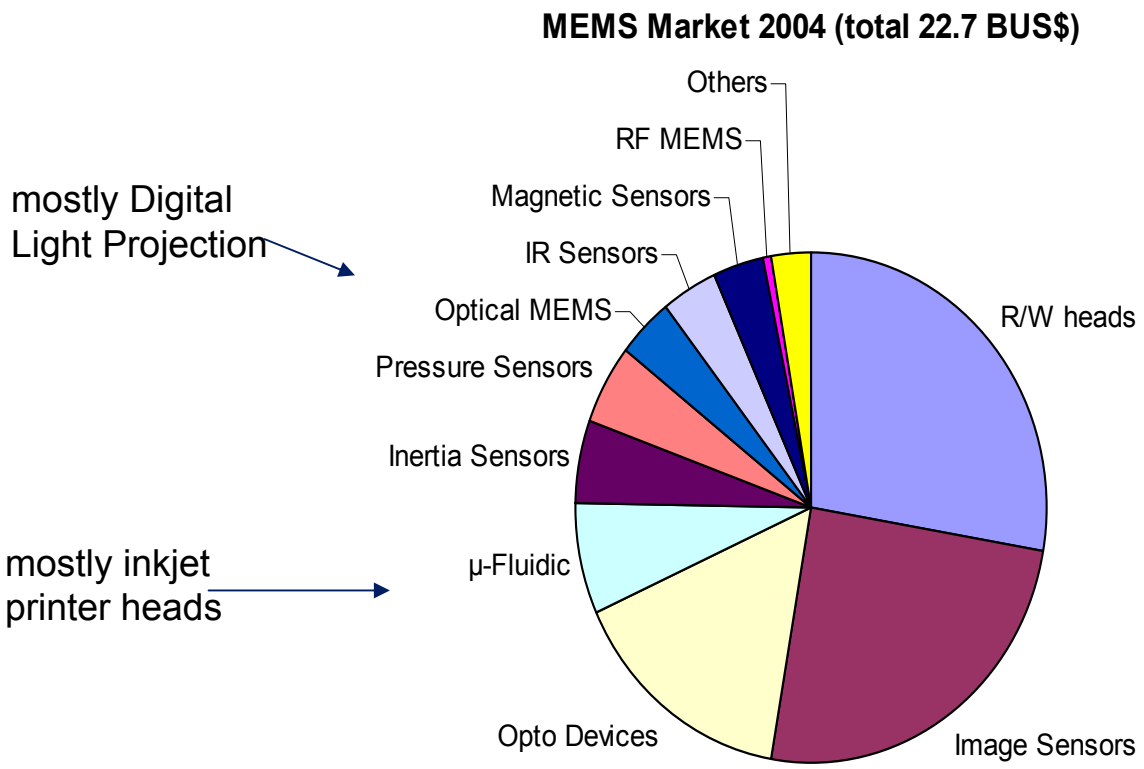
Industrialization of Micro-Electro-Mechanical Systems

