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EE C247B – ME C218 Introduction to MEMS Design Spring 2016

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Lecture Module 2: Benefits of Scaling

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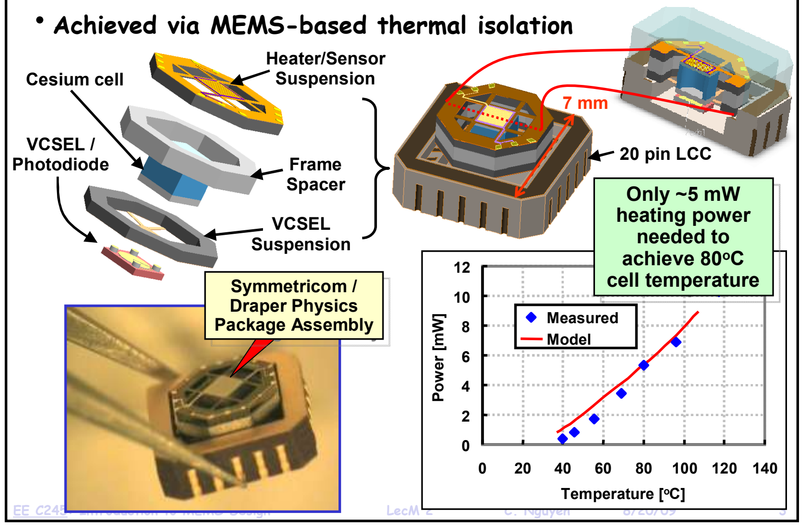
Physics Package Power Diss. < 10 mW

- Achieved via MEMS-based thermal isolation



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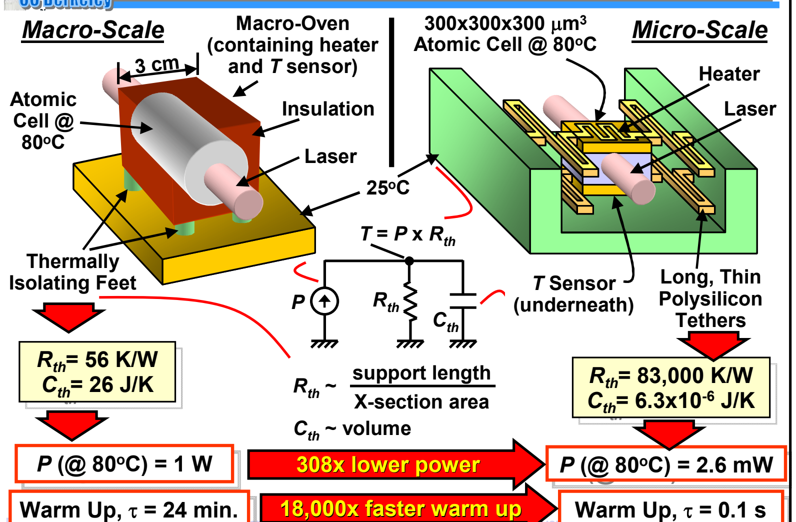
Micro-Scale Oven-Control Advantages



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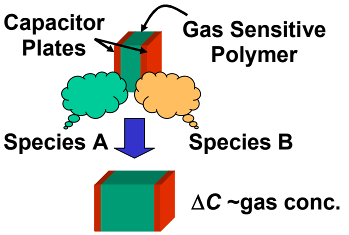
Micro Gas Analyzers (MGA)

Micro Gas Analyzers

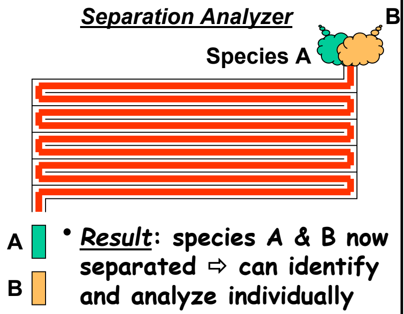
- *Objective*: enable remote detection of chemical agents via tiny, ultra-low power, fast, chip-scale gas analyzers that greatly reduce the incidence of false positives
- *Approach*: use micromachining technologies to implement separation-based analyzers (e.g., gas chromatographs, mass spectrometers) at the micro-scale to enhance gas selectivity

