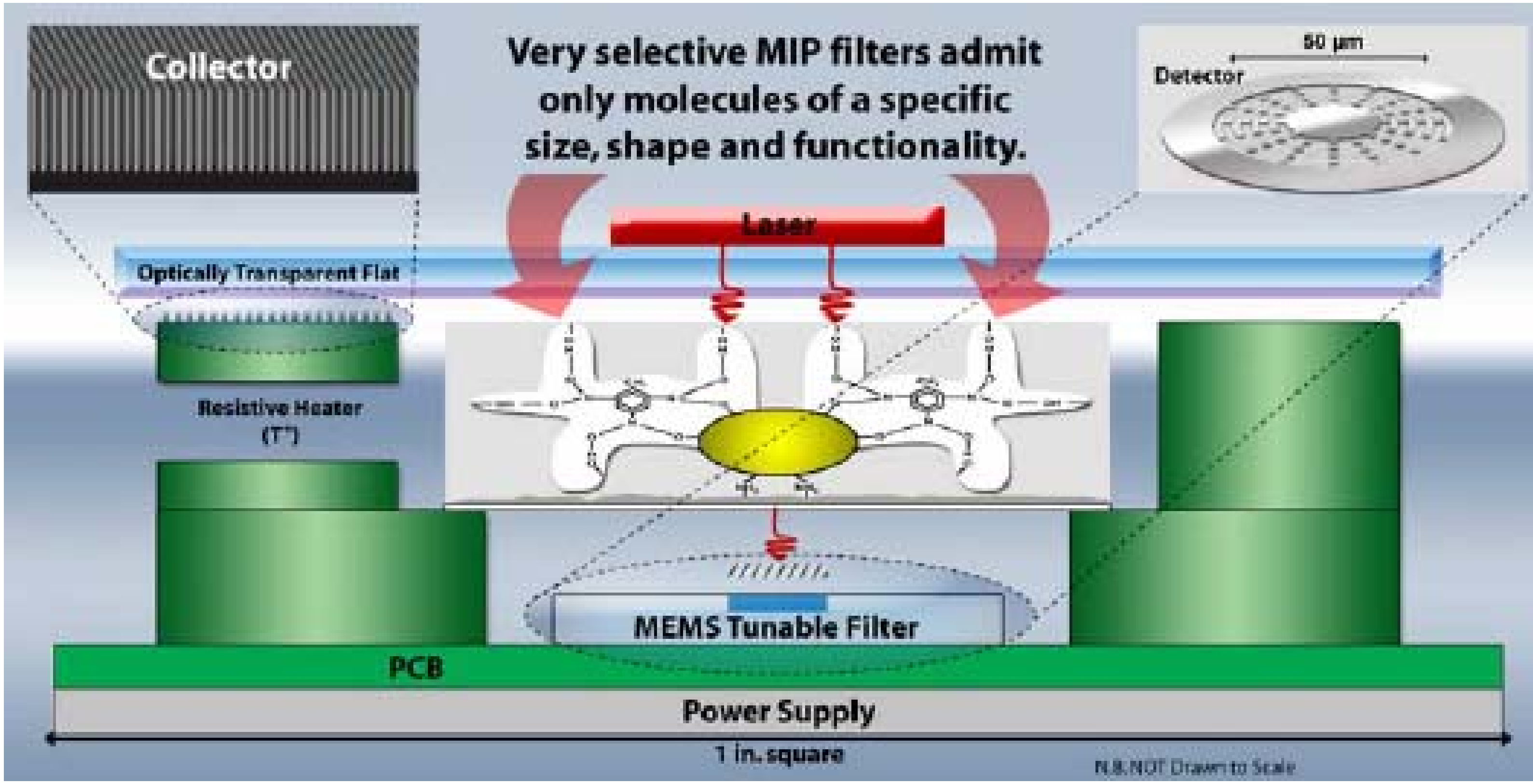
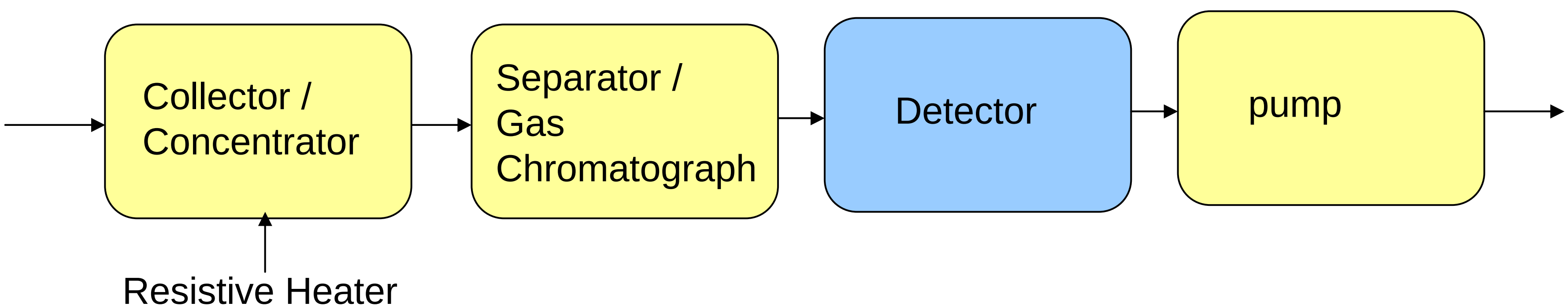
