## Micro-Scale Oven-Control Advantages

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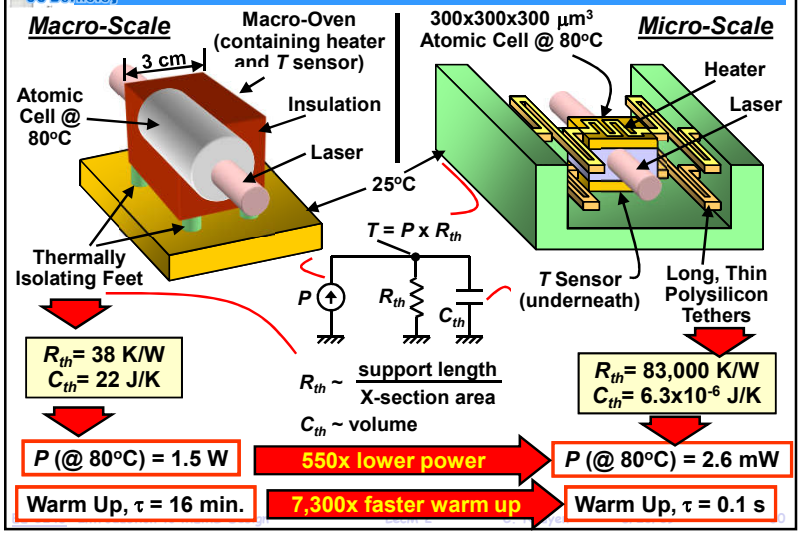


## Physics Package Power Diss. < 10 mW

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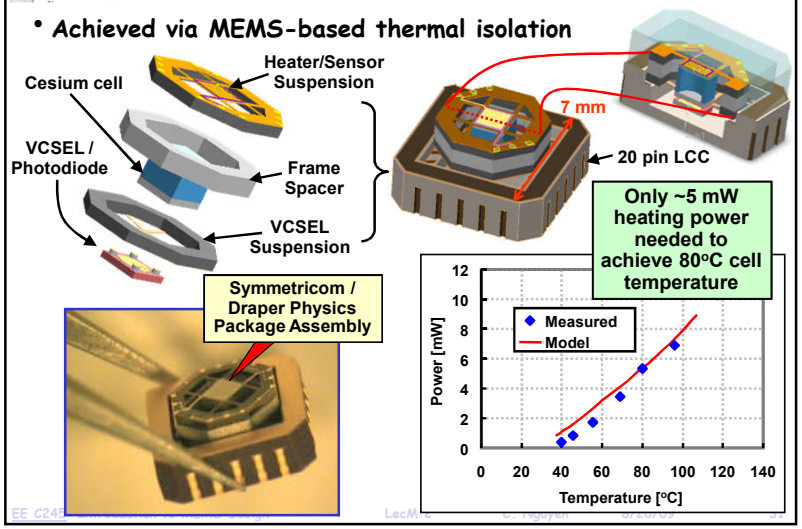
- Achieved via MEMS-based thermal isolation




## Micro Gas Analyzers (MGA)

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## Micro Gas Analyzers

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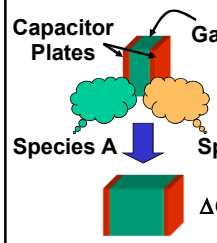
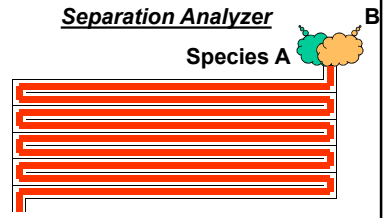
- *Objective*: enable remote detection of chemical agents via tiny, ultra-low power, fast, chip-scale gas analyzers that greatly reduce the incidence of false positives
- *Approach*: use micromachining technologies to implement separation-based analyzers (e.g., gas chromatographs, mass spectrometers)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

## Advantages of Miniaturization

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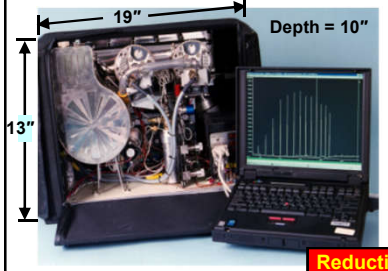
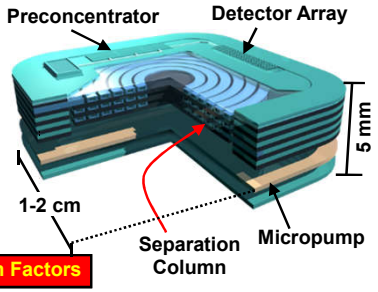
**Portable Gas Chromatograph**




**Chip-Scale Gas Chromatograph**




| | | Reduction Factors | | |
|---|---|---|---|---|
| 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