Conventional Sensor



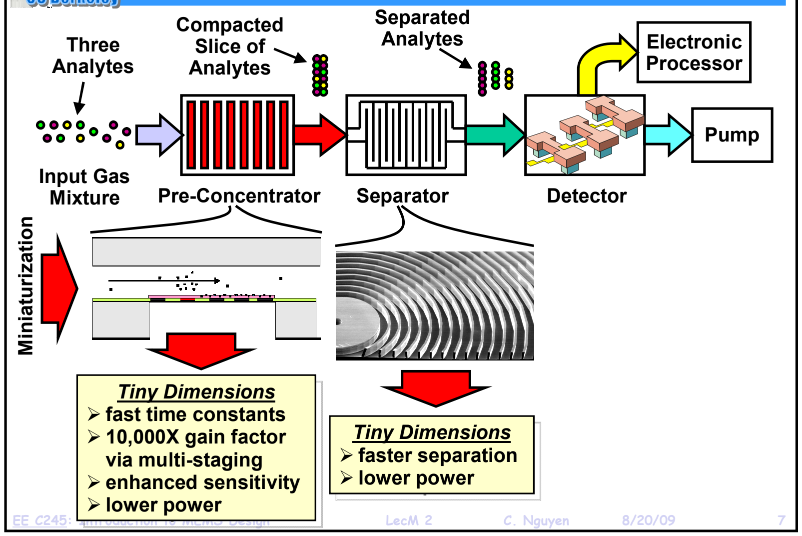
- *Problem*: polymer has finite sensitivity to both A & B

Separation Analyzer



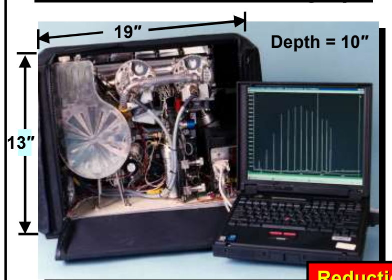
- *Result*: species A & B now separated ⇨ can identify and analyze individually