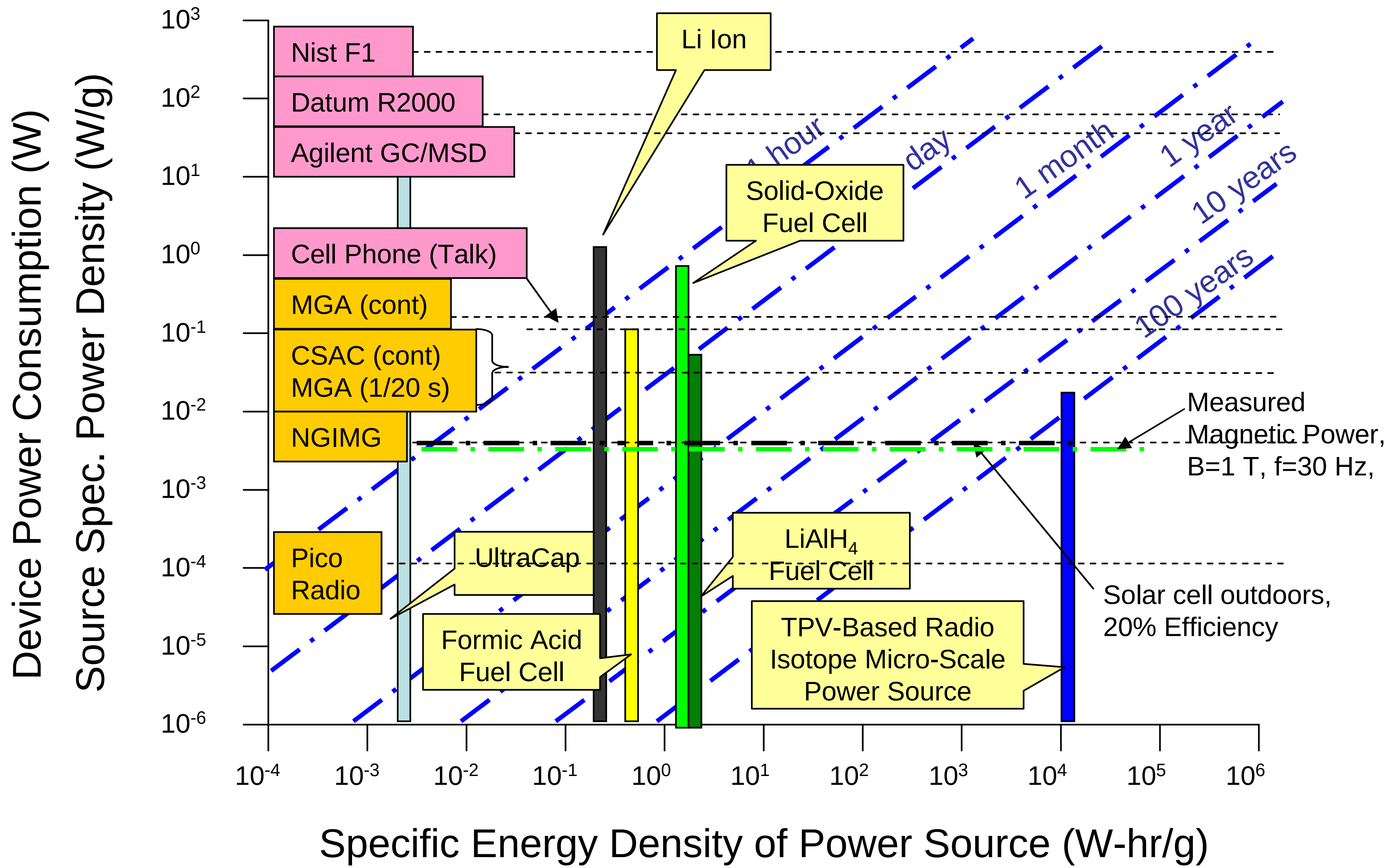
System Description





