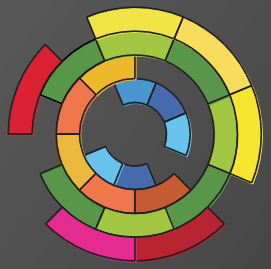

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Sensors in Design 2012: Smart Sensors Product Roadmaps

UBM Electronics

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Integration Challenges in MEMS Smart Sensor Fabrication

Joseph Doll
Stanford University

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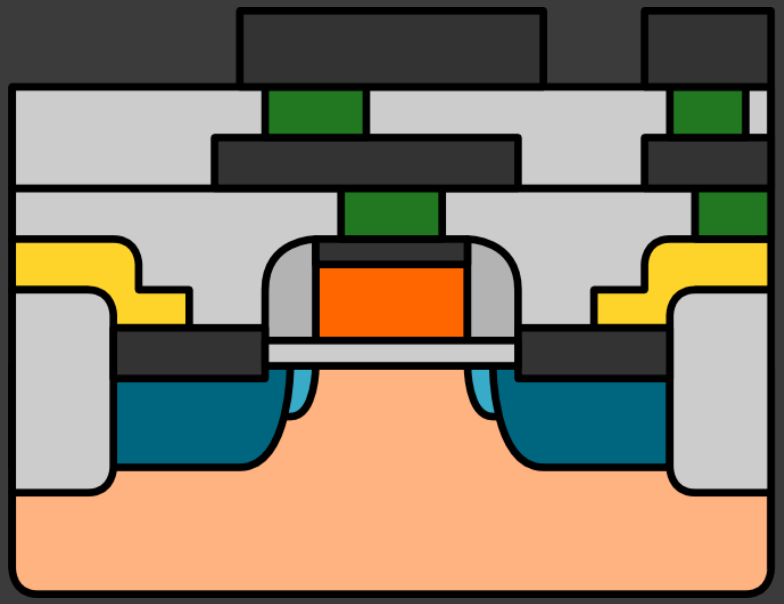
Outline

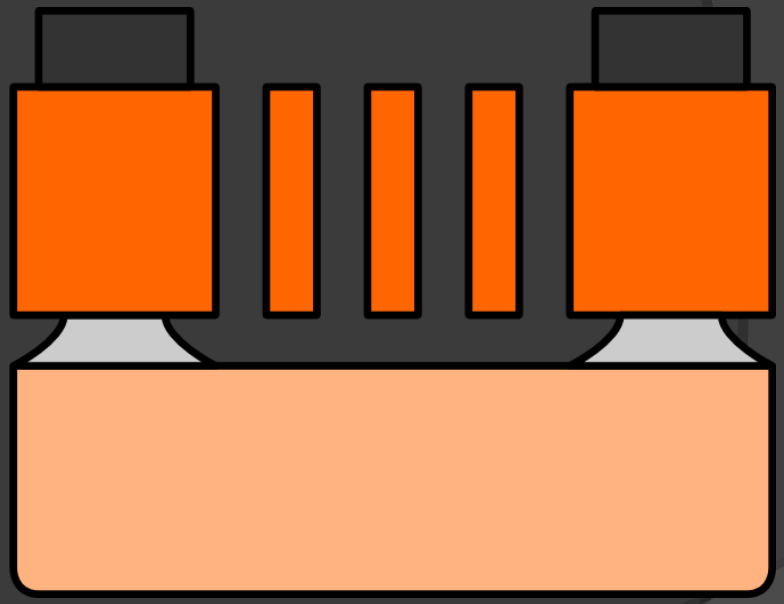
- Intro to CMOS and MEMS fabrication
- Integration and signal transduction options
- Product examples