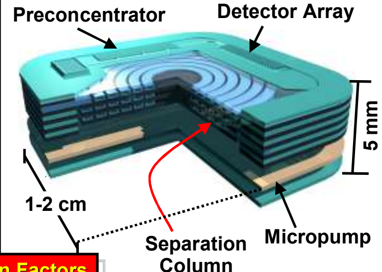
Basic Approach: Separation Analyzer



Advantages of Miniaturization

Portable Gas Chromatograph | *Chip-Scale Gas Chromatograph*



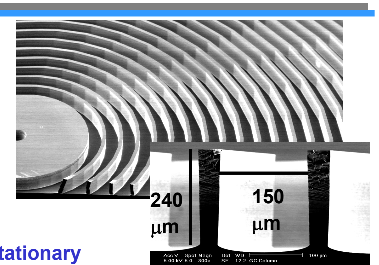


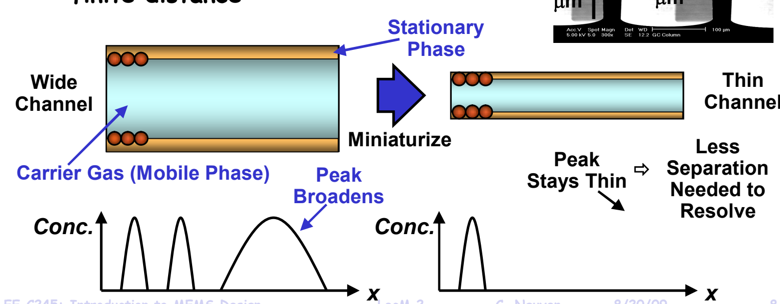
Reduction Factors

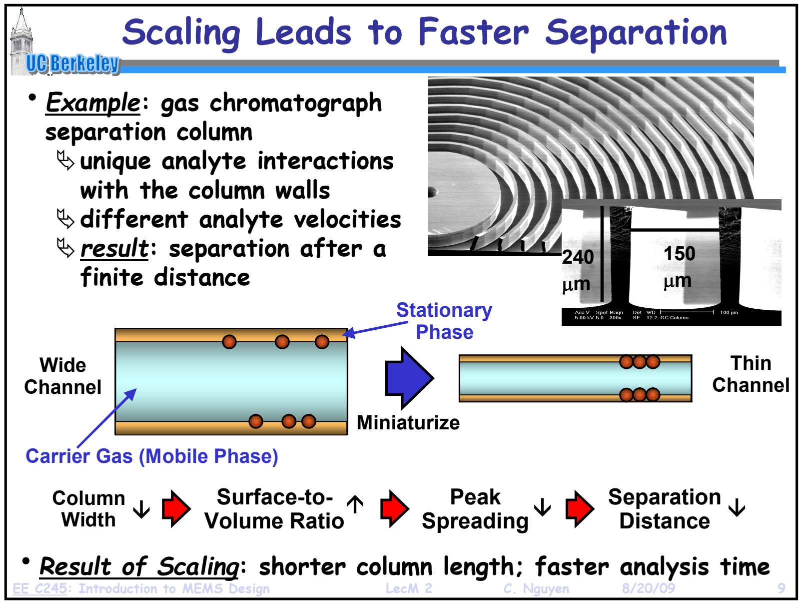
Portable		Reduction	Chip-Scale	
Size	40,500 cm^3	20,000X	Size	2 cm^3
Sensitivity	1 ppb	1,000X	Sensitivity	1 ppt
Analysis Time	15 min.	225X	Analysis Time	4 sec
Energy Per Analysis	10,000 J	10,000X	Energy Per Analysis	1 J

Scaling Leads to Faster Separation

- *Example*: gas chromatograph separation column
  - unique analyte interactions with the column walls
  - different analyte velocities
  - *result*: separation after a finite distance