ENERGY HARVESTING

Power Consumption vs. Longevity



Energy Harvesting Demonstration Vehicle

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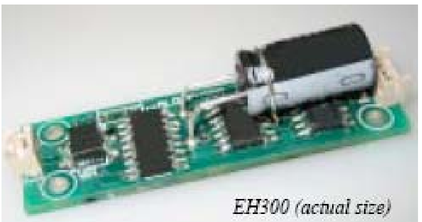
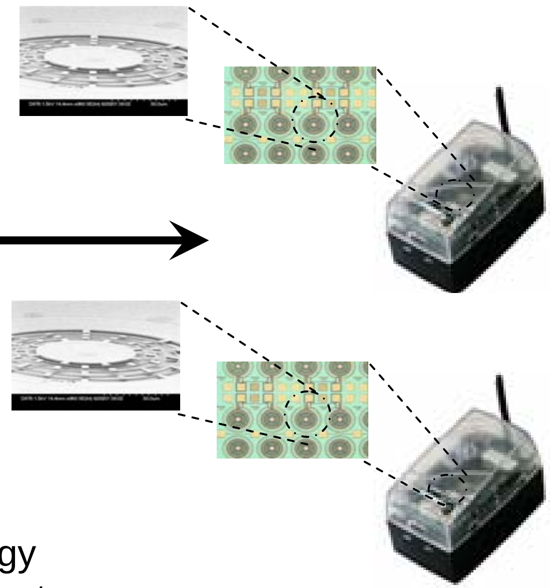
Energy Harvesting Module

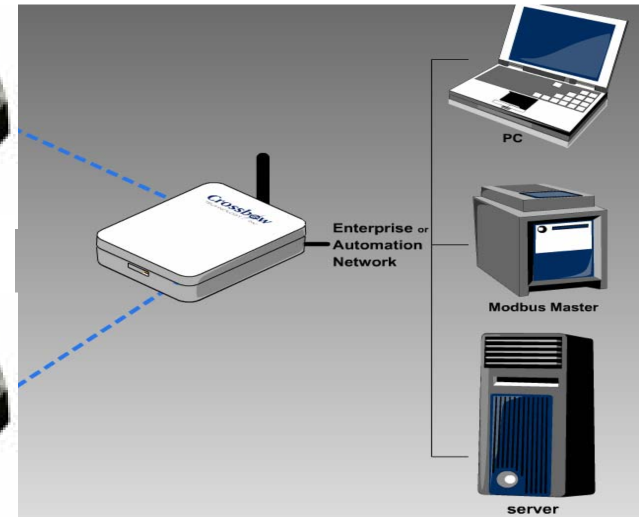


Energy Harvester

VIBRATIONS



Crossbow environmental wireless sensor network



	Process	Current Draw @ 3V	Units
Mica2™	Transmit	27†	ma
	Receive (Sleep Mode)	10†† <1	mA µA
	Processing (Sleep Mode)	8 <15	mA µA
MTS400 Sensor Module	Temperature & Humidity	0.1	mA
	Light Intensity	10	mA
	Barometer	1	mA
	2-axis Accelerometer	<0.6	mA

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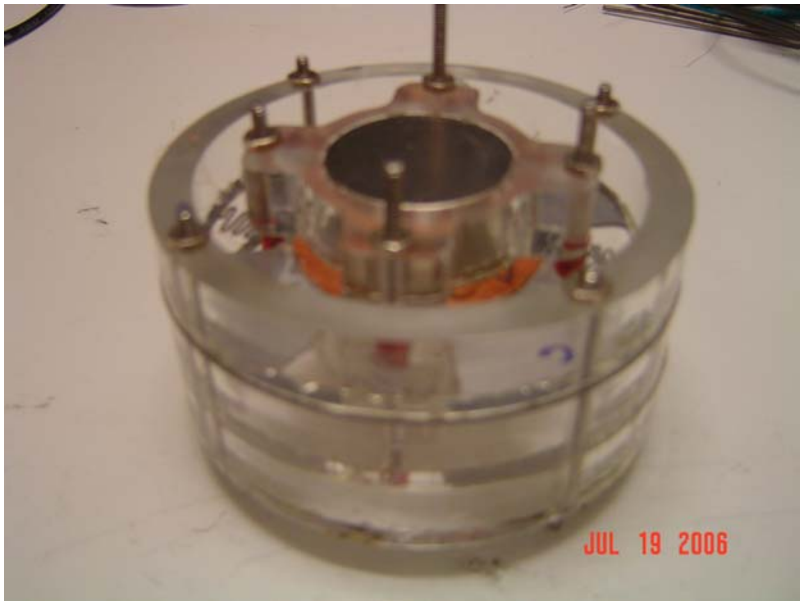
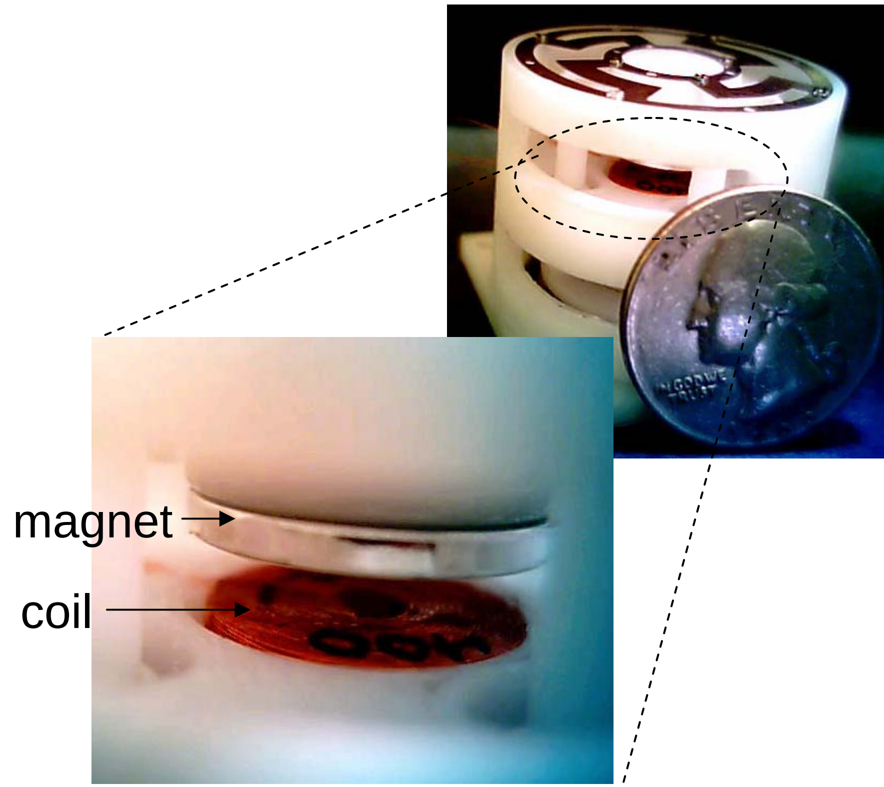
Energy Harvesting Prototypes