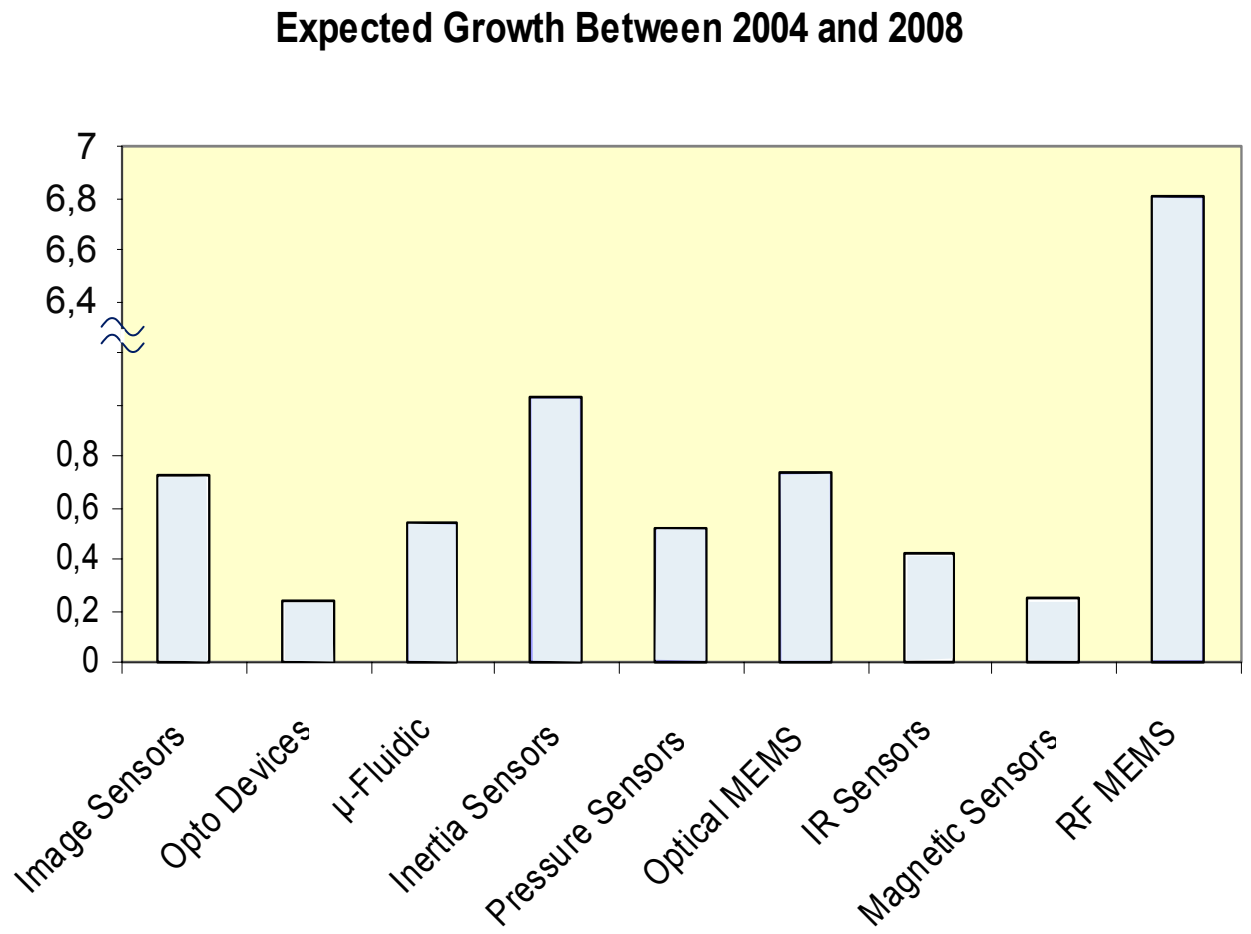
Werner Weber
Infineon Technologies

Never stop thinking

Semiconductor-based MEMS market



Growth potential of different technologies



Trends in MEMS

- Killer applications: the markets of Read/Write heads, Opto Devices and Digital Light Projection and Image Sensors for cameras and mobile phones have already taken off
- Emerging areas: acceleration sensors, pressure sensors, RF MEMS, biosensors for DNA analysis, water & air quality, body functions are future hype candidates

Other Trends

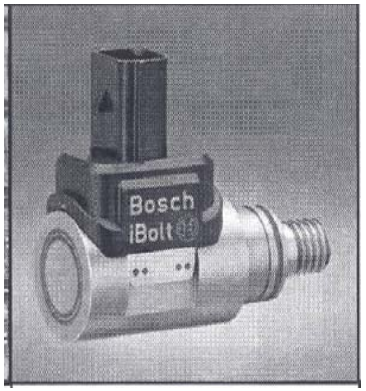
- The growing role of system integration
- Integration in system on chip

- Importance of packaging
- Separation of sensor and logic chip plus 3D integration

- More complex applications combine multiple sensor signals
- Application/customer-specific solutions (see next page)

Customer oriented solutions are a differentiator

- Sensor is a common part (traditional cantilever)
- BOSCH integrated such sensor in a regular bolt to fasten seat of car
- Customer just needs to replace existing bolts by new one
- functional housing of sensor - adapted to customer needs - finally yields differentiator



