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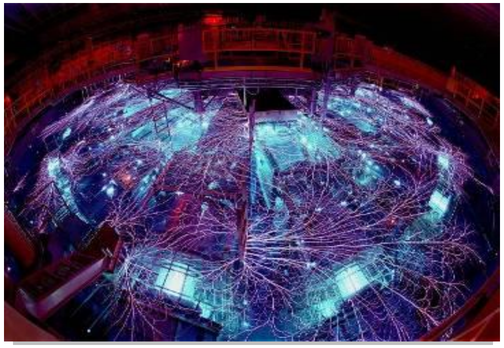

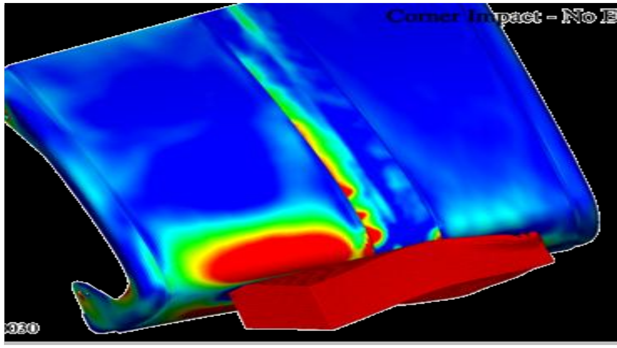

Optimized SAW Chemical Sensor with Microfluidic Packaging

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Optimized SAW Chemical Sensor with Microfluidic Packaging

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MicroChemLab Concept

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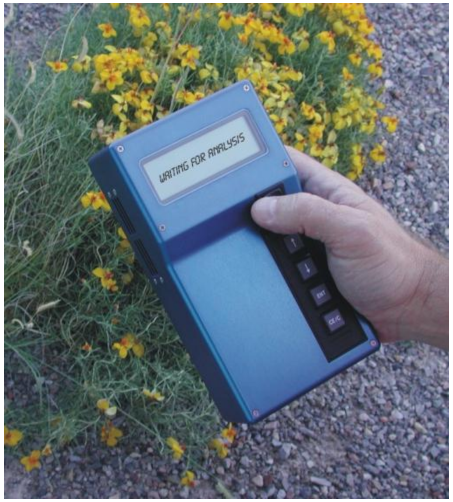
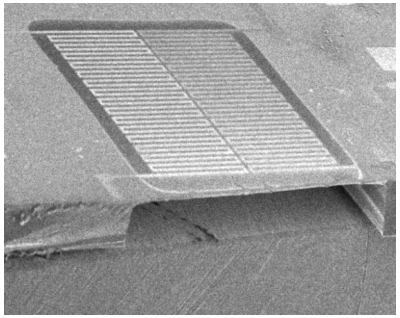
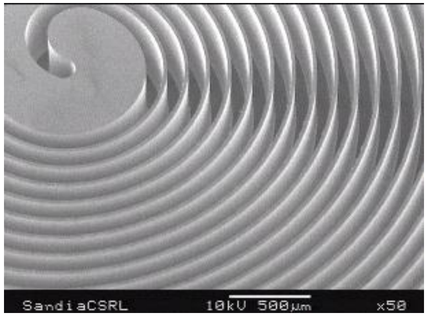
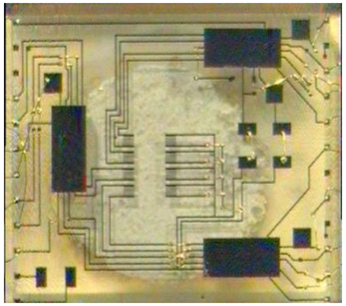
- Rapid and accurate detection of trace amounts of select chemicals with a hand-held, portable, reasonably priced instrument.
- Made use of custom micromachined components, custom integrated circuits, and novel coatings to achieve all of this.

Three key microelectronic technologies developed to enable MicroChemLab:

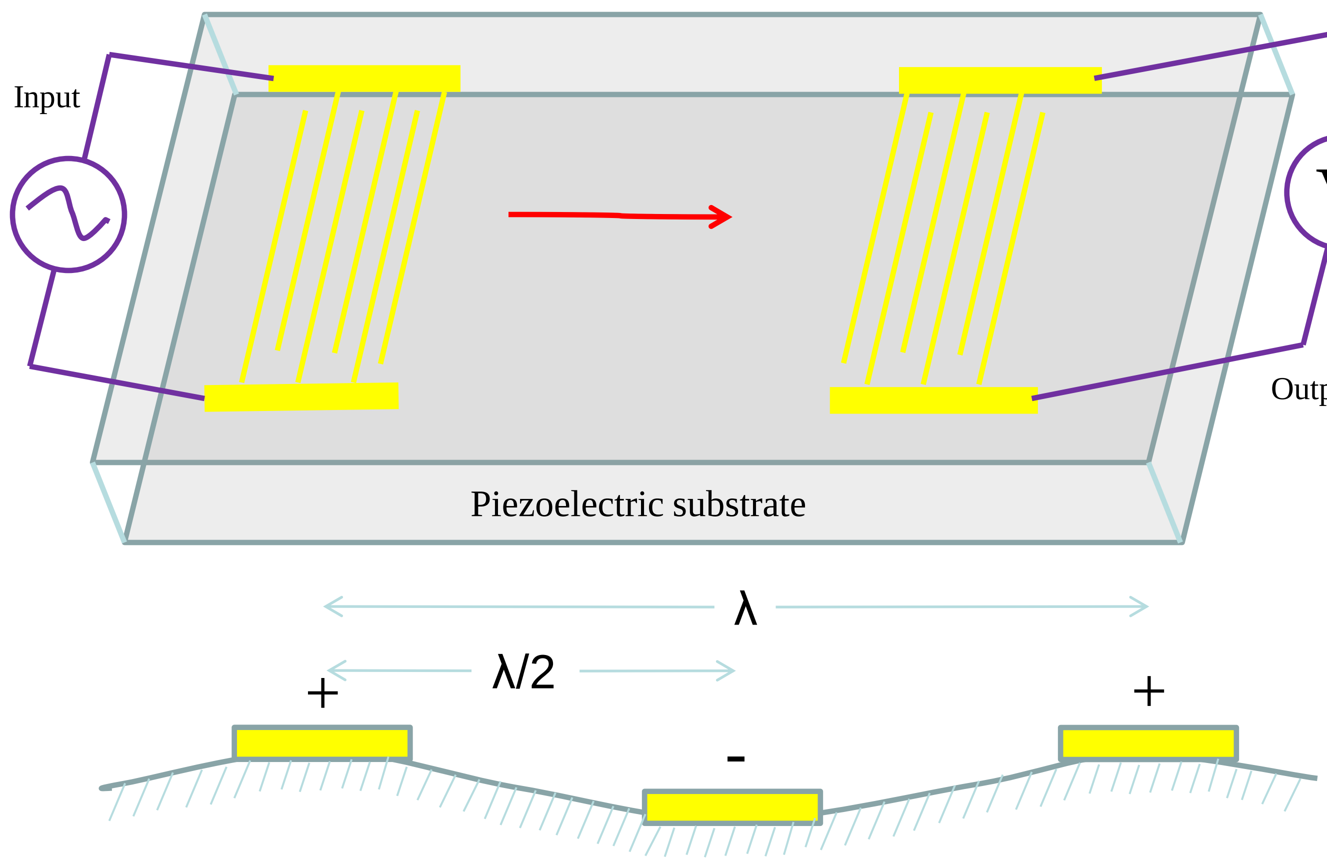




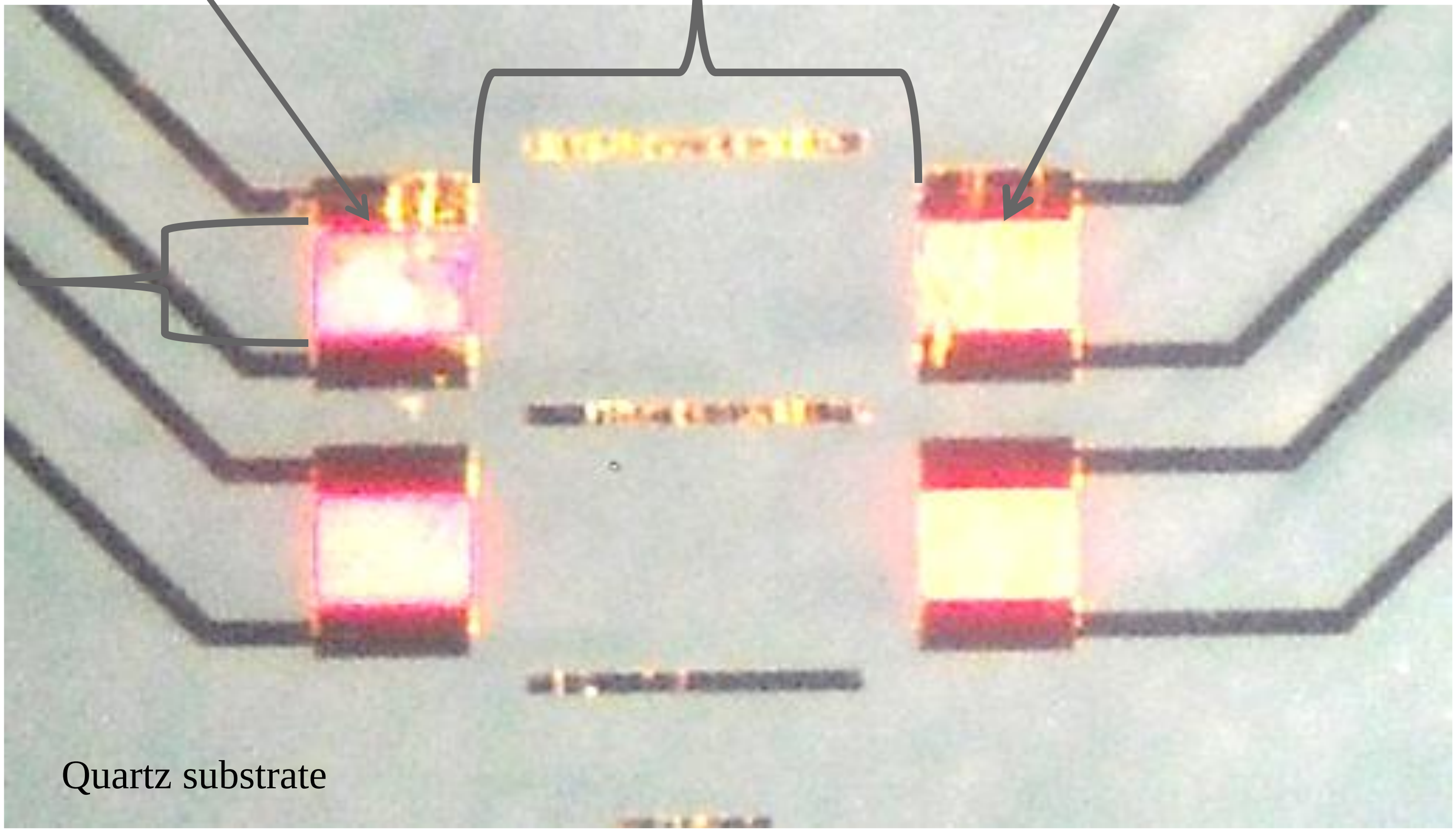




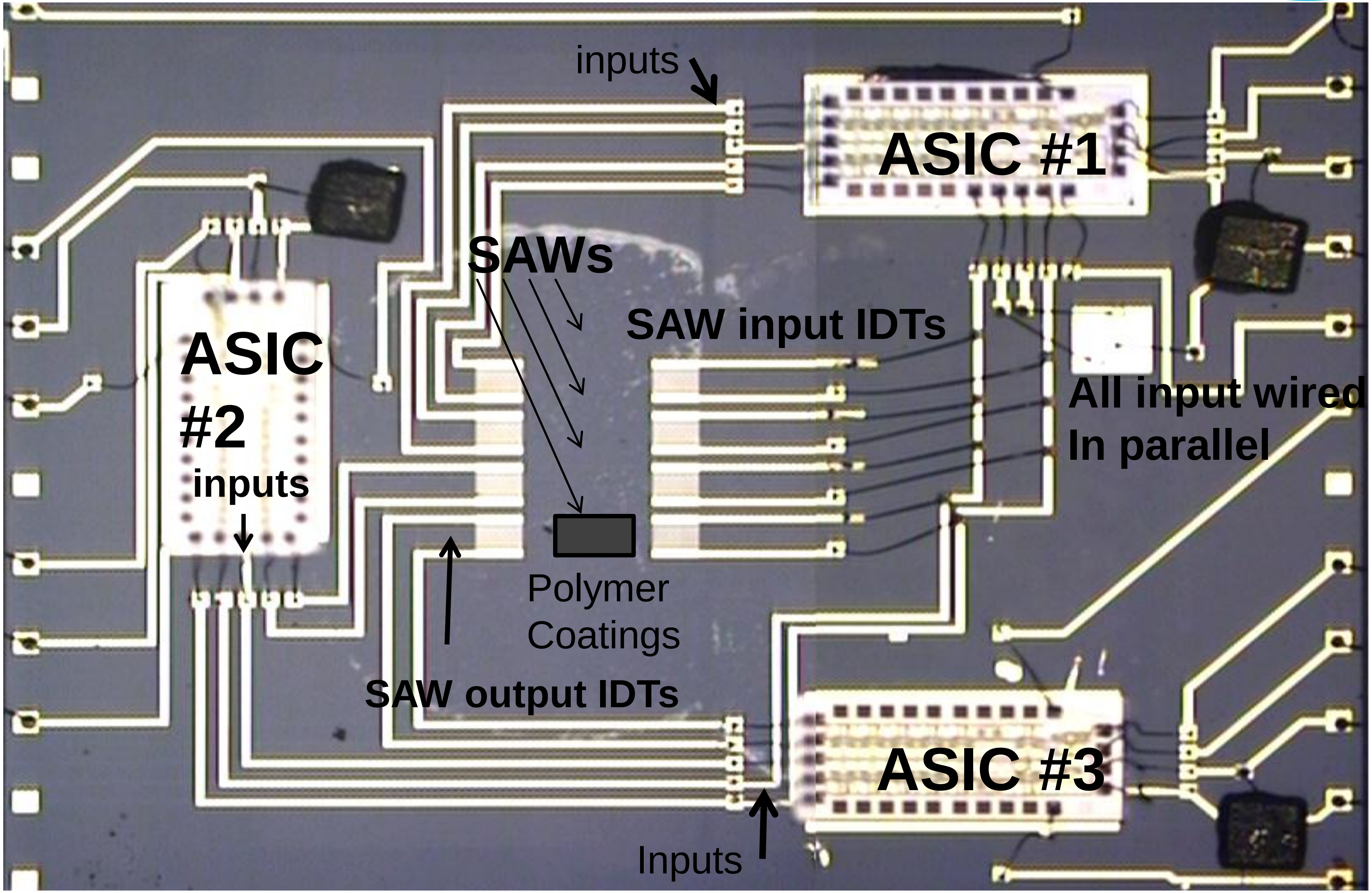
- Sample collection via a preconcentrator made from chemically selective sol-gel coatings on a silicon nitride membrane
- Coated micro-gas chromatograph column produced via deep reactive etching of Si to separate input gases.
- **High frequency coated SAW array for selective detection of chemicals.**
- **Best sensitivity: 1ppm**



The Detector: A Basic Surface Acoustic Wave Filter



Original Sandia Microchemlab SAW Design



Original MicroChemLab Detector Multi-Chip Module (MCM)

Problems with the Original SAW Detector

- Power loss through the SAW (i.e. insertion loss) was about a factor of 2,000 (36dB) uncoated, 20,000 (46dB) coated.
- Its input impedance made the SAW appear like a capacitor at the operating frequency of 510MHz.
- Zero temperature coefficient operation of quartz design is obviated, since the device operates far from 22.5^{o}C point.
- The detection method used an odd combination of phase and frequency detection that combined problematic features of both modes of operation.
- Noise is a problem throughout the design.