1st Generation: 3.85 mW/cc/g



- Hockey puck size
- Resonant Frequency ~30Hz
- Maximum acceleration ~120 mg

2nd Generation: 9.9 mW/cc/g



- Volume ~19 cm^3
- Resonant Frequency ~90Hz
- Maximum acceleration ~1 g

FY07 Experimental Results @35 Hz

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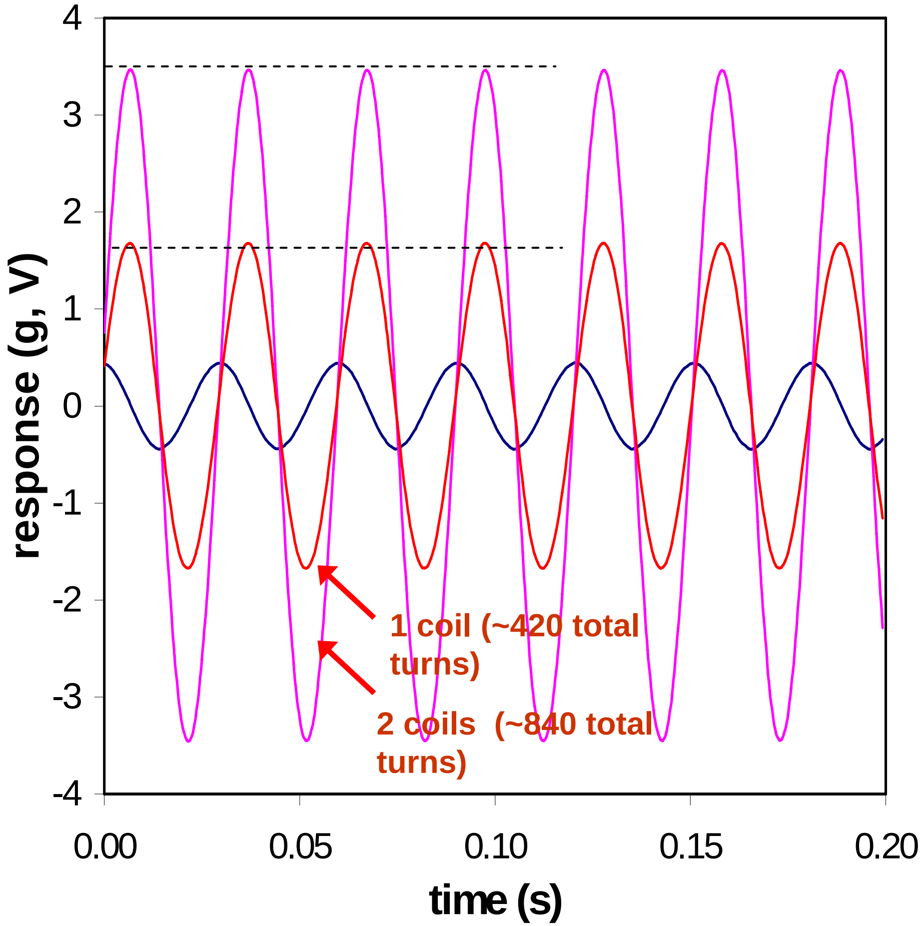
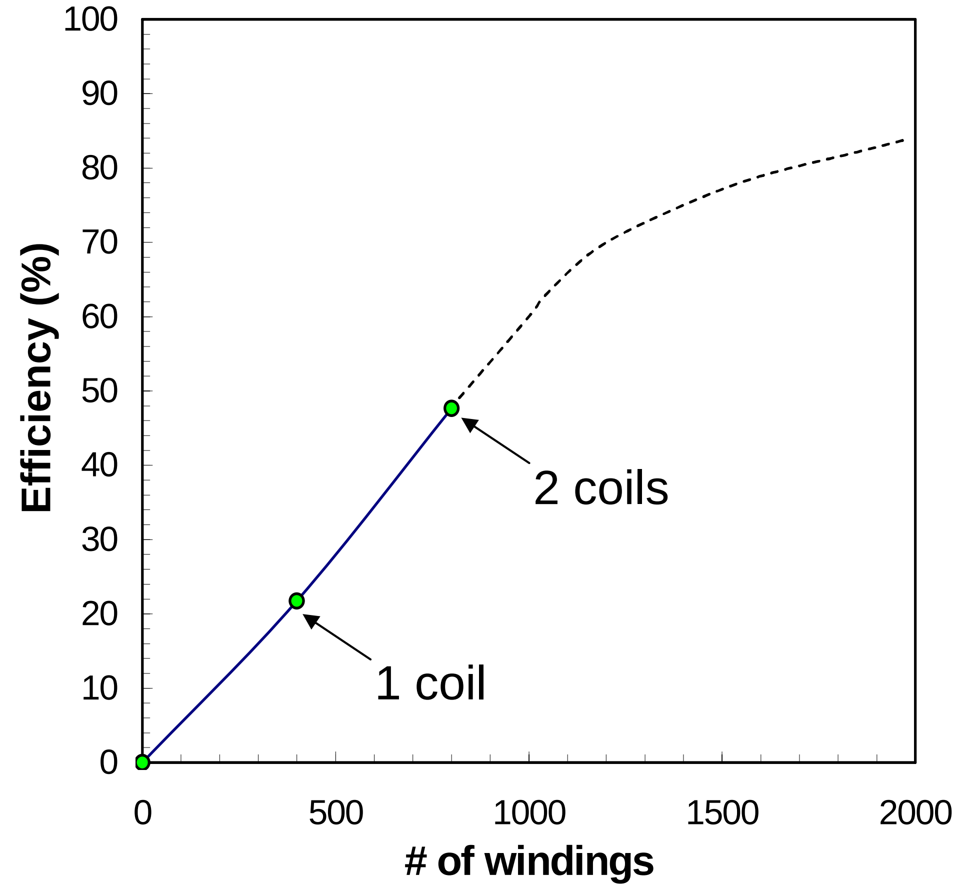
Voltage doubles when # windings doubles