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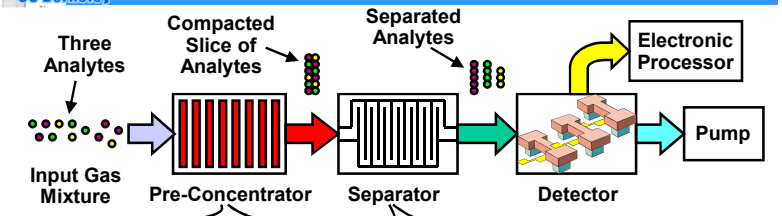


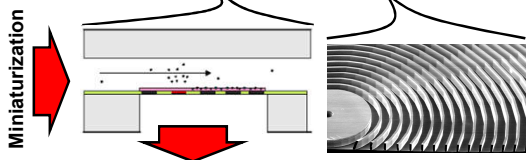


***Tiny Dimensions***
- fast time constants
- 10,000X gain factor via multi-staging
- enhanced sensitivity
- lower power

***Tiny Dimensions***
- faster separation
- lower power



## Scaling Leads to Faster Separation

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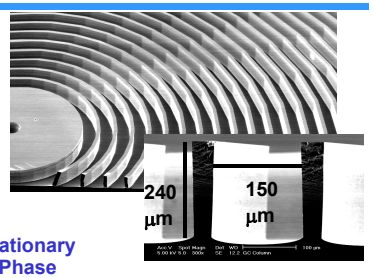
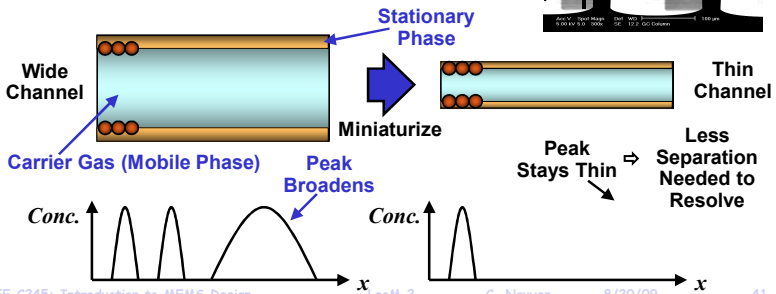
- *Example*: gas chromatograph separation column
  - unique analyte interactions with the column walls
  - different analyte velocities
  - *result*: separation after a finite distance






## Scaling Leads to Faster Separation

UC Berkeley

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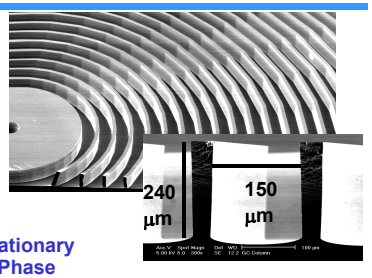


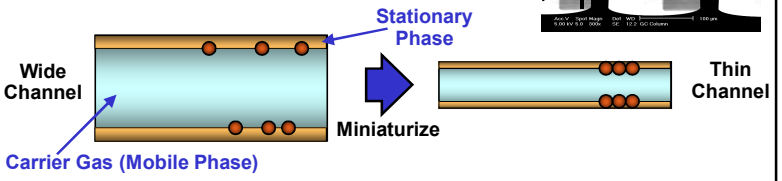


Column Width ↓ ⇒ Surface-to-Volume Ratio ↑ ⇒ Peak Spreading ↓ ⇒ Separation Distance ↓

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

## Gas Chromatography in Less Than 4s!

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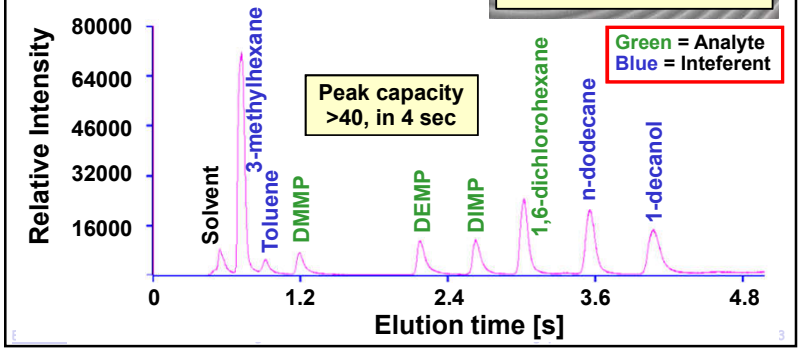
**Design/Measurement Data:**
0.75m x 100μ column
0.1μ DB-5 stationary phase
Heart-cut 275 msec peak injection
Temperature: ~30 deg C/sec
$H_2$ carrier: 35-39 psi at 1 psi/sec