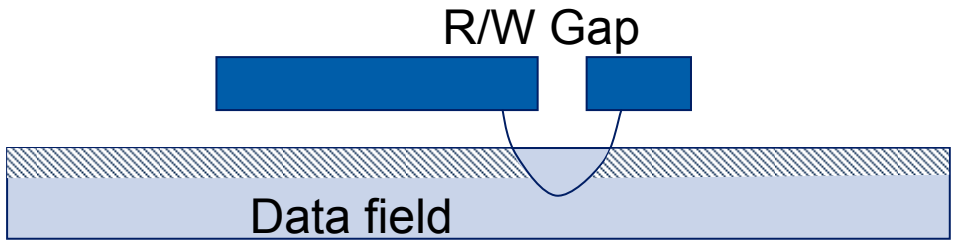
Bolt weight sensor (BOSCH)

Agenda

- R/W Heads
- Image Sensors
- OptoDevices
- µ-Fluidics
- Optical MEMS for Light Transmission
- Pressure Sensors
- Inertia
- Magnetic Sensors
- Infrared Sensors
- Radio Frequency MEMS

R/W heads
(revenue of 9.3 BUS$ in 2007)

Conventional R/W head



Advanced R/W head

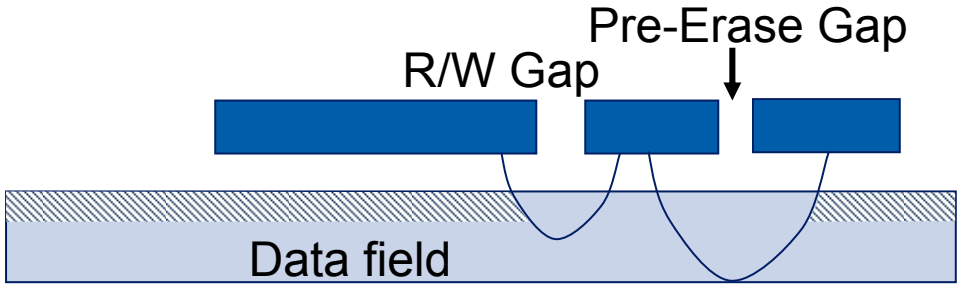
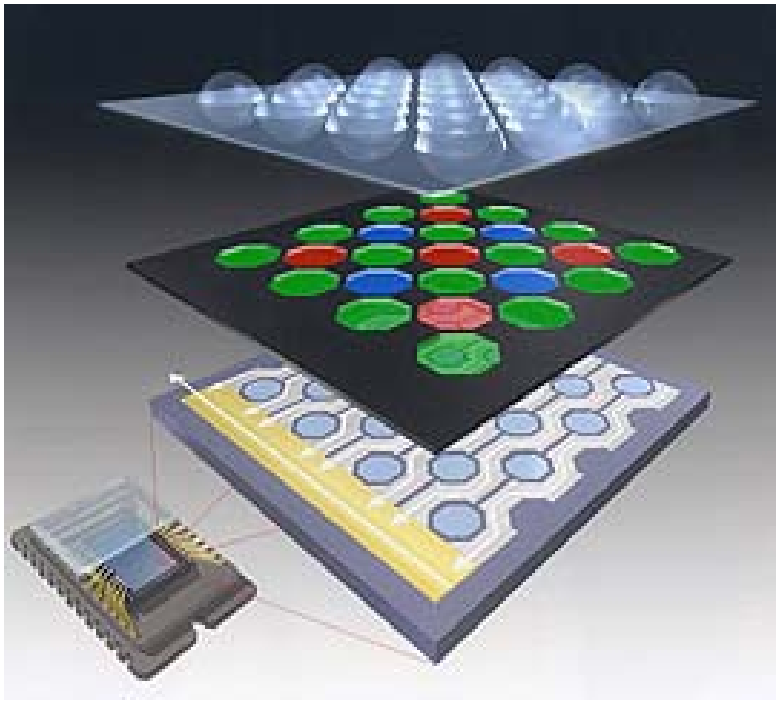
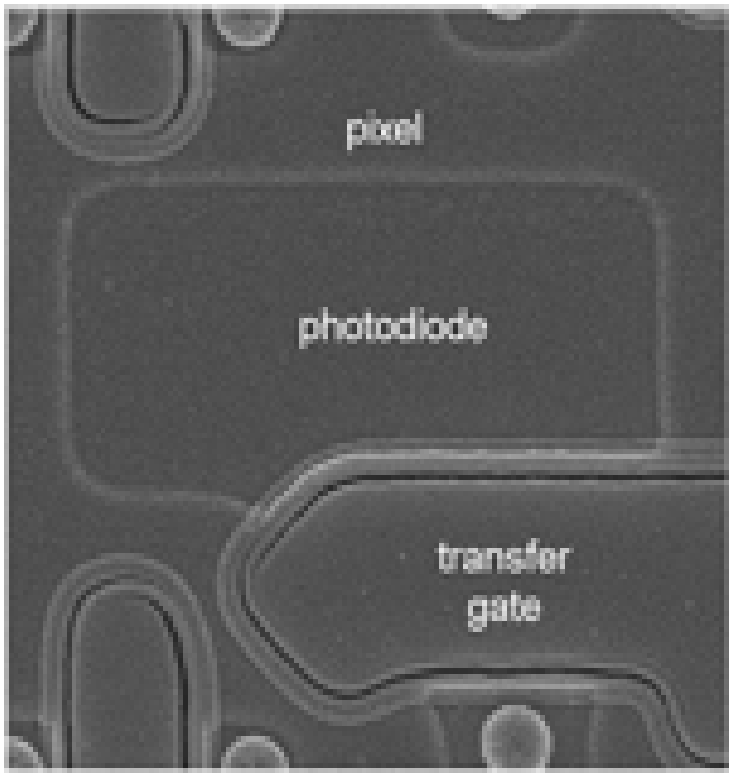
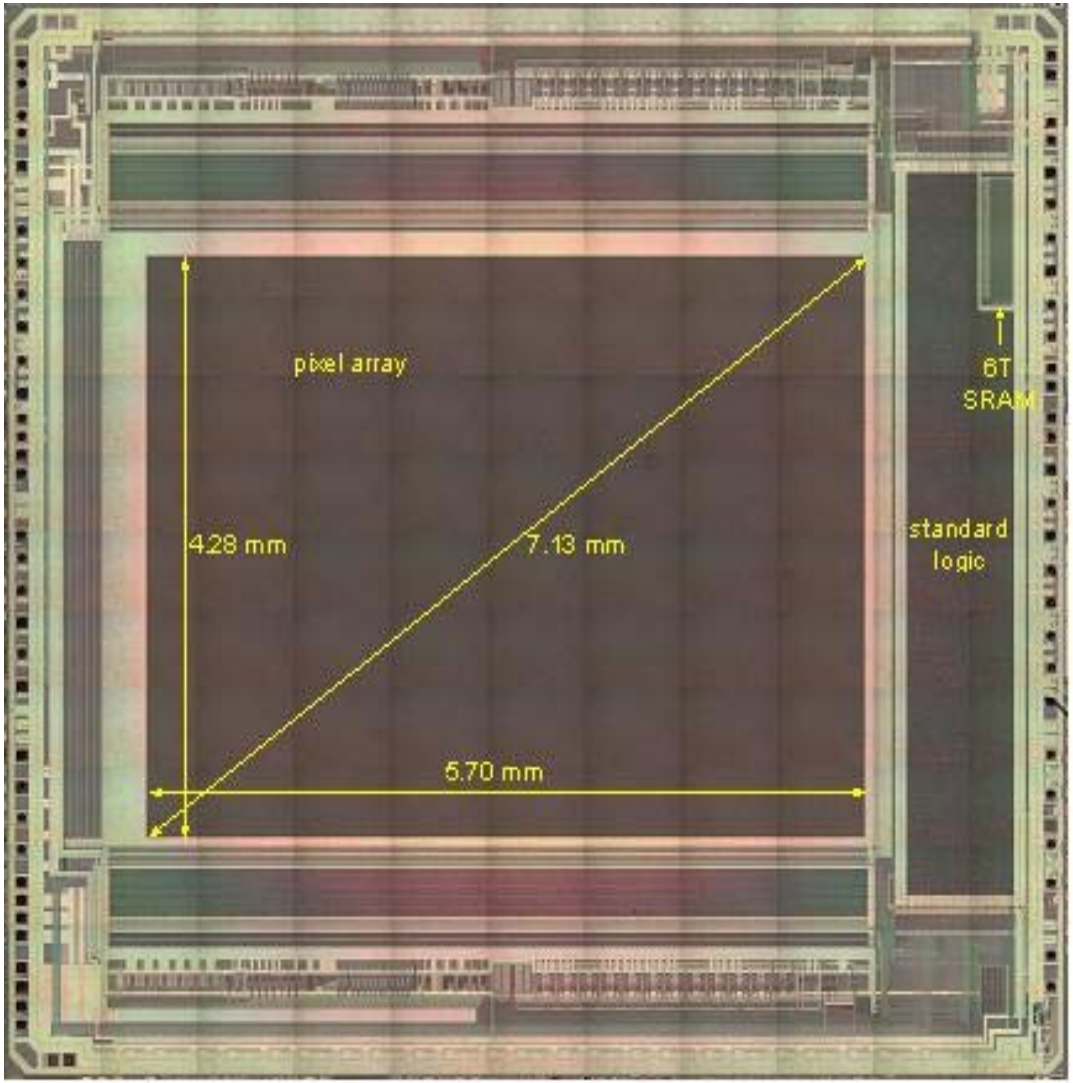