Experimental Optimization of the SAW Detector

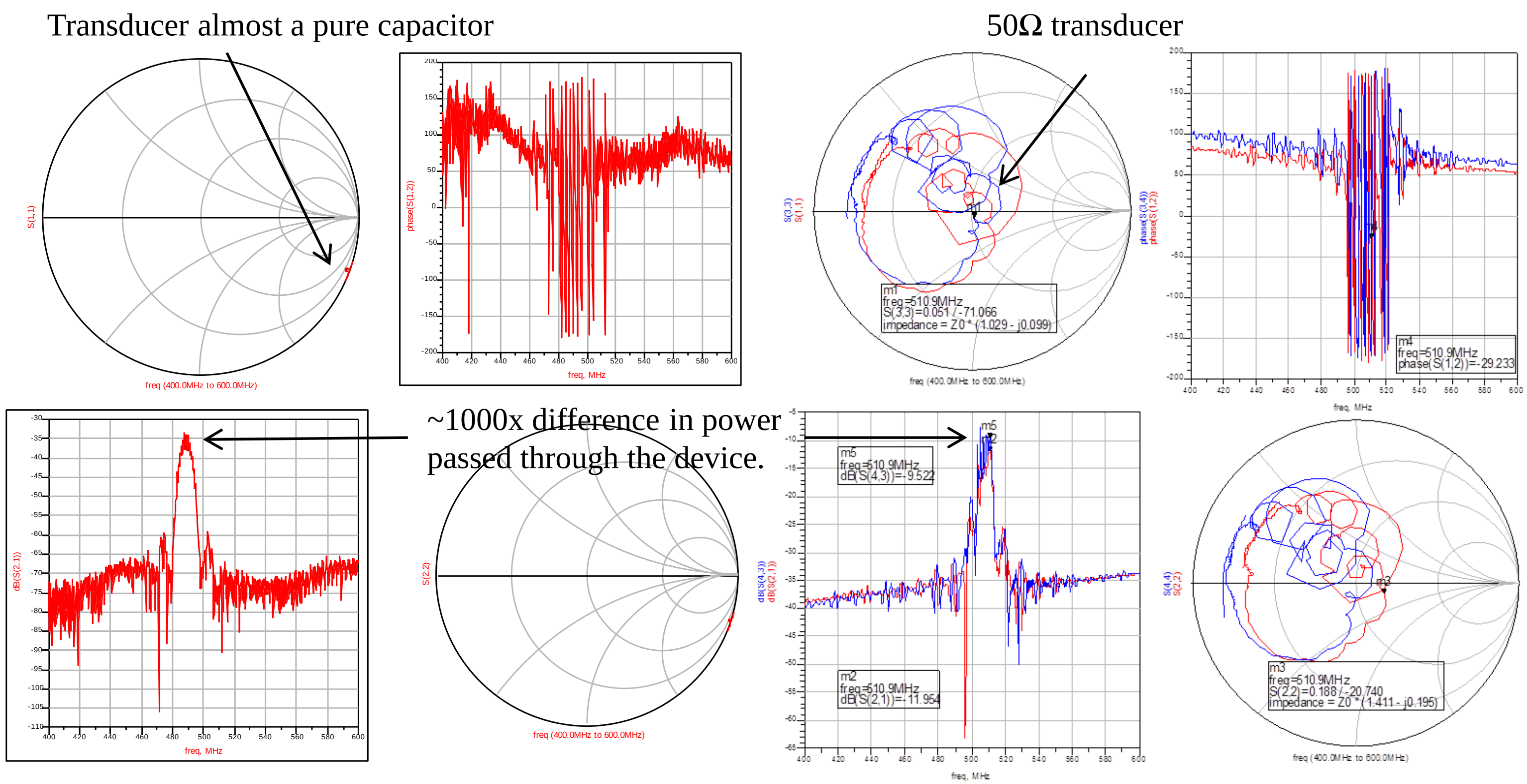
- Create SAW designs with lowest possible power loss and with a reasonable match to 50Ω.
- Answer the following questions:

  1) How much coating area is enough?

  2) Is the best detector wide and close together or narrow and long?

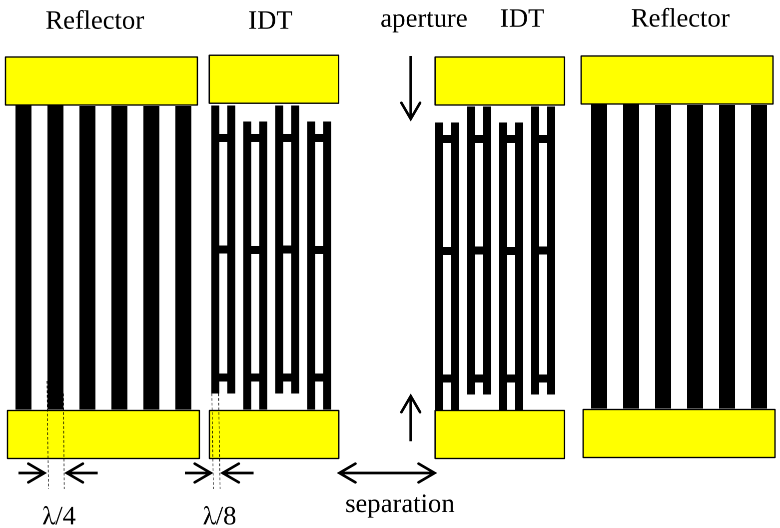
  3) What is the best design approach to satisfy the above criteria of minimum loss and best match?

  4) Should the detector be operated in a phase or a frequency detection mode?