Process overviews

CMOS

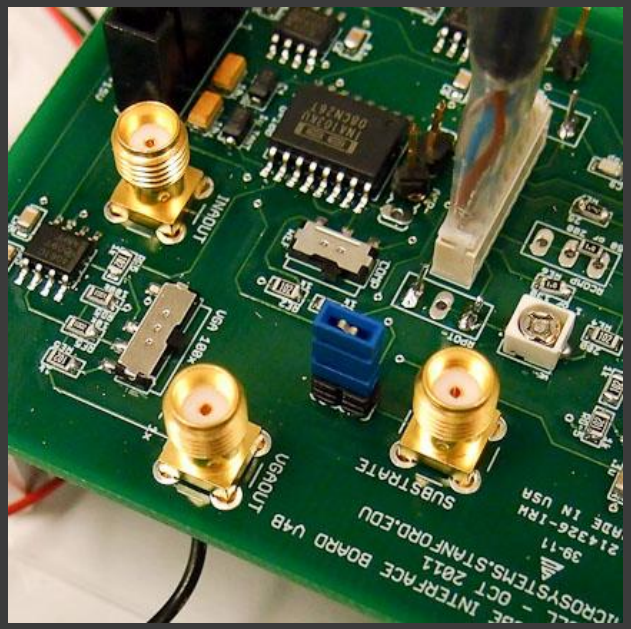


MEMS

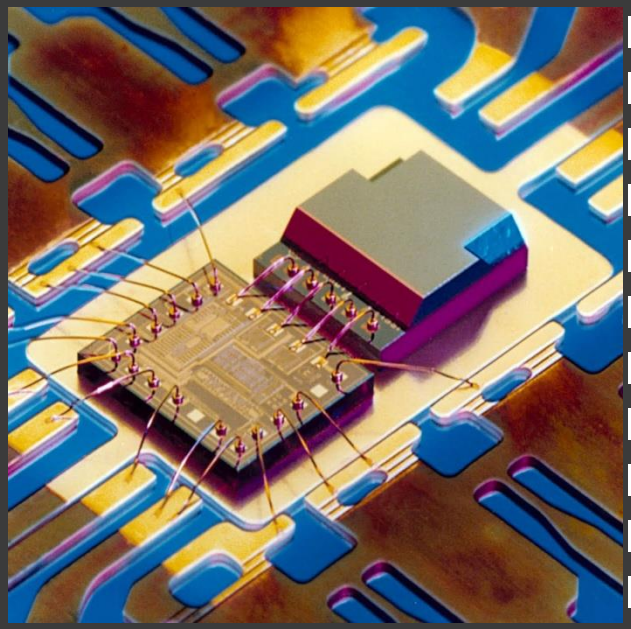


Integration options

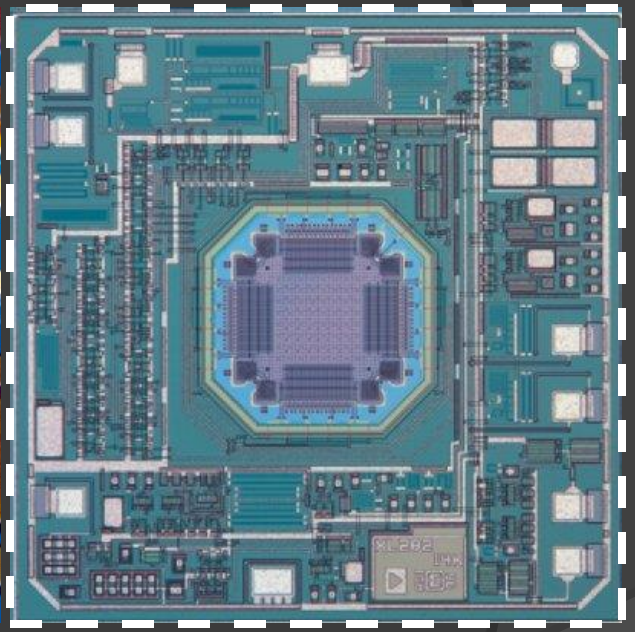
Board



Hybrid



Monolithic



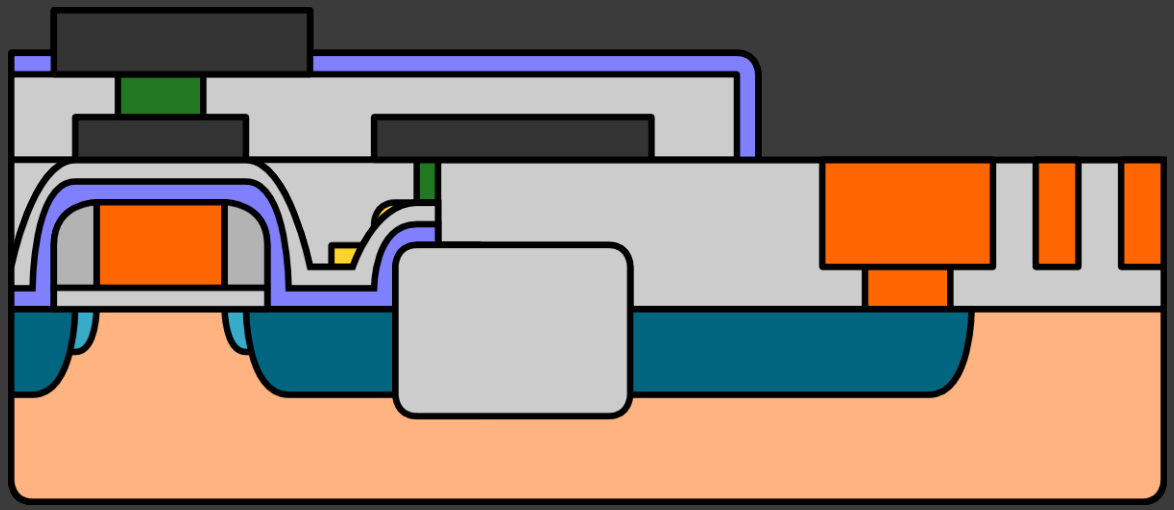
Images courtesy of Freescale Semiconductor and Analog Devices

Monolithic integration

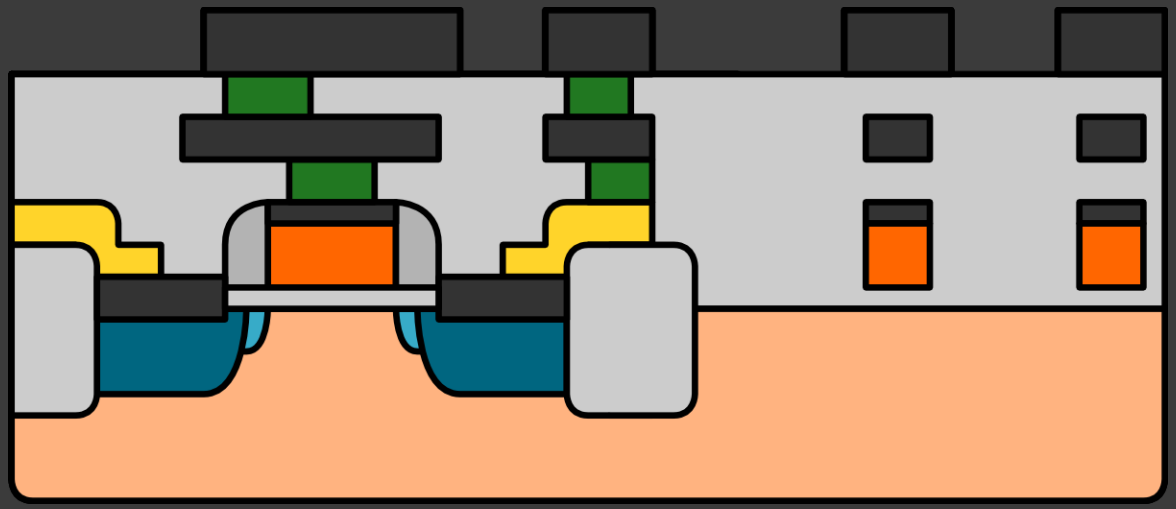
- Benefits
  - Performance (e.g. capacitive sensors)
  - Package size
- Challenges
  - Planarity
  - Processing temperature (< 450C)
  - Contamination and limited material options
  - Complexity (development time, mask costs, optimization)
- Fabrication options (pre, intra, post)