Image Sensors
(revenue of 8.4 BUS$ in 2007)





5 Megapixel Image Sensor



source: Micron/Nokia

Opto Devices for light generation
(revenue of 3.8 BUS$ in 2007)

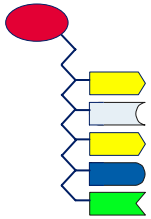
- Photodiodes
- Laser Pickup (of recorded data)
- Laser Transmitter

µ-Fluidics
(revenue of 2.3 BUS$ in 2007)

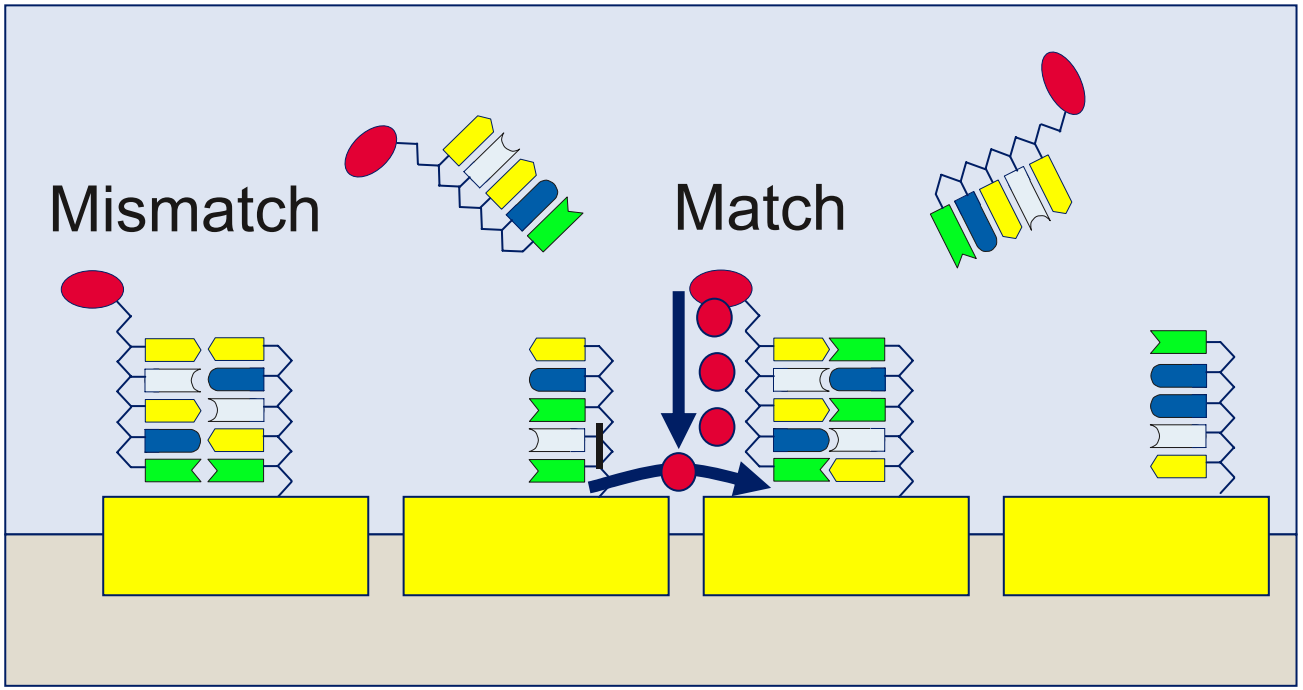
- InkJet Printing
- Biochip
- µ-Pumps
- Nebulizer
- Needleless injector
- Drug delivery
- Micro reaction
- Lab-on-a-chip