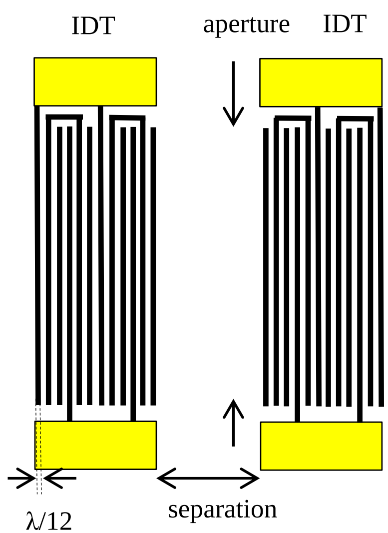
Original 49fp SAW Design

Resonator SAW, 50fp Design, 100λ Aperture 100λ Separation



SAW Resonator Design

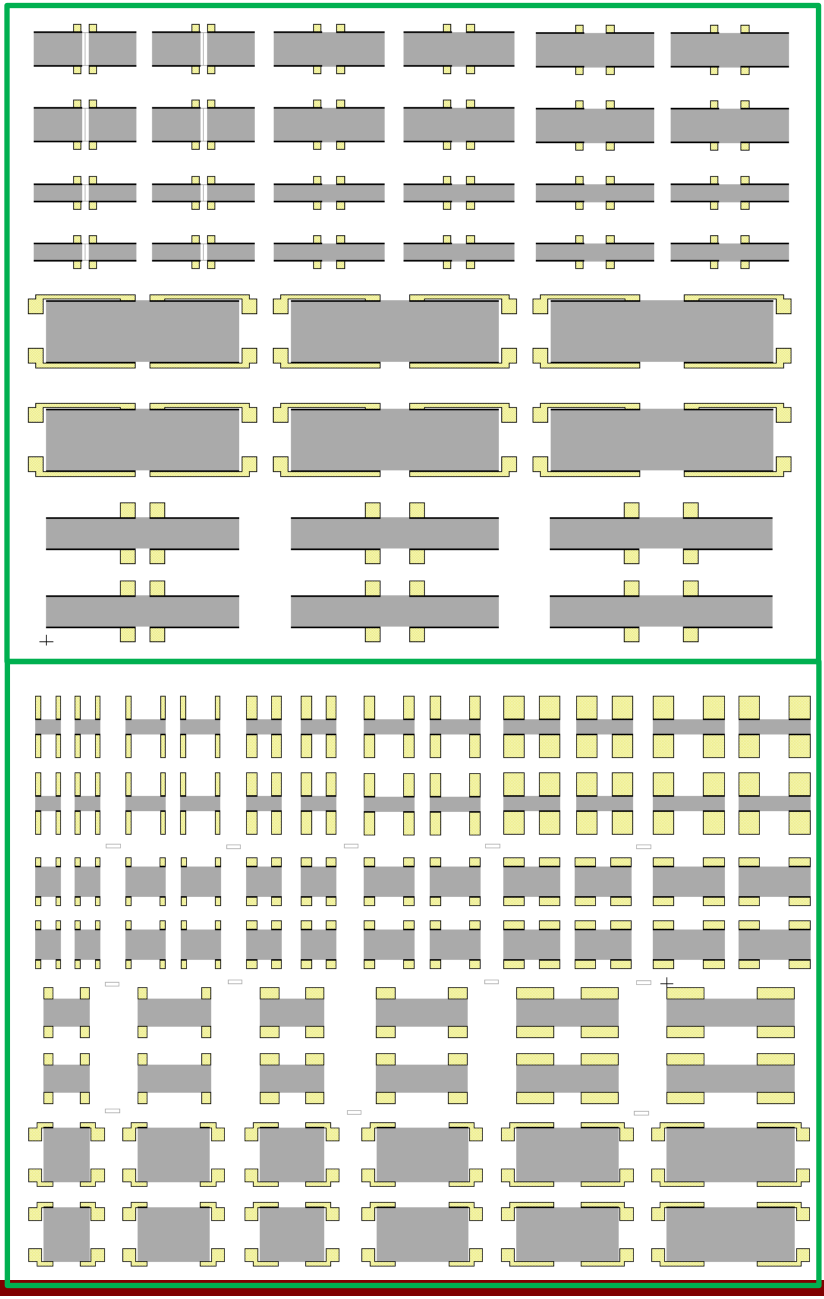
- Minimum feature size: λ/8
- Split finger IDT design
- Experiment aperture: 100λ and 200λ
- Experiment separation: 50λ, 100λ, 150λ
- Longest device: 750λ
- Length of best device: 750λ



SAW Floating Electrode Uni-directional Transducer (FEUDT) Design

- Minimum feature size: λ/12
- Reflector / director design
- Experiment aperture: 100λ and 200λ
- Experiment separation: 100λ and 200λ
- Longest device: 480λ
- Length of best device: 270λ

Comparison of Two Methods for Lowering Sensor Loss



Resonator SAW Mask Set

- 12 different designs
- E-beam patterning for fingers
- Minimum feature size: 450nm
- At least 2 devices per design
- 510MHz and 960MHz
- Varied aperture: 100λ and 200λ
- Varied separation: 50λ, 100λ, 150λ