Scaling Leads to Faster Separation
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• Example: gas chromatograph separation column
unique analyte interactions with the column walls
different analyte velocities
result: separation after a finite distance
240 μm
150 μm
Stationary Phase
Wide Channel
Miniaturize
Thin Channel
Carrier Gas (Mobile Phase)
Column Width ↓
Surface-to-Volume Ratio ↑
Peak Spreading ↓
Separation Distance ↓
• Result of Scaling: shorter column length; faster analysis time
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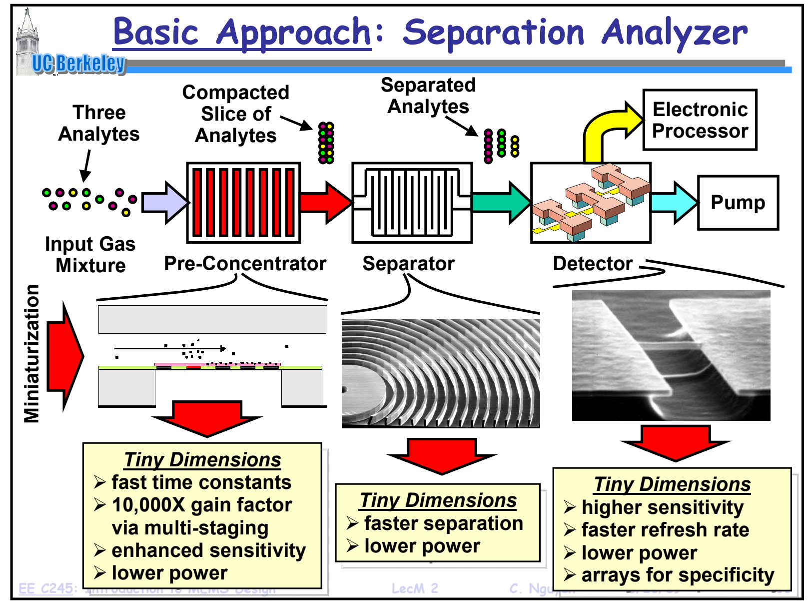
Basic Approach: Separation Analyzer
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Three Analytes
Compacted Slice of Analytes
Separated Analytes
Electronic Processor
Pump
Input Gas Mixture
Pre-Concentrator
Separator
Detector
Miniaturization
Tiny Dimensions
➢ fast time constants
➢ 10,000X gain factor via multi-staging
➢ enhanced sensitivity
➢ lower power
Tiny Dimensions
➢ faster separation
➢ lower power
Tiny Dimensions
➢ higher sensitivity
➢ faster refresh rate
➢ lower power
➢ arrays for specificity
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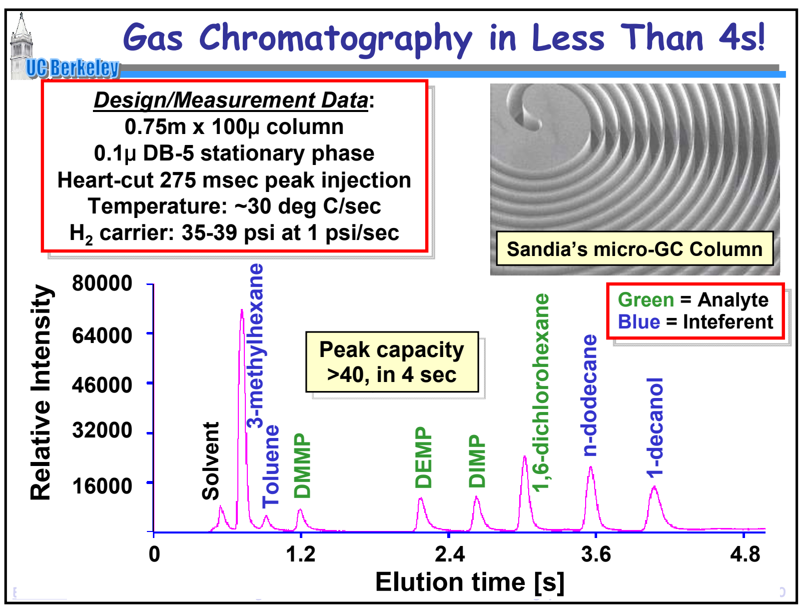
Gas Chromatography in Less Than 4s!
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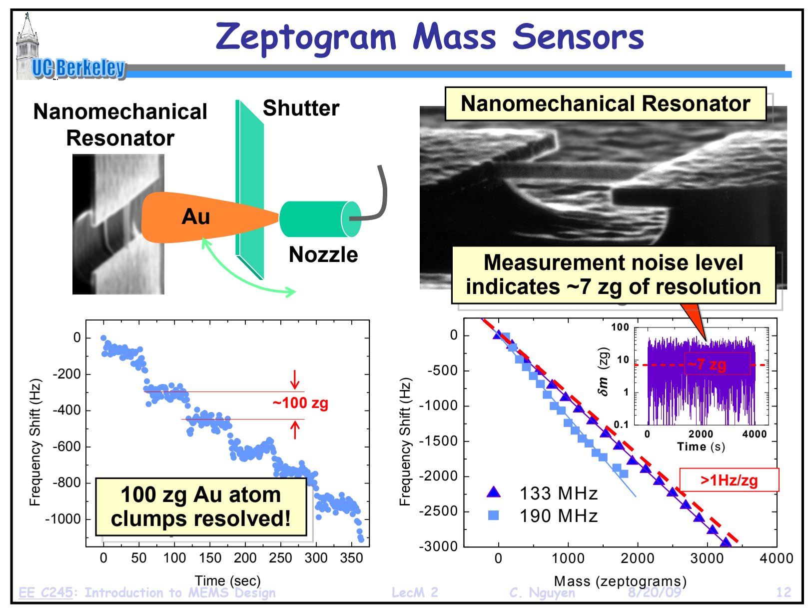
Design/Measurement Data:
0.75m x 100μ column
0.1μ DB-5 stationary phase
Heart-cut 275 msec peak injection
Temperature: ~30 deg C/sec
H_2 carrier: 35-39 psi at 1 psi/sec
Sandia's micro-GC Column
Green = Analyte
Blue = Inteferent
Peak capacity >40, in 4 sec
Relative Intensity
80000
64000
46000
32000
16000
Solvent
3-methylhexane
Toluene
DMMP
DEMP
DIMP
1,6-dichlorohexane
n-dodecane
1-decanol
0
1.2
2.4
3.6
4.8
Elution time [s]