Pre-CMOS

Intra-CMOS

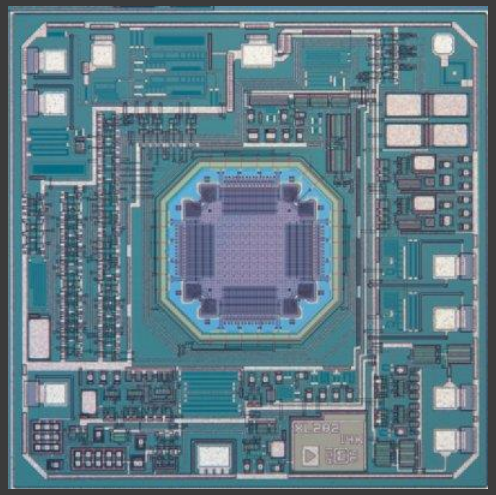


Post-CMOS

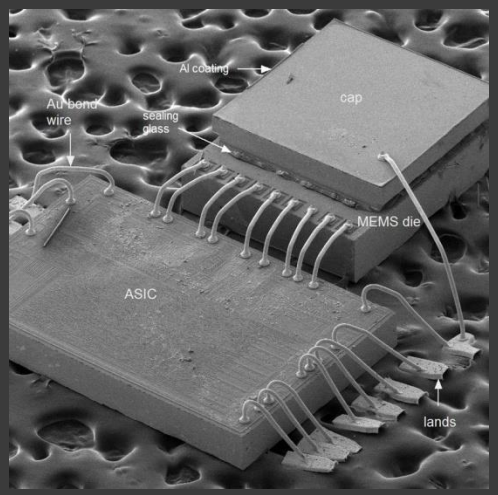


Hybrid integration

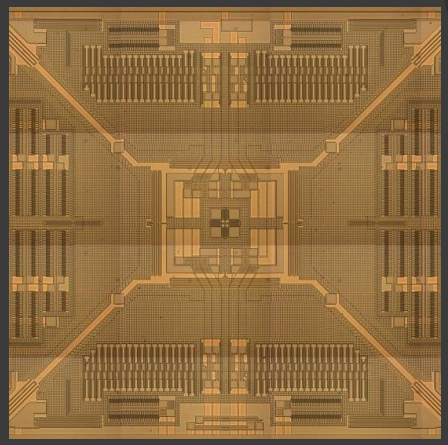
ADXL202 (1999)

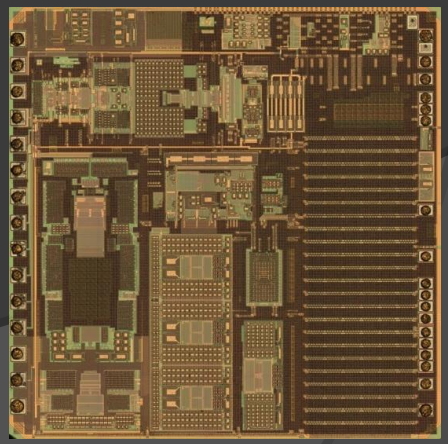


ADXL345 (2009)

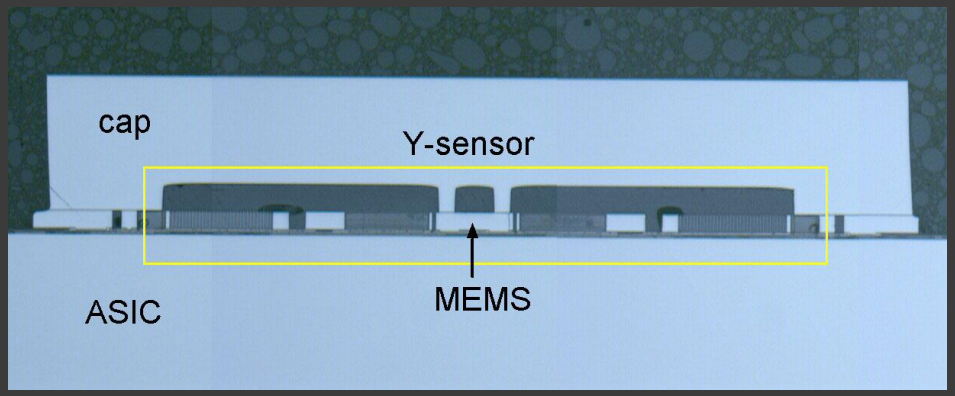


iPhone 4 Gyroscope (STMicroelectronics)





Galaxy Nexus Gyroscope (Invensense)



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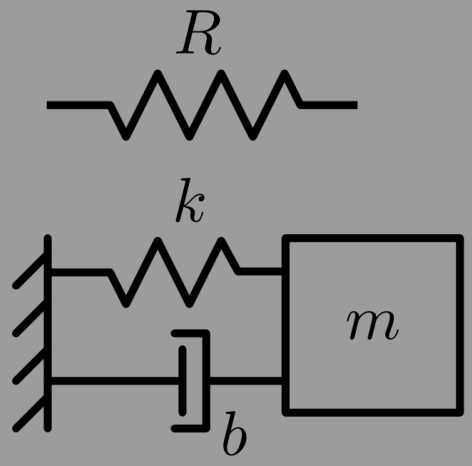
Images courtesy of Chipworks