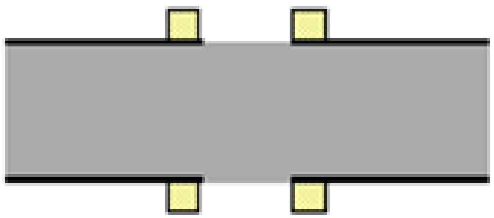
FEUDT SAW Mask Set

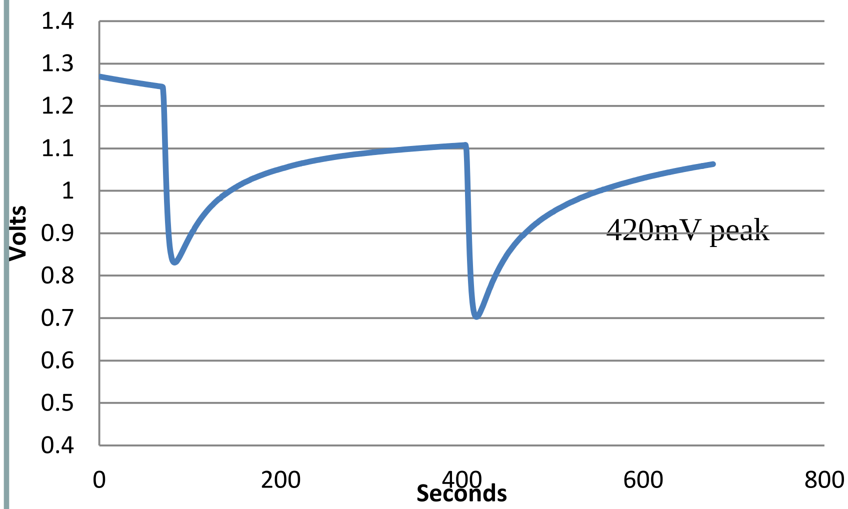
- 24 different designs
- E-beam patterning for fingers
- Minimum feature size: 320nm
- At least 2 devices per design
- 500MHz and 900MHz
- Varied aperture: 100λ and 200λ
- Varied separation: 100λ and 200λ

Resonator SAW 12

f_c = 961.0MHz,
200λ aperture, 150λ separation with
10 drops of DKAP coating.

Sensitivity: 20.5-21.0mV/ppm, noise 0.20mVrms
Detection threshold: 9.5ppb (without preconcentrator)



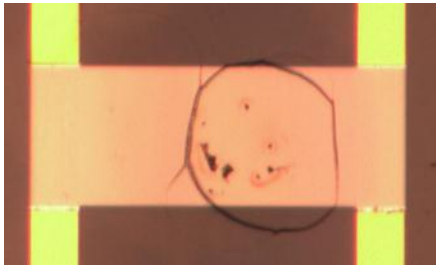


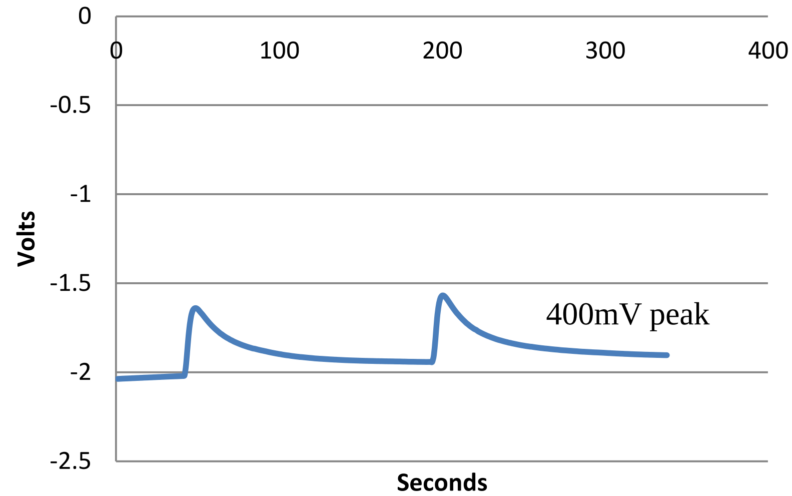
Resonator SAW 12 with 20ppm DMMP input gas

FEUDT SAW 2B

f_c = 900.3MHz,
100λ aperture, 200λ separation with
4 drops of DKAP coating.

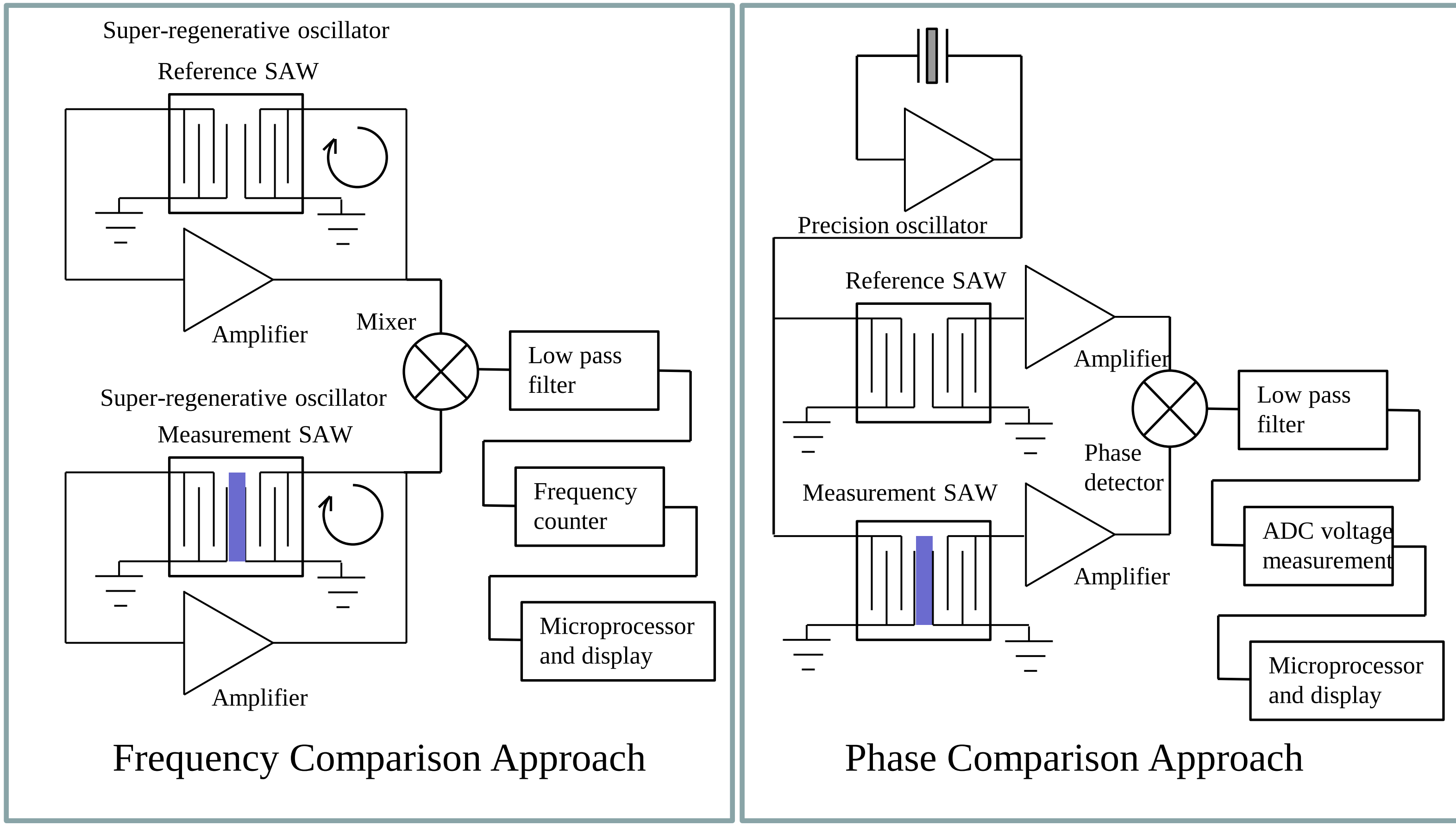
Sensitivity: 20mV/ppm, noise 0.19mVrms
Detection threshold: 9.5ppb (without preconcentrator)