Zeptogram Mass Sensors
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Nanomechanical Resonator
Shutter
Au
Nozzle
Nanomechanical Resonator
Measurement noise level indicates ~7 zg of resolution
~100 zg
100 zg Au atom clumps resolved!
Frequency Shift (Hz)
Time (sec)
~7 zg
>1Hz/zg
133 MHz
190 MHz
Mass (zeptograms)
Time (s)
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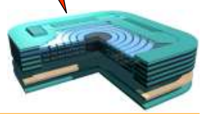
Gas Analyzer Technology Progression

Agilent 6852A
Vol: 60,000 cm^3
Power: 20 W
Energy/Analysis: 18 kJ
Analysis Time: 15 min.

LLNL
Vol: 40,500 cm^3
Power: 11.5 W
Energy/Analysis: 10 kJ
Analysis Time: 15 min.

Sandia µChem Lab
Vol: 1,050 cm^3
Power: 4.5 W
Energy/Analysis: 540 J
Analysis Time: 2 min.

- small enough for projectile delivery
- 1 ppt det. limit
- very fast
- battery operable



Gas Chromatograph/Mass Spectrometer (GC/MS) is a "gold standard" in chemical gas detection with excellent immunity to false alarms

Problems: too big, too slow, power hungry

Solution: use MEMS technology to miniaturize the GC/MS, which in turn makes it faster and more energy efficient

MGA Objective
Vol: 2 cm^3
Power: <200 mW
Energy/Analysis: 1 J
Analysis Time: 4 s

Messages Going Forward …

- MEMS are micro-scale or smaller devices/systems that operate mainly via a mechanical or electromechanical means
- MEMS ⇨ NEMS offer the same scaling advantages that IC technology offers (e.g., speed, low power, complexity, cost), but they do so for domains beyond electronics:

Size ↓ ➡
- resonant frequency ↑ (faster speed)
- actuation force ↓ (lower power)
- # mechanical elements ↑ (higher complexity)
- integration level ↑ (lower cost)

- Micro … nano … *it's all good*
- Just as important: MEMS or NEMS have brought together people from diverse disciplines ⇨ this is the key to growth!
- What's next? ⇨ Nano-nuclear fusion? Chip-scale atomic sensors?

… limitless possibilities …

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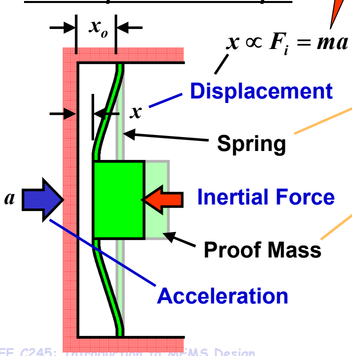
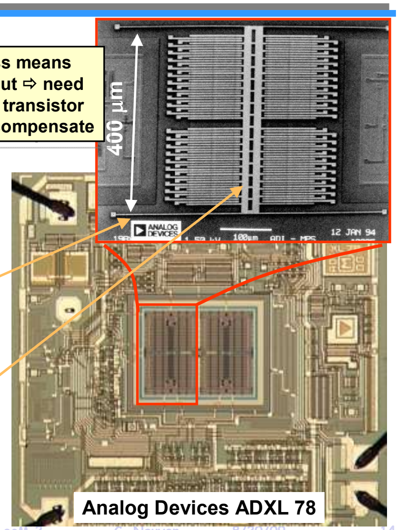
Example: Micromechanical Accelerometer

- *The MEMS Advantage*:
  - >30X size reductio[n] accelerometer mec[hanical]
  - allows integration w[ith]

Tiny mass means small output ⇨ need integrated transistor circuits to compensate

Basic Operation Principle





Analog Devices ADXL 78