Transduction fundamentals

- Sensor resolution (sensitivity + noise)
- Noise sources



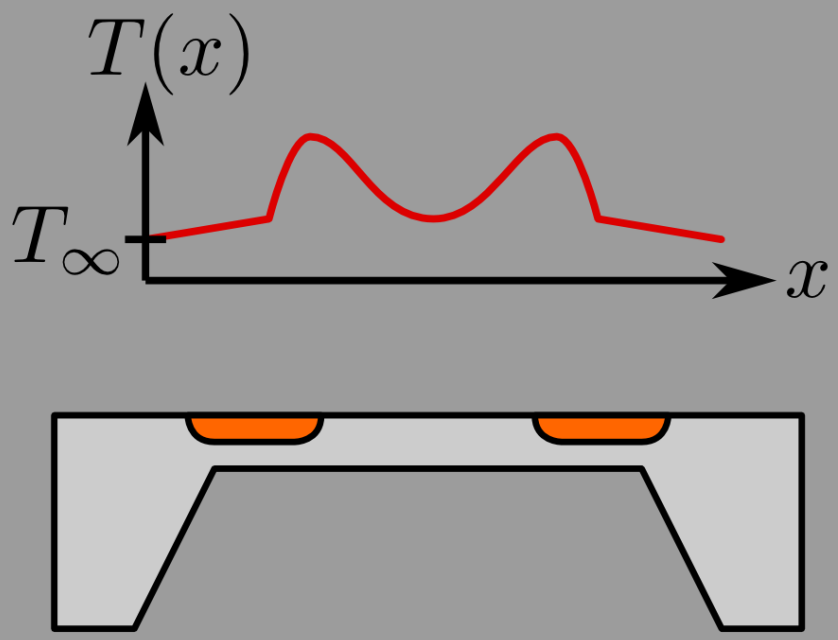
$$V_J = \sqrt{4k_bTR}$$

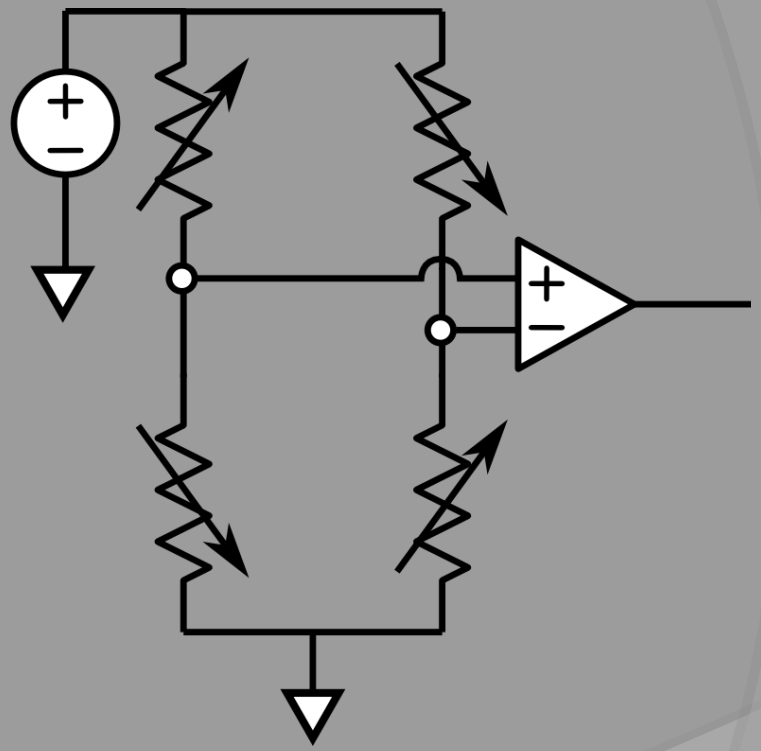
$$F_{Th} = \sqrt{4k_bTb}$$

$$a_{Th} = \frac{\sqrt{4k_bTb}}{m}$$

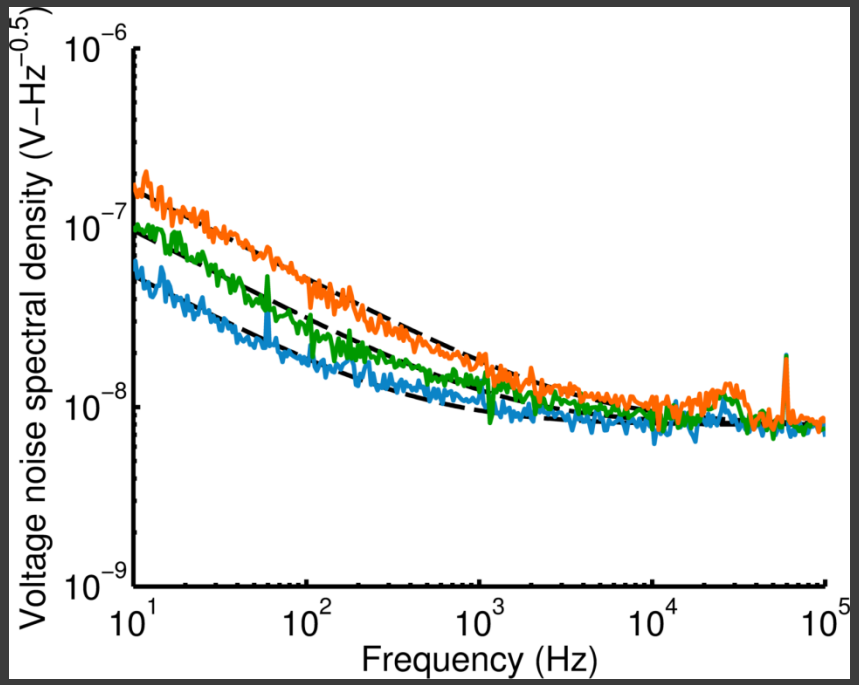
- Amplifier vs. sensor noise
- Temperature stability and signal drift
- Other issues: power dissipation, linearity, bandwidth