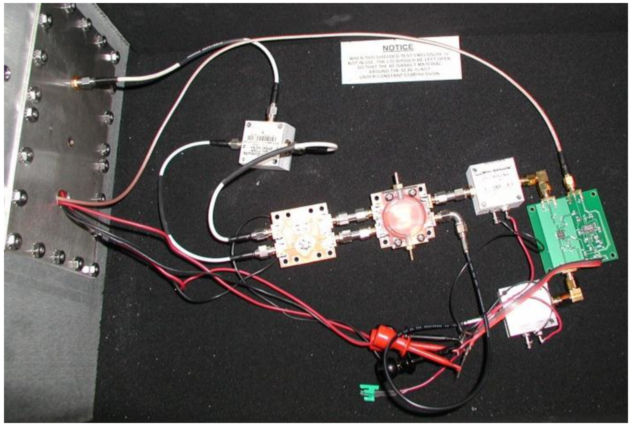


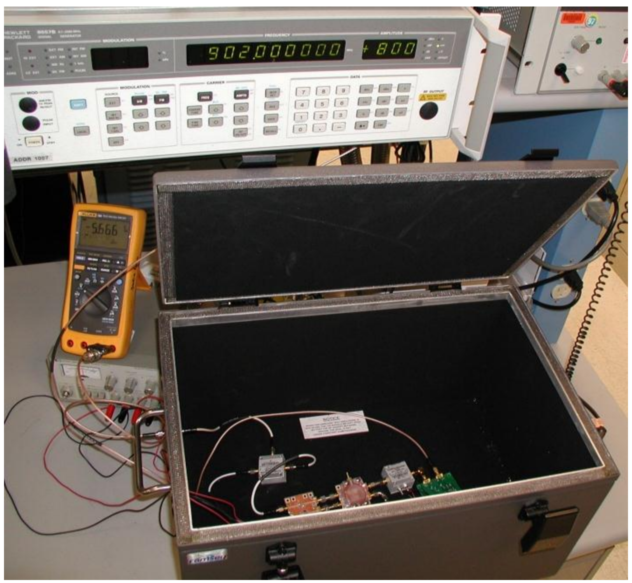
FEUDT SAW 2b with 20ppm DMMP input gas

Comparison Tests of the Best Resonator vs. the Best FEUDT SAW



Two Methods for SAW-based Mass Sensing





Phase detection approach

- Uses COTS parts
- Frequency set by precision oscillator
- Still uses dual SAW approach
- Shielded box to eliminate RFI

Use of phase detection vs. legacy system:

- Eliminates oscillator phase noise
- Eliminates mode hopping
- Has less of a high frequency advantage

Integrate New SAWs and Electronics in Existing Packaging

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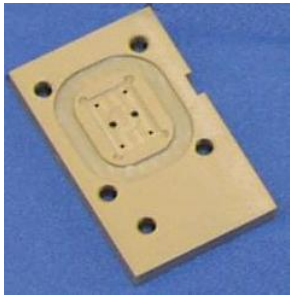
- Present system is highly optimized mechanically.
- Need to use existing preconcentrator, GC column, and gas handling hardware.
- Each piece makes electrical and fluidic connection.