- We have not saturated
- We can still extract more energy with better coil design / smaller wire diameter.





FY07 Experimental Results

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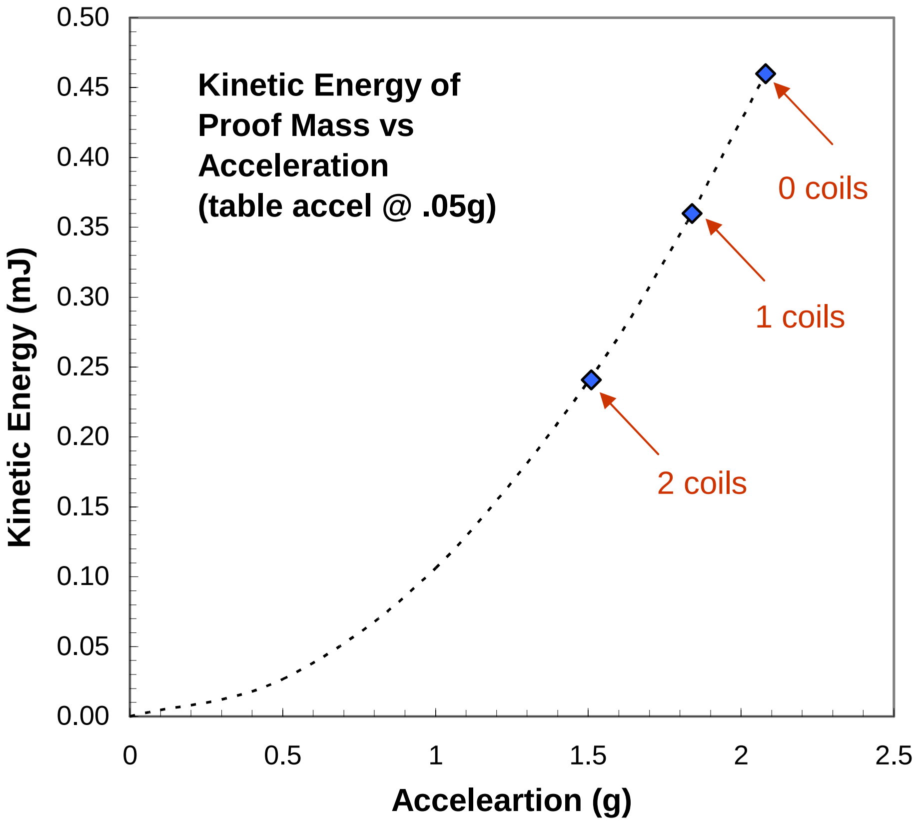
As coils / windings increase, electrical dampening increases and kinetic energy of the vibrating mass decreases.