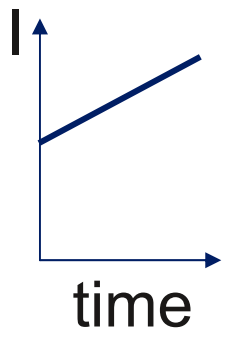
DNA Detector

Single stranded DNA



Single Stranded DNA with marker





µ-Fluidics
(revenue of 2.3 BUS$ in 2007)

- InkJet Printing 
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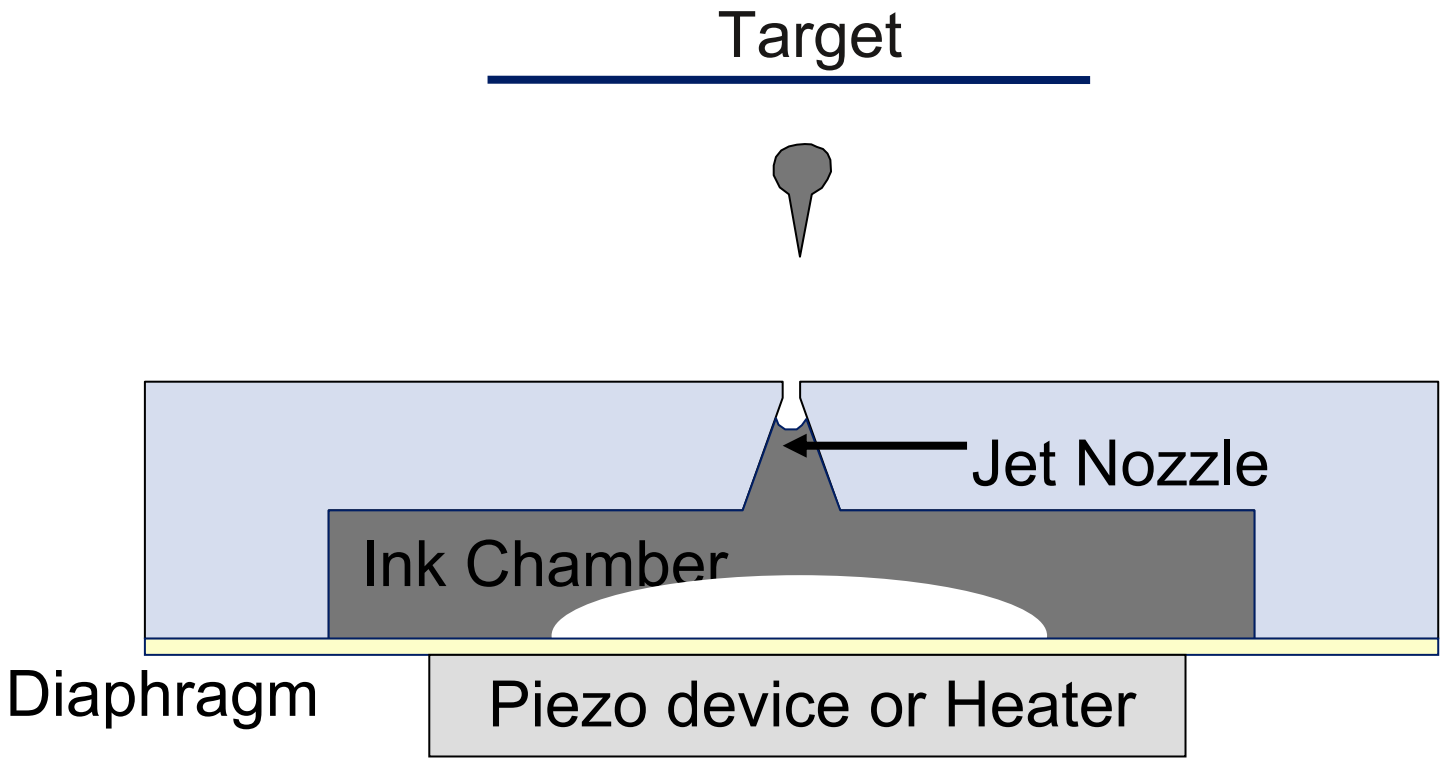
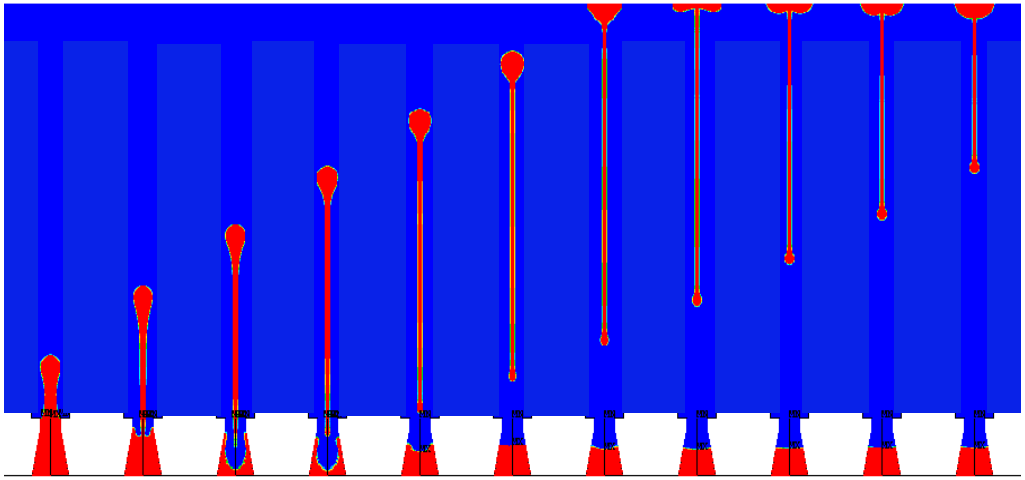
Printer heads