Preconcentrator manifold



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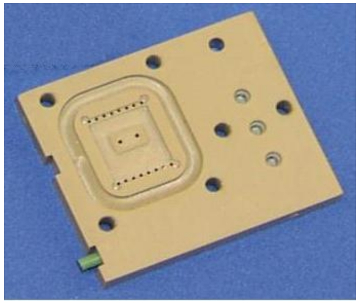
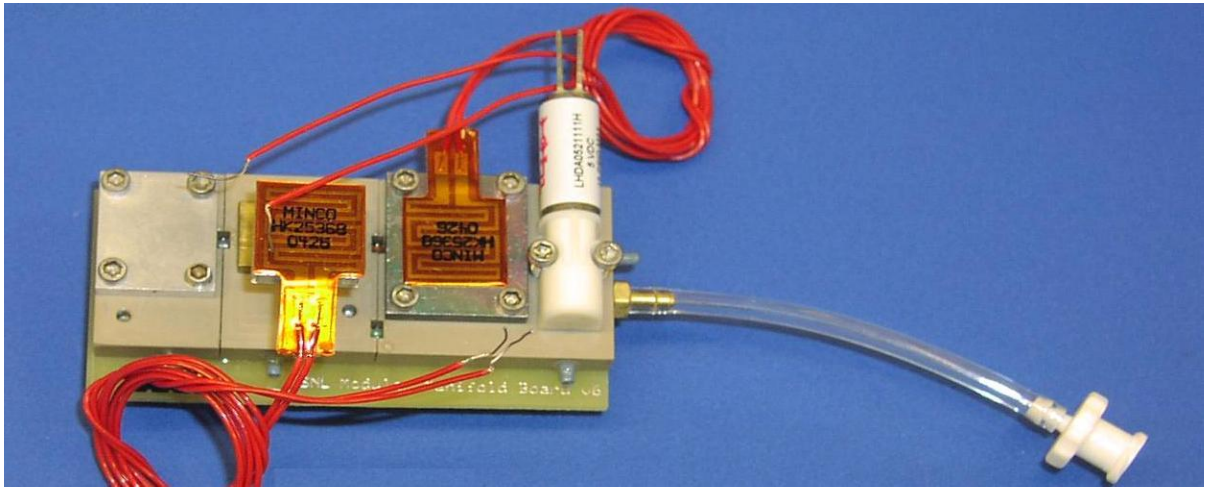
GC Column manifold

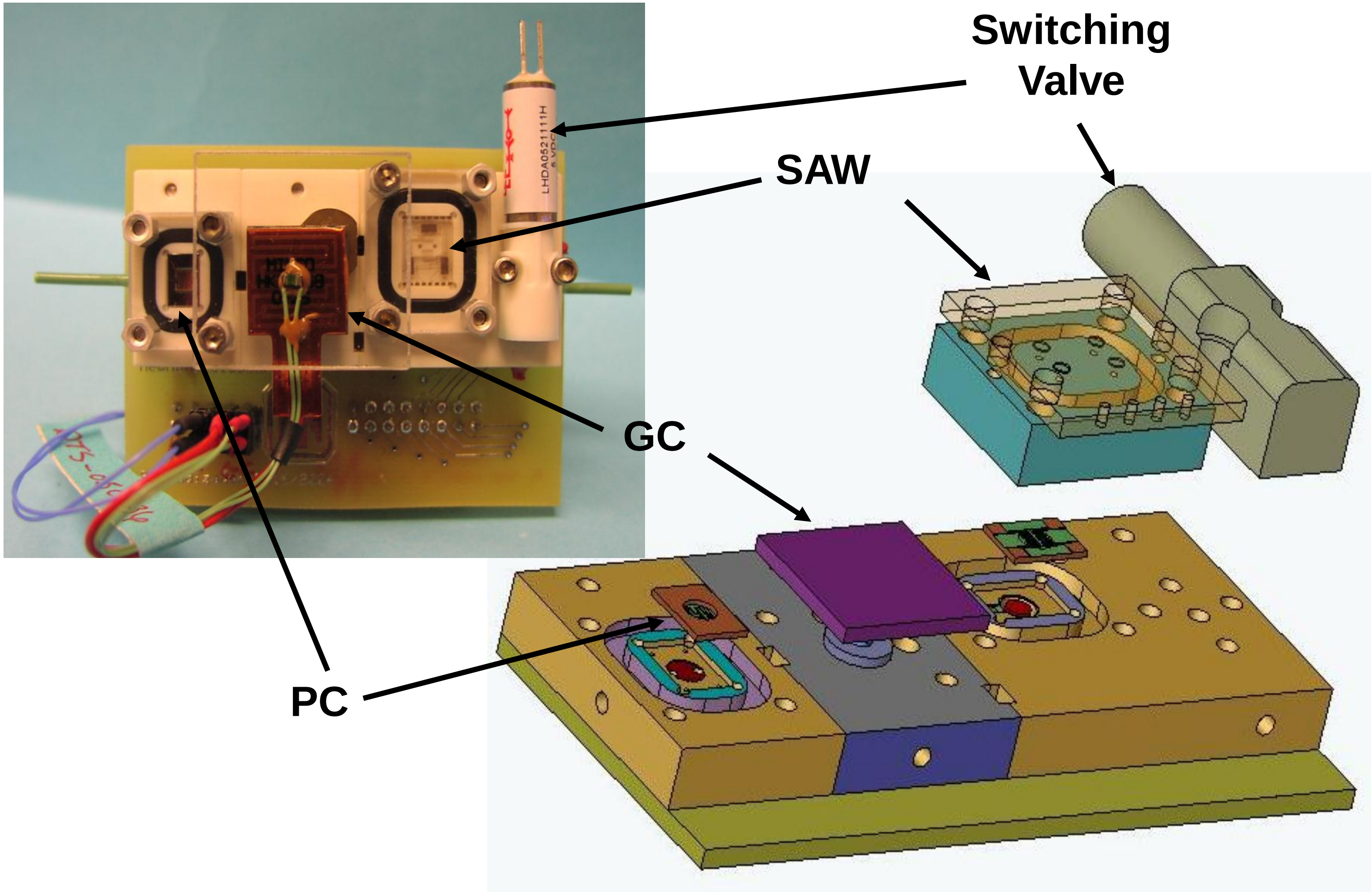
+

SAW Array Manifold





Modular Gas Manifold for Easy Component Assembly and Maintenance



Results Thus Far

- We have an optimum SAW design.
- We have an optimum electronics architecture.
- Sensitivity w/o preconcentrator: 10ppb
- Sensitivity (est. with) preconcentrator: 330ppt

(This is a factor of 3000x improvement)