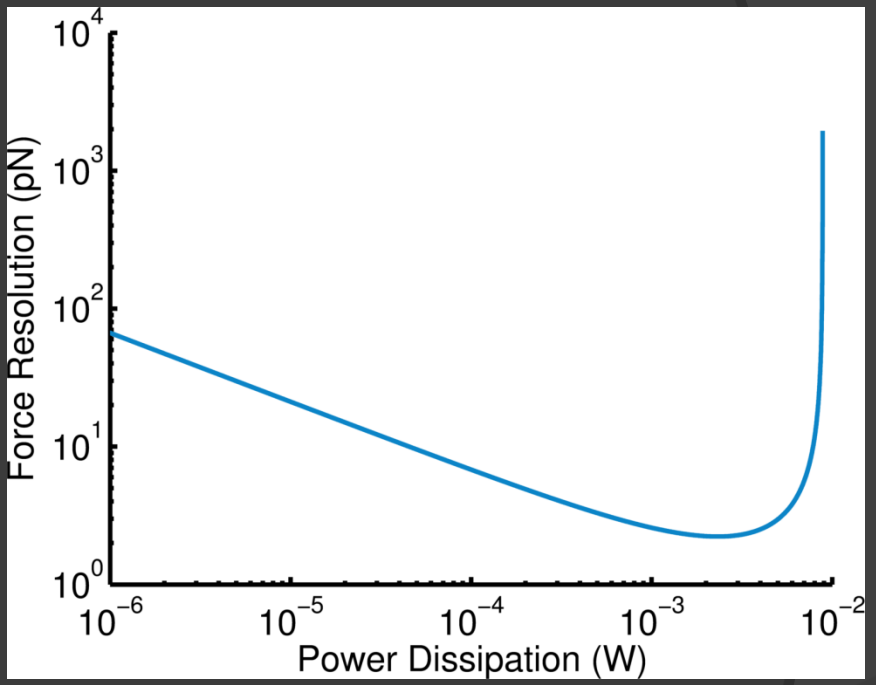
Piezoresistive





Piezoresistive

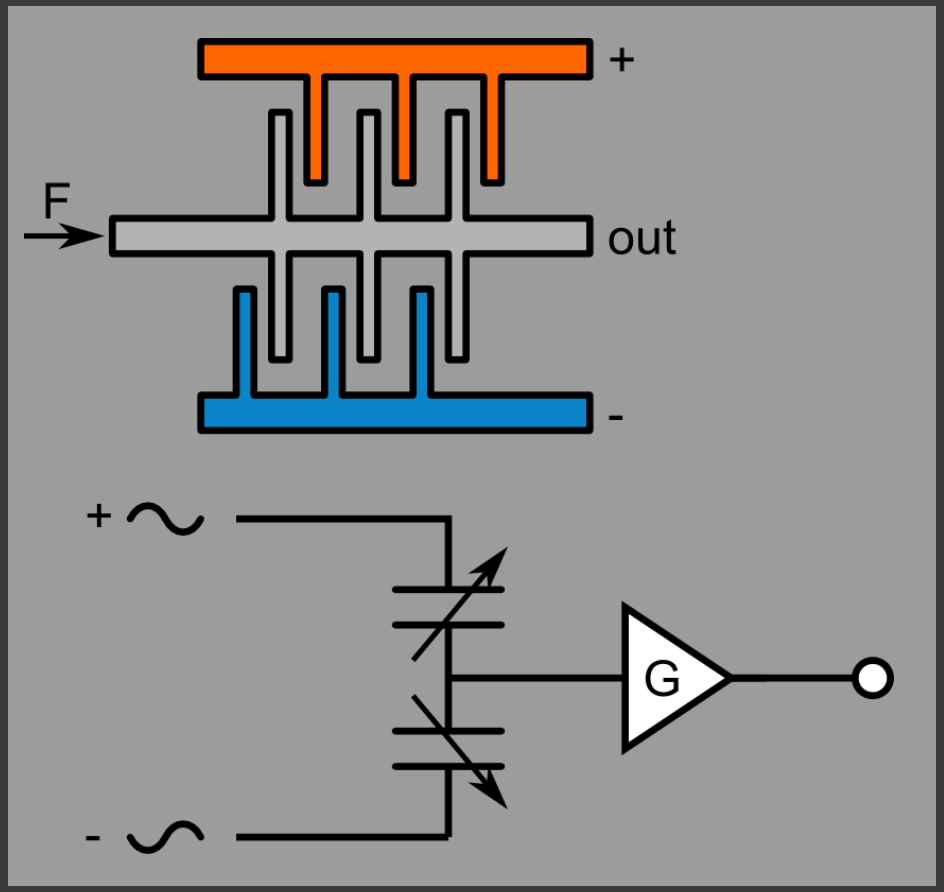




Issues

1) Long-term stability (temp and noise)
2) Power dissipation design tradeoffs
3) Actuation for self-test

Capacitive



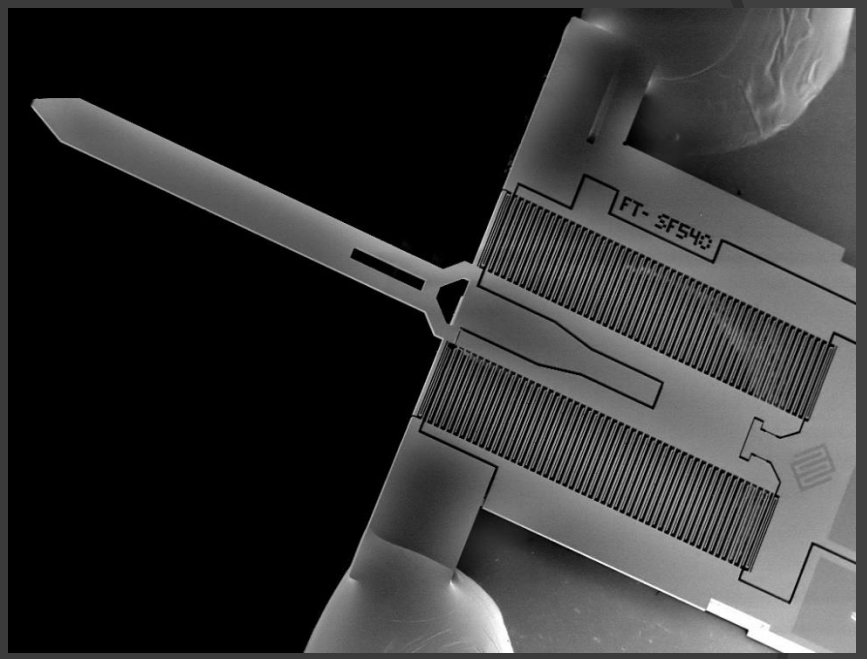
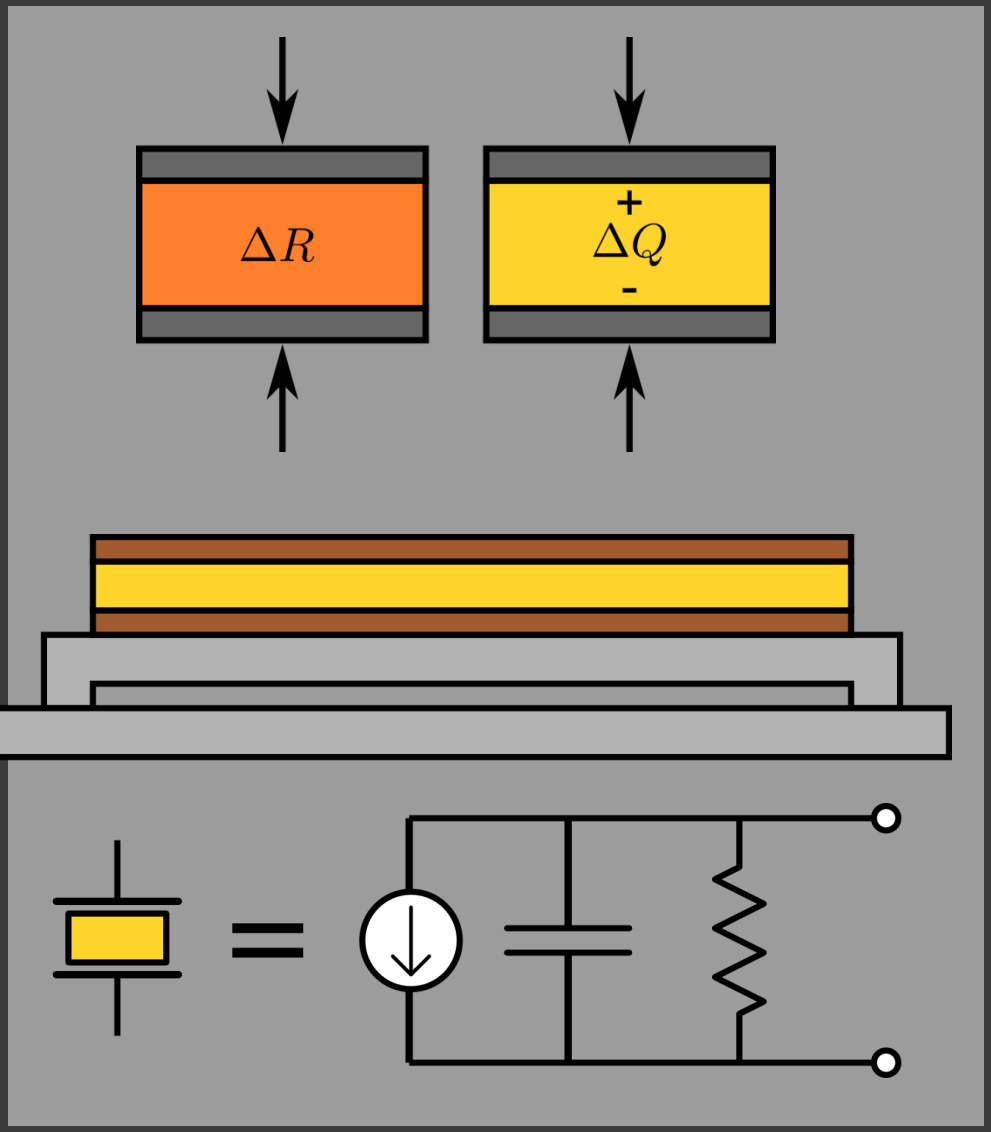