Inkjet printer in action

Simulation (increment of 25 µs)



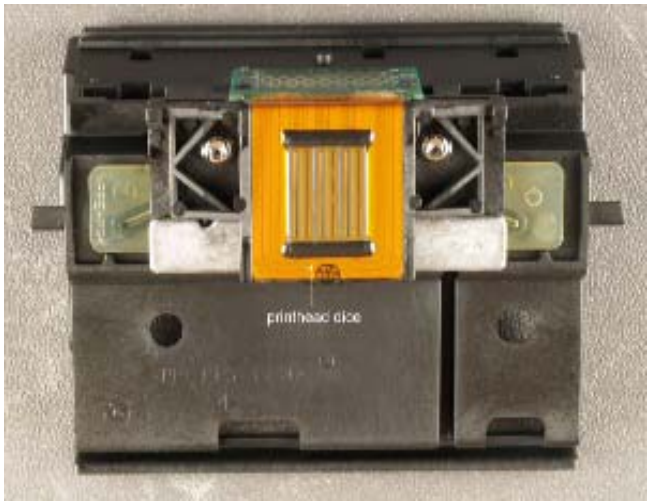
Source: Jyi-Tyan Yeh, Industrial Technology Research Institute, Hsinchu Taiwan
7th National Computational Fluid Dynamics Conference 2000

