EE C245 – ME C218
Introduction to MEMS Design
Fall 2011

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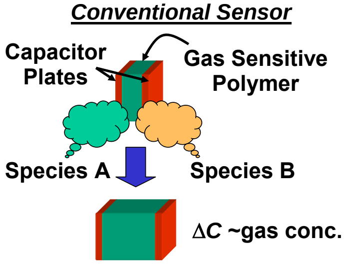
Lecture Module 2: Benefits of Scaling

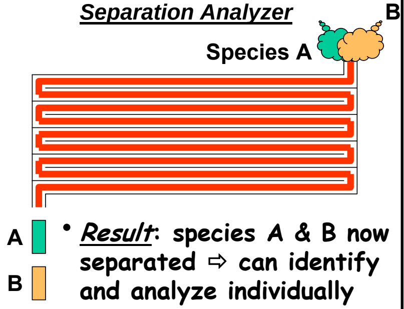
Micro Gas Analyzers (MGA)

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

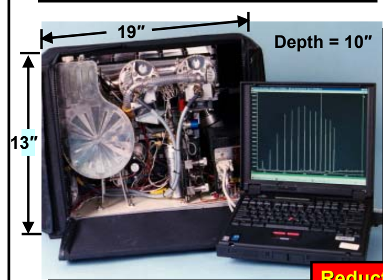


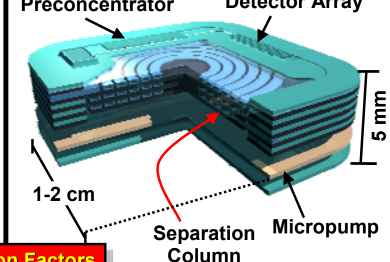
- *Problem*: polymer has finite sensitivity to both A & B



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

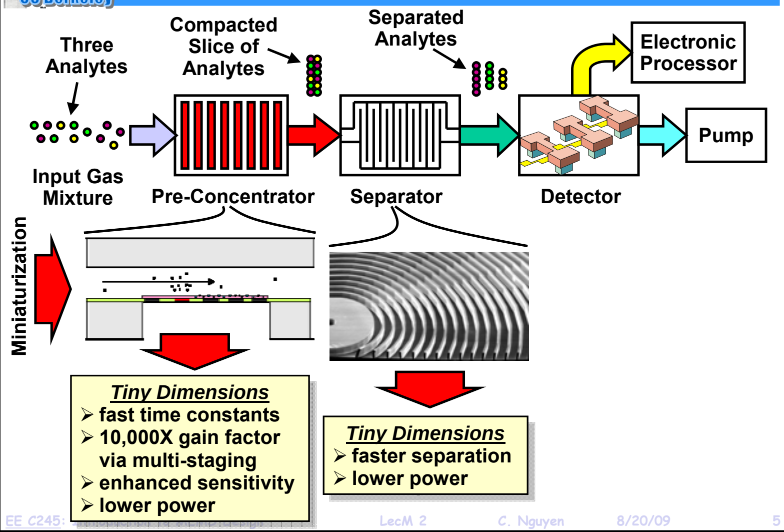
Advantages of Miniaturization





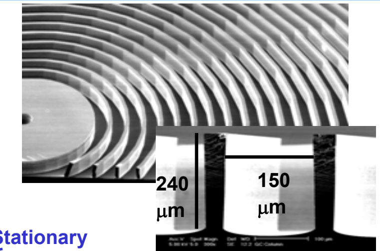
Size	40,500 cm^3	20,000X	Size	2 cm^3
Sensitivity	1 ppb	1,000X	Sensitivity	1 ppt
Analysis Time	15 min.	225X	Analysis Time	4 sec
Energy Per Analysis	10,000 J	10,000X	Energy Per Analysis	1 J

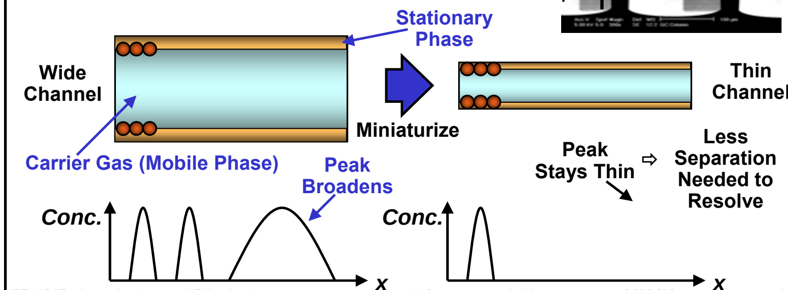
Basic Approach: Separation Analyzer



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





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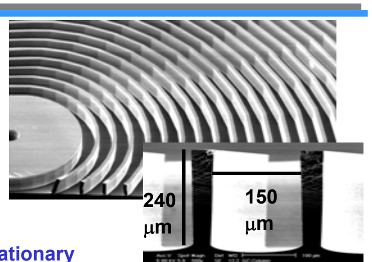
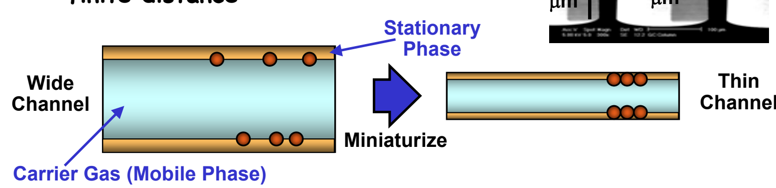