Therefore, there is an optimum # of coils / windings to maximize energy extraction



- Kinetic energy of proof mass dampened by opposing B field
- Can calculate efficiency
  - KE(no coils) – KE(1coil) x 100 / KE(no coils)

KE eff ~ 22% per coil

Rectified Power efficiency

- P(1 coil) x 100 / KE(no coils)*f

Power eff ~ 21.5%

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Vibration Data (Results Summary)

Test Condition	Avg Output Power (μW)
Car Off	0.43
Car Idling	19.2
Freeway	639 – 1352
Paved Surface Road	331-511
Dirt Road	290 – 662
Walking	18 – 47
Vibration Table @ 30Hz, 0.035g (peak power)	13500

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Summary

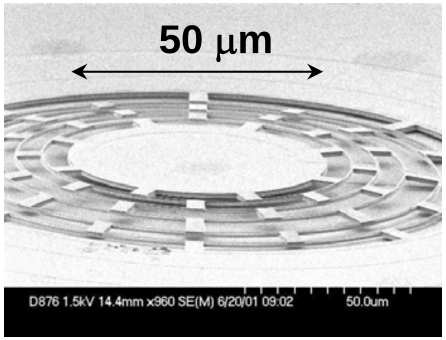
- SSC-SD is developing
  - Micro arrayable spectrometers to replace large, expensive, user intensive laboratory grade analysis equipment.
    - Sensors will be low-cost, expandable to meet emerging threat conditions, accurate, and consume less than 10 mW.
    - Will utilize JWARN, JCID and HOLSTER in its final implementation
  - Energy Harvesting Modules based on vibrational energy with power densities of >9mW/cm^3/g.
    - As demonstration vehicle we will power Crossbow wireless sensor nodes.

Backup

Our Concept

Combine demonstrated MEMS tunable optical filters with Molecularly Imprinted Polymers (MIPs) for Surface Enhanced Raman Spectroscopy (SERS).

MEMS Optical Filter



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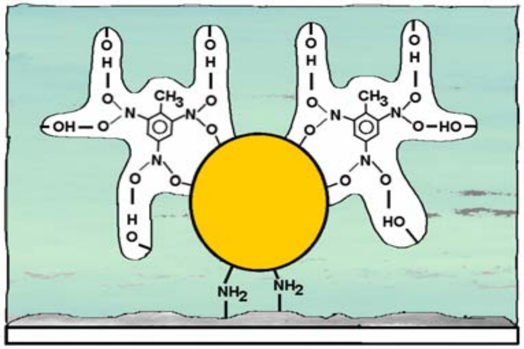
MIPs



Operational Concept (How it Works)