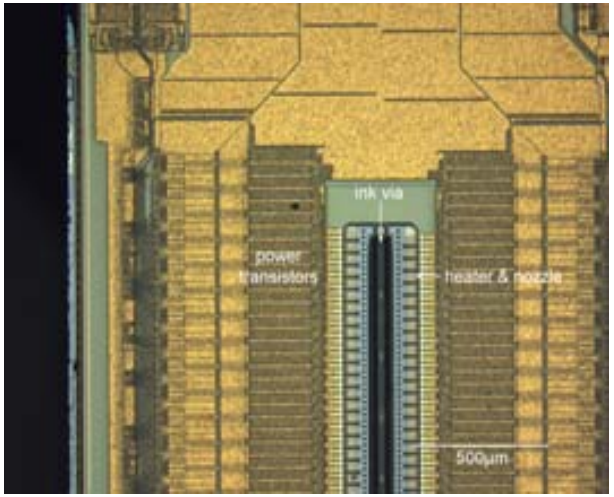
Photograph

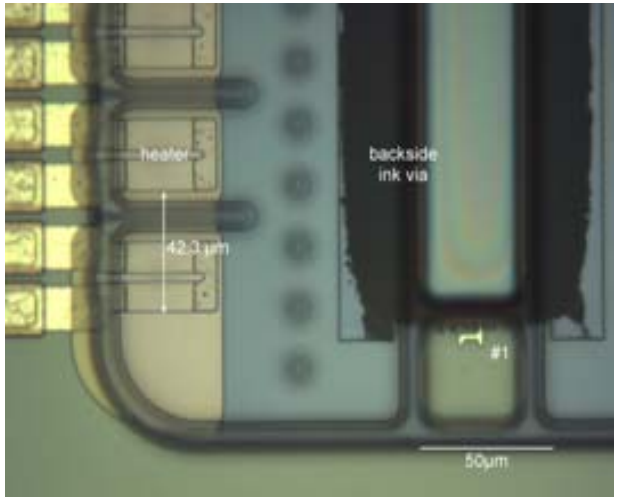
Source: M. Grove, et al., Display Works '99, 1999.

Recent trend: printhead integrated into printer

…. rather than into the print cartridge - reducing the cost for replacement ink cartridges







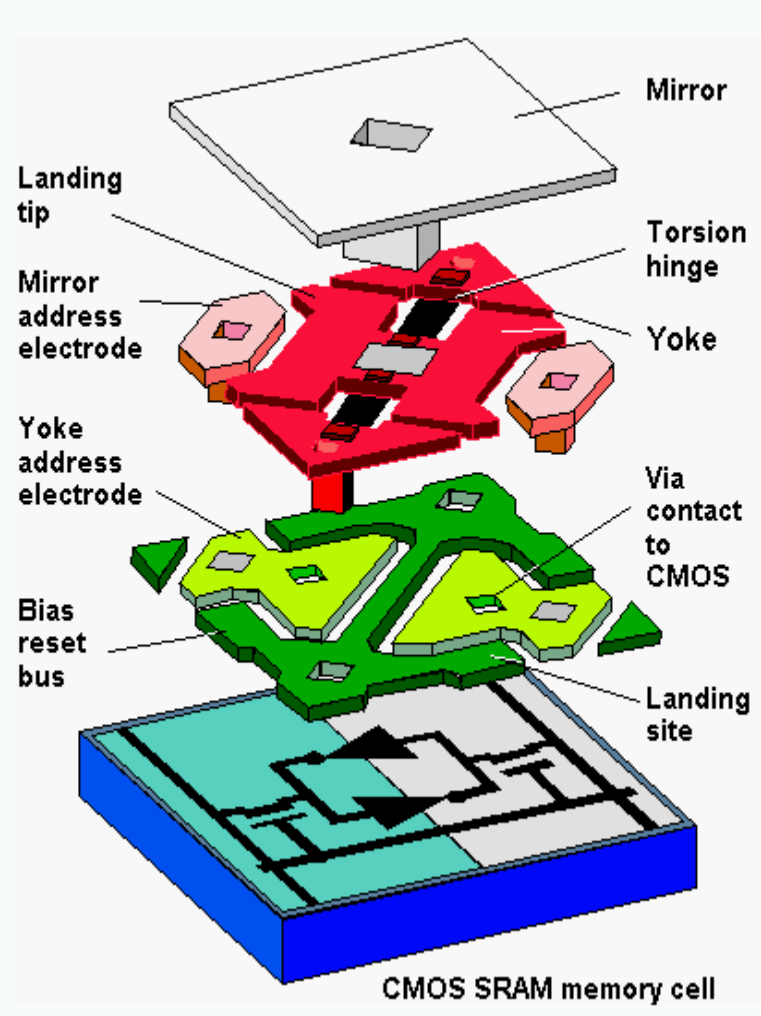
source: Kodak/ST

Optical MEMS for light transmission
(revenue of 2.0 BUS$ in 2007)