Image courtesy of Femtotools

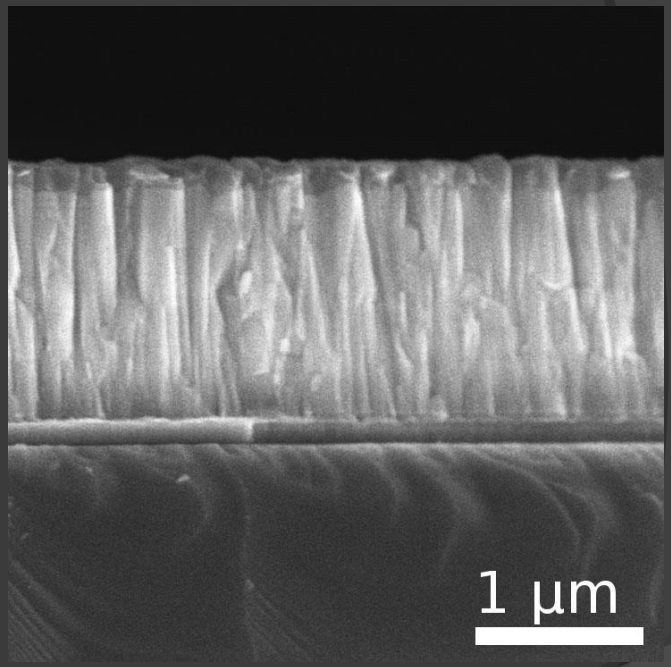
Issues

1) Parasitics
2) Dynamic range (snap-in)
3) Motional impedance



Piezoelectric

Example: AlN on Ti

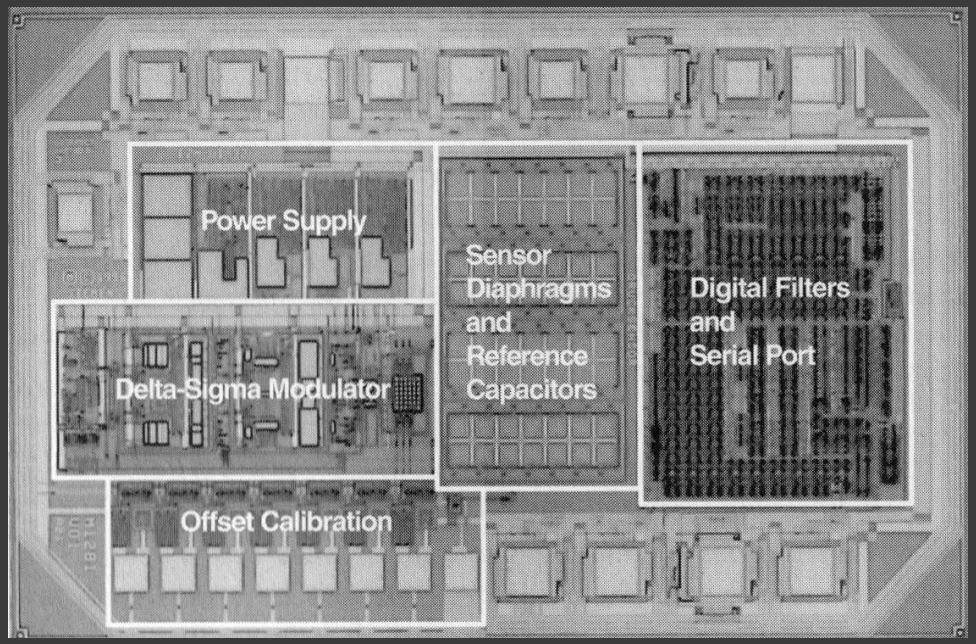


Issues

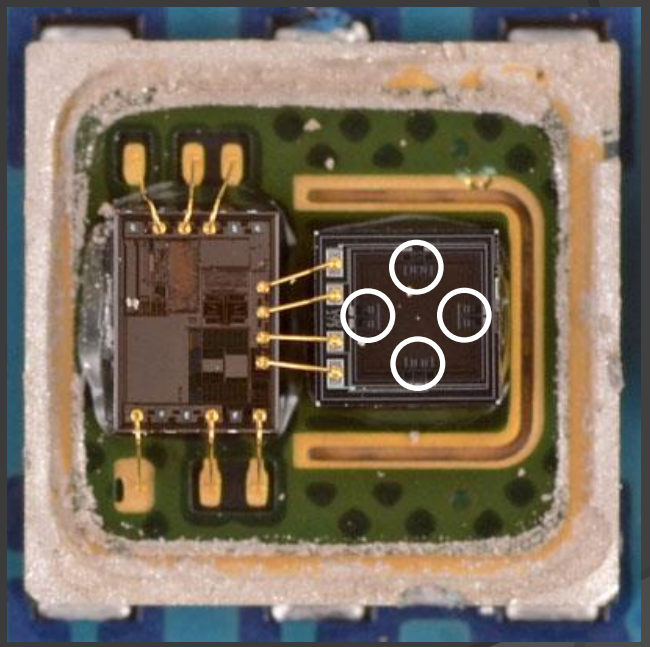
1) Charge vs. voltage readout
2) DC sensitivity
3) Film quality and stress
4) Metal electrode compatibility