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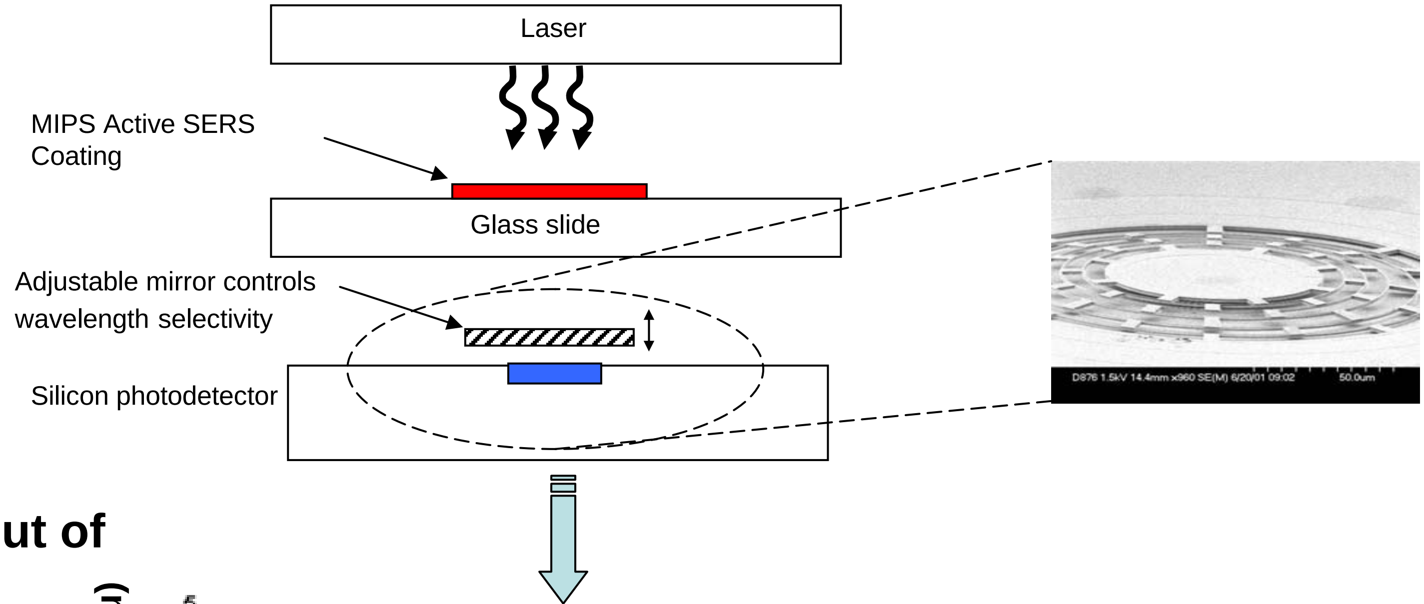
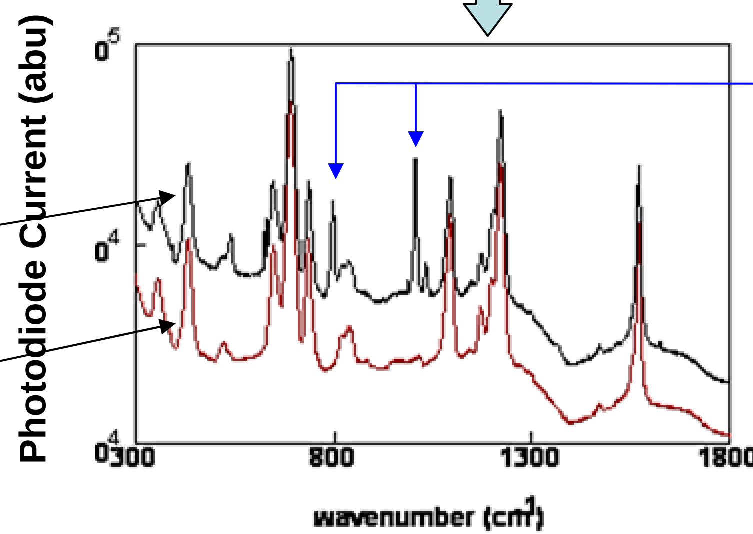
Depiction of proposed assembly for testing. Assembly includes FPI sensor, glass slide with coating and halogen or broad spectrum LED light source.



Expected Output of Photodiode:

Top spectrum *is coating reacting with Toluene (TIC)*

Bottom spectrum *is unreacted Coating*



Proportional to Distance between mirrors

Additional peaks positively identify presence of Toluene (TIC)