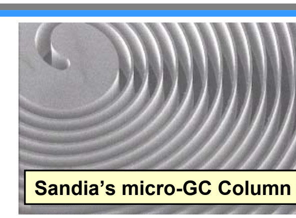


Column Width ↓ ➔ Surface-to-Volume Ratio ↑ ➔ Peak Spreading ↓ ➔ Separation Distance ↓

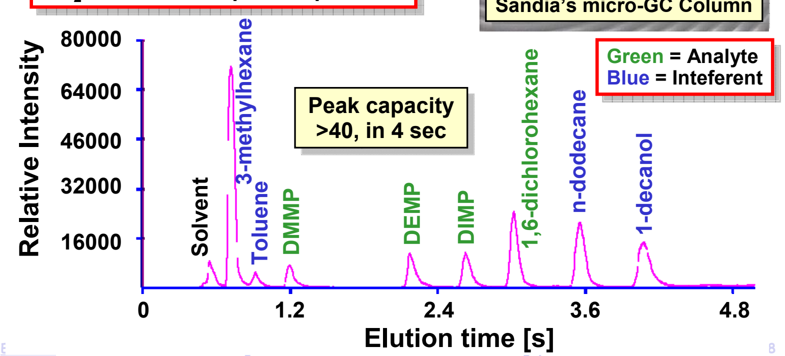
- *Result of Scaling*: shorter column length; faster analysis time

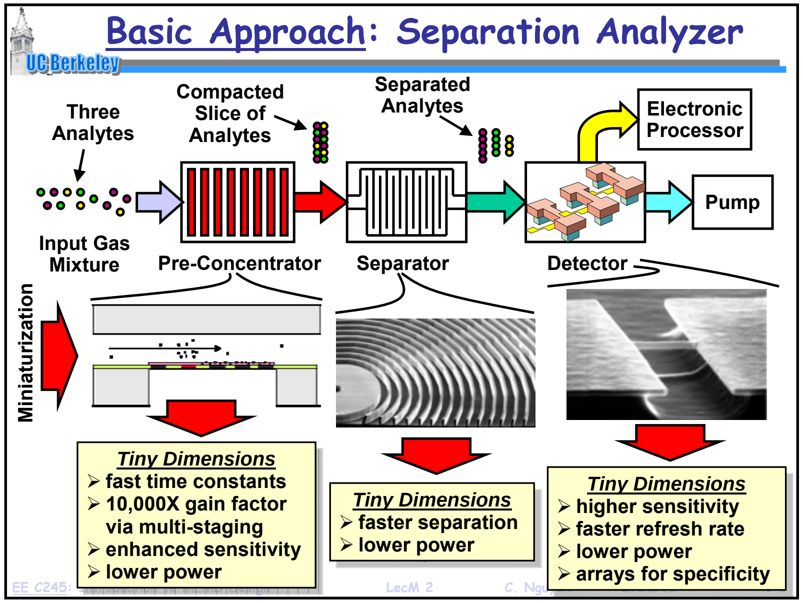
Gas Chromatography in Less Than 4s!

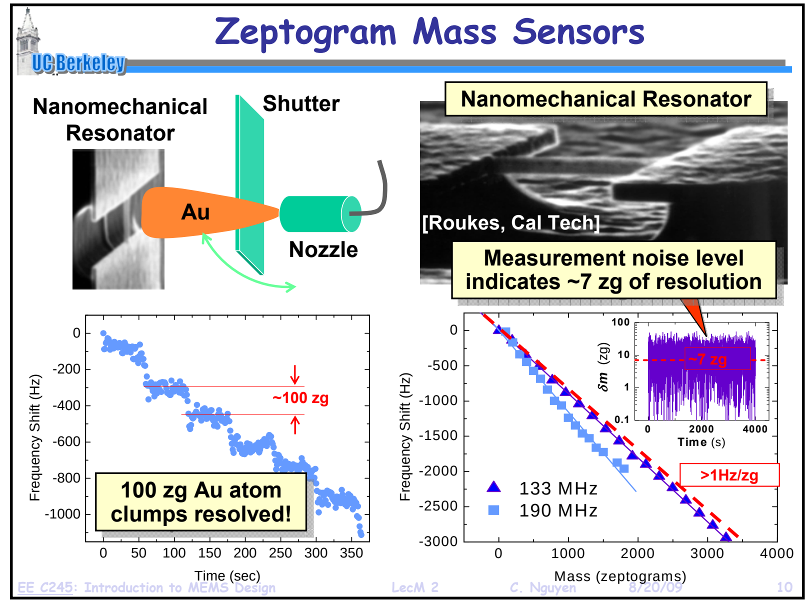
Design/Measurement Data:
0.75m x 100µ column
0.1µ DB-5 stationary phase
Heart-cut 275 msec peak injection
Temperature: ~30 deg C/sec
H_2 carrier: 35-39 psi at 1 psi/sec