Pressure sensors

Capacitive, monolithic (Infineon)



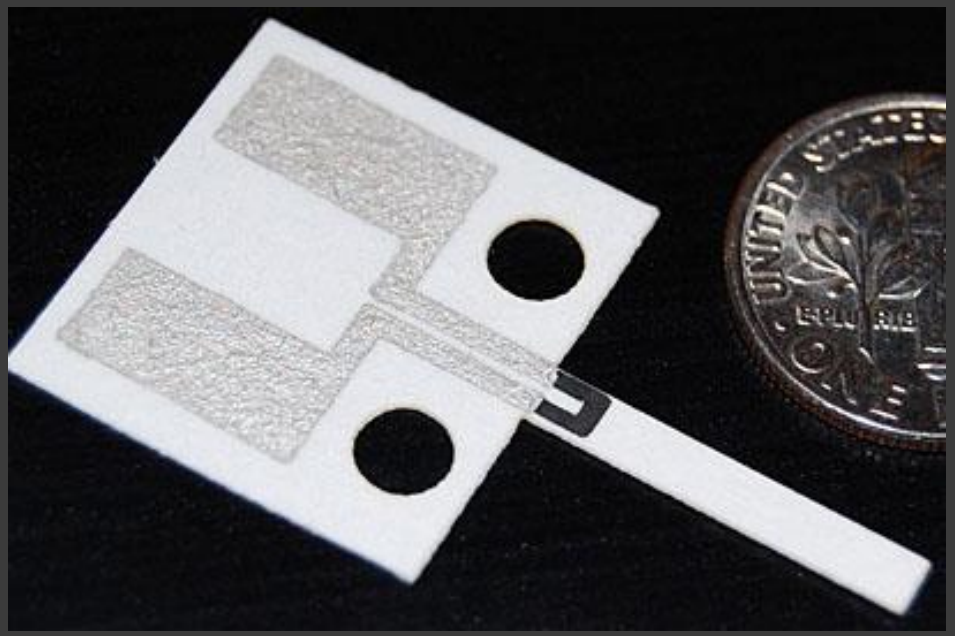
Piezoresistive, hybrid (Bosch)



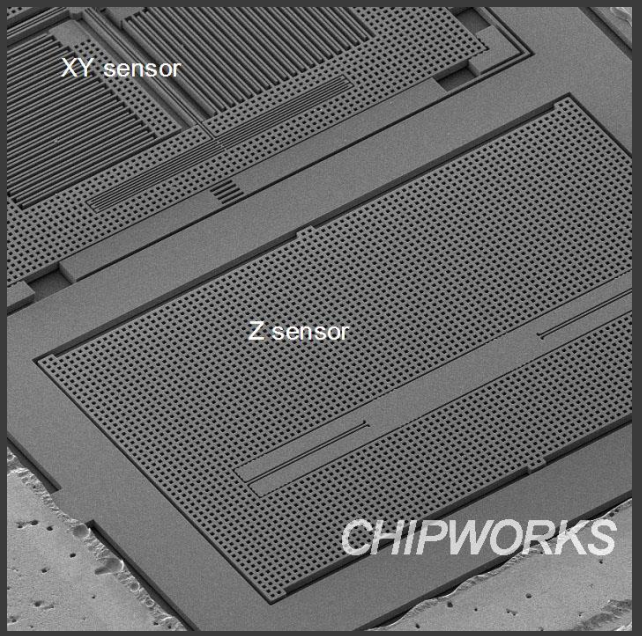
Images courtesy of Infineon Technologies and iFixit

Accelerometers

Piezoresistive, screen printed (Harvard)



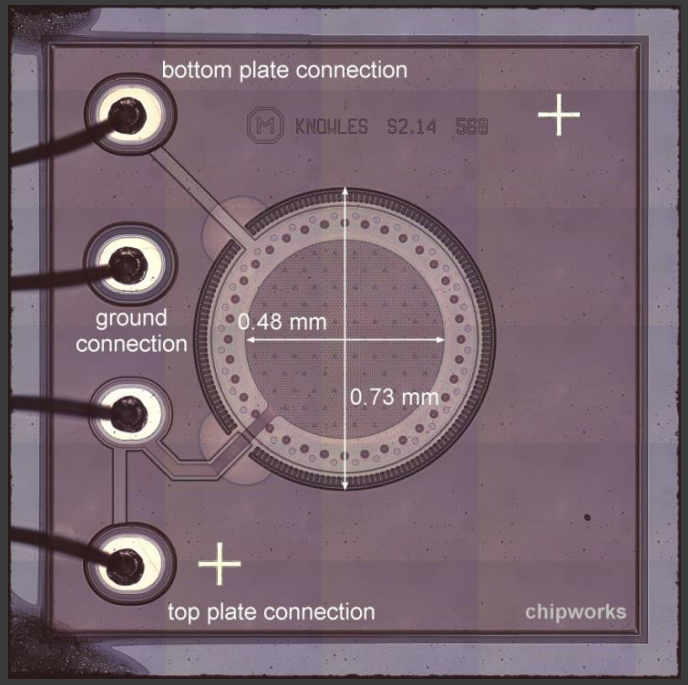
Capacitive, hybrid (STMicroelectronics)