Binding + optical detection greatly reduces false positives

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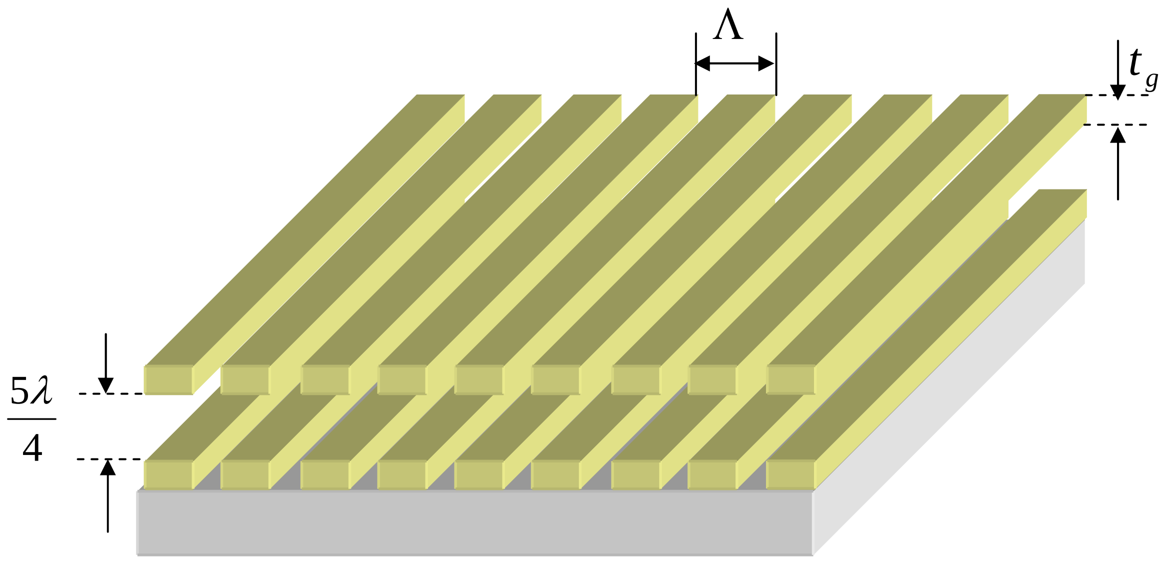
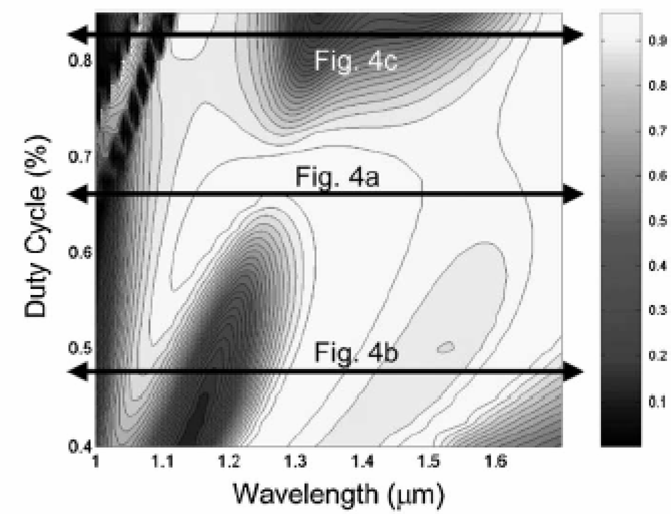
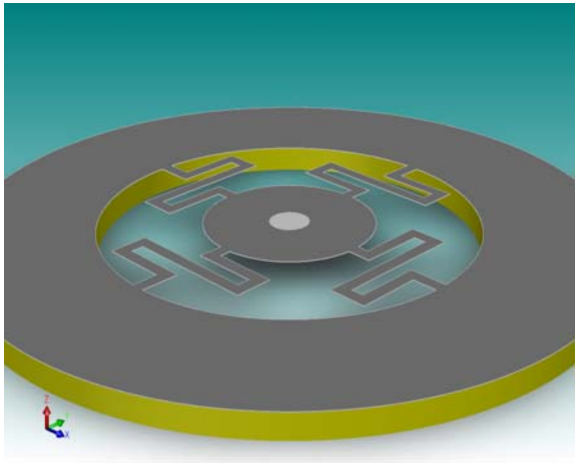
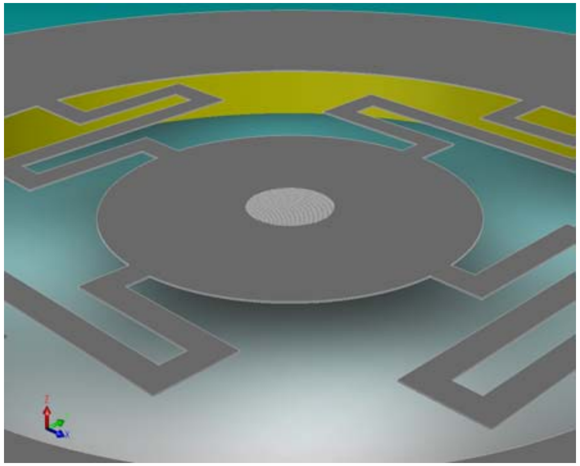
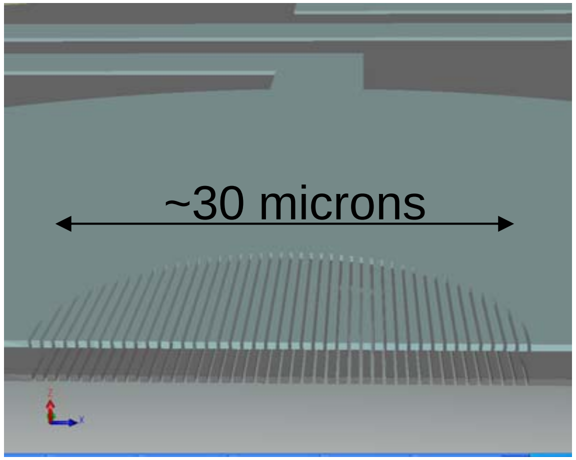
High-Contrast sub-wavelength Grating (HCG) Mirror











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Background: Common Vibration Sources

VIBRATION SOURCE	PEAK ACCELERATION (m/s^2)	FREQUENCY (Hz)
BASE OF 3-AXIS MACHINE TOOL	10	70
KITCHEN BLENDER CASING	6.4	121
CLOTHES DRYER	3.5	121
DOOR FRAME JUST AS DOOR CLOSES	3	125
SMALL MICROWAVE OVEN	2.25	121
HVAC VENTS IN OFFICE BUILDING	0.2 – 1.5	60
WOODEN DECK WITH FOOT TRAFFIC	1.3	385
BREADMAKER	1.03	121
EXTERNAL WINDOWS (2 FT. X 3 FT) NEXT TO A BUSY STREET	0.7	100
NOTEBOOK COMPUTER WHILE CD IS BEING READ	0.6	75
WASHING MACHINE	0.5	109
SECOND STORY FLOOR OF A WOOD FRAME OFFICE BUILDING	0.2	100
REFRIGERATOR	0.1	240