## Basic Approach: Separation Analyzer

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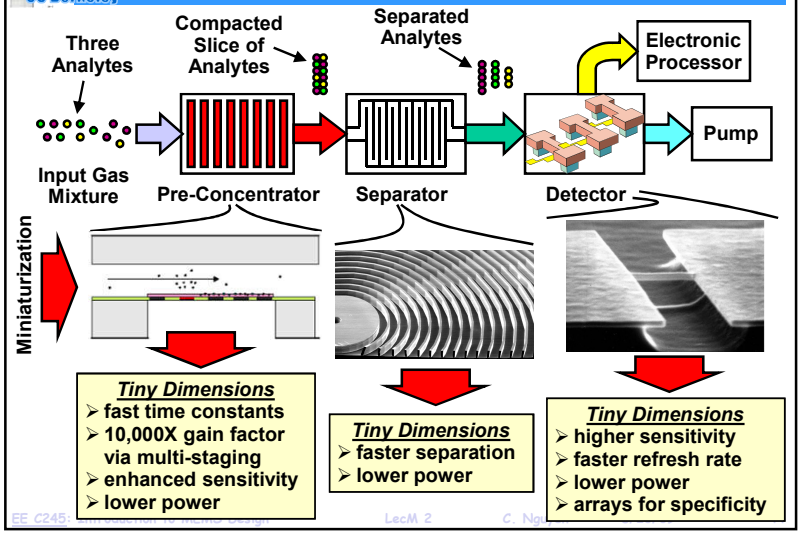


***Tiny Dimensions***
- fast time constants
- 10,000X gain factor via multi-staging
- enhanced sensitivity
- lower power

***Tiny Dimensions***
- faster separation
- lower power

***Tiny Dimensions***
- higher sensitivity
- faster refresh rate
- lower power
- arrays for specificity

## Zeptogram Mass Sensors

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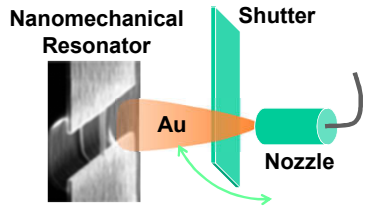
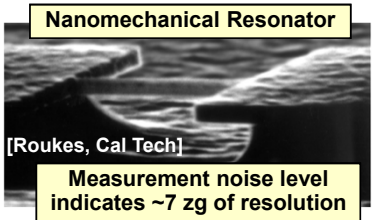
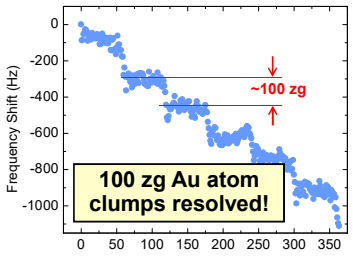
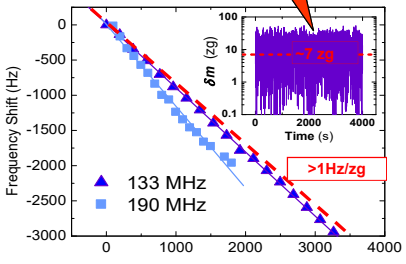



Measurement noise level indicates ~7 zg of resolution




## Gas Analyzer Technology Progression

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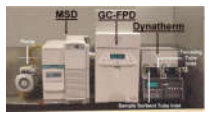


**Agilent 6852A**
Vol: 60,000 cm³
Power: 20 W
Energy/Analysis: 18 kJ
Analysis Time: 15 min.

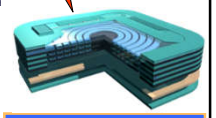
Gas Chromatograph/Mass Spectrometer (GC/MS) is a "gold standard" in chemical gas detection with excellent immunity to false alarms

***Problems***: too big, too slow, power hungry

**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



***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

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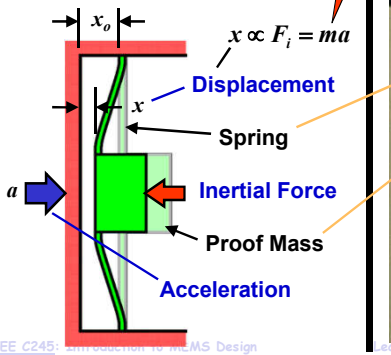
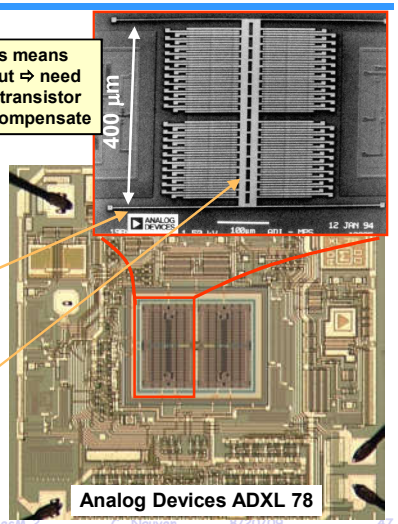
- *The MEMS Advantage:*
  - >30X size reductio
    accelerometer mec
  - allows integration

*Basic Operation Principle*




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






## Messages Going Forward …

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- 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 …