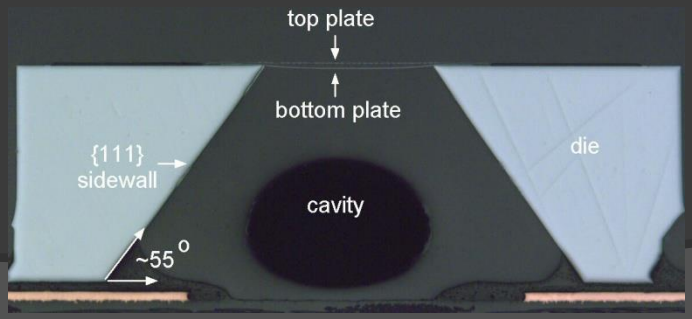


Images courtesy of IEEE and Chipworks

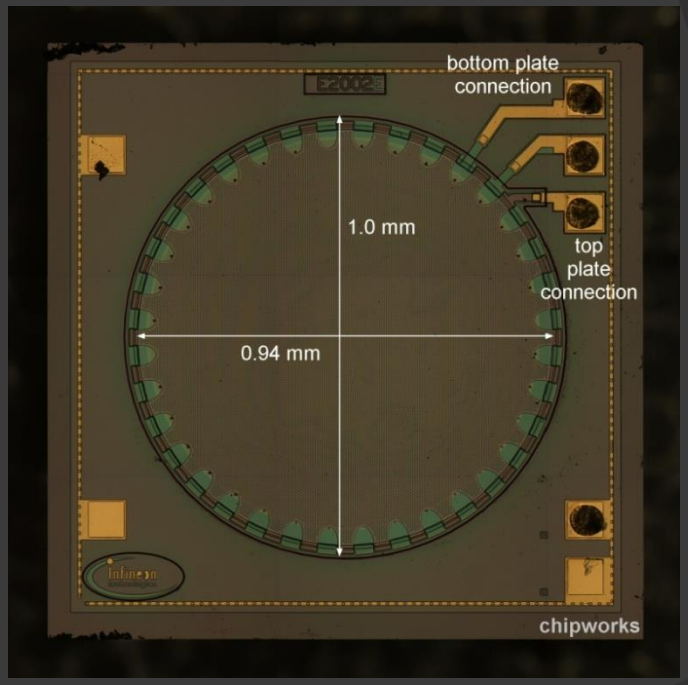
Microphones

Capacitive, hybrid (Knowles)





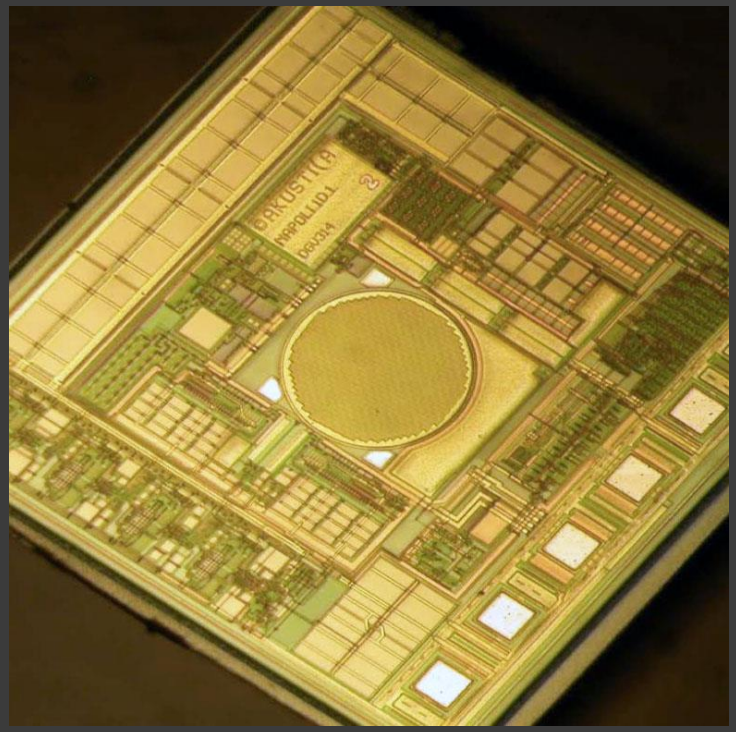
Capacitive, hybrid (Infineon)

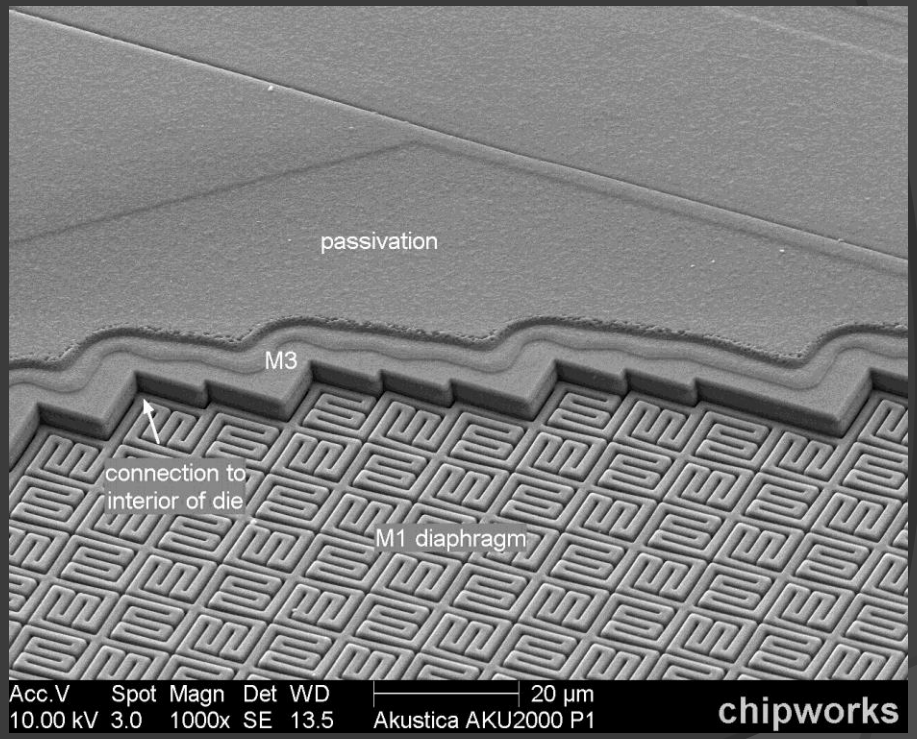


Images courtesy of Chipworks

Microphones

Capacitive, monolithic (Akustica)





Images courtesy of Chipworks

Conclusions

- CMOS and MEMS can be integrated at the board, package or die levels. Hybrid (package level) integration is the most common approach.
- Capacitive transduction is dominant, but piezoresistive and piezoelectric transduction each have merits and are widely used. All can operate near the thermomechanical noise floor.
- Approaches vary widely. Most packaging/transduction combinations are in commercial production.

Thank you!