Sandia's micro-GC Column




Basic Approach: Separation Analyzer
UC Berkeley
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


Zeptogram Mass Sensors
UC Berkeley
Nanomechanical Resonator
Shutter
Au
Nozzle
Nanomechanical Resonator
[Roukes, Cal Tech]
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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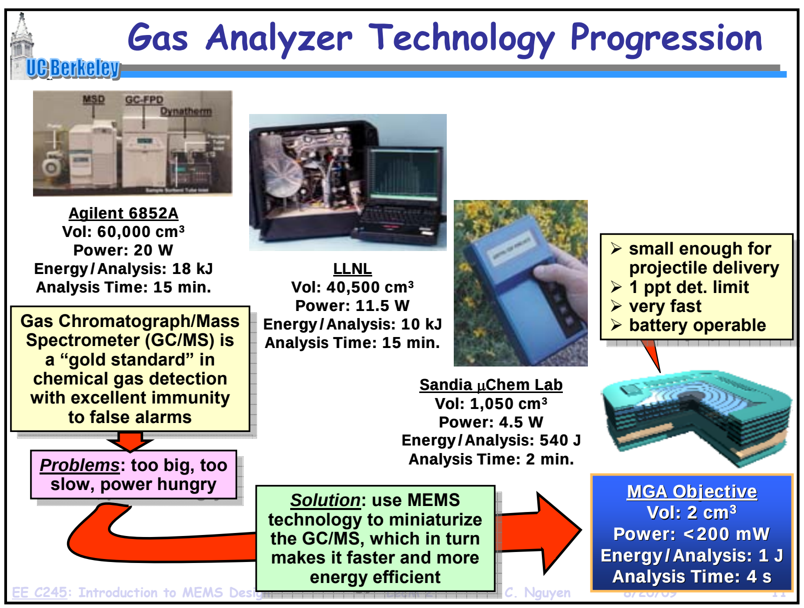
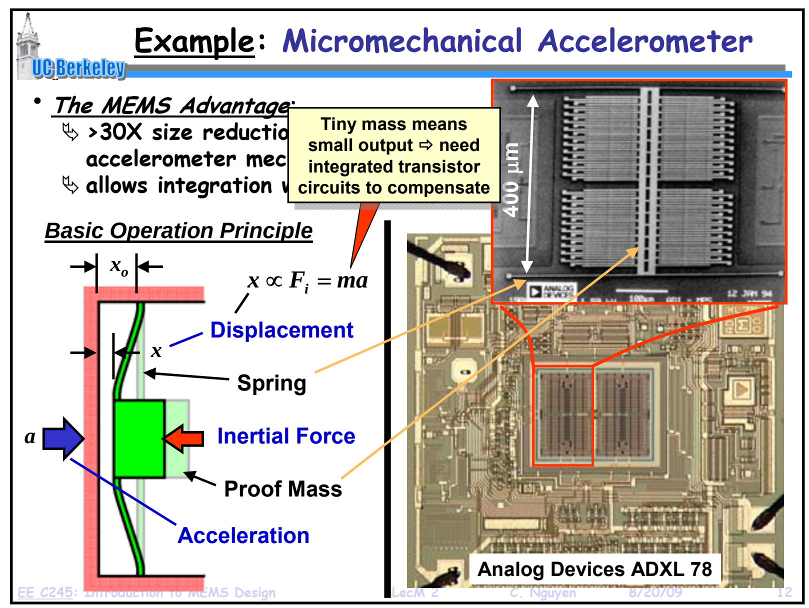

Gas Analyzer Technology Progression
UC Berkeley
Agilent 6852A
Vol: 60,000 cm³
Power: 20 W
Energy/Analysis: 18 kJ
Analysis Time: 15 min.
LLNL
Vol: 40,500 cm³
Power: 11.5 W
Energy/Analysis: 10 kJ
Analysis Time: 15 min.
Sandia μChem Lab
Vol: 1,050 cm³
Power: 4.5 W
Energy/Analysis: 540 J
Analysis Time: 2 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 cm³
Power: <200 mW
Energy/Analysis: 1 J
Analysis Time: 4 s


Example: Micromechanical Accelerometer
UC Berkeley
• The MEMS Advantage:
>30X size reductio
accelerometer mec
allows integration
Tiny mass means small output ⇨ need integrated transistor circuits to compensate
400 μm
Basic Operation Principle
x_o
$x \propto F_i = ma$
Displacement
Spring
Inertial Force
Proof Mass
Acceleration
Analog Devices ADXL 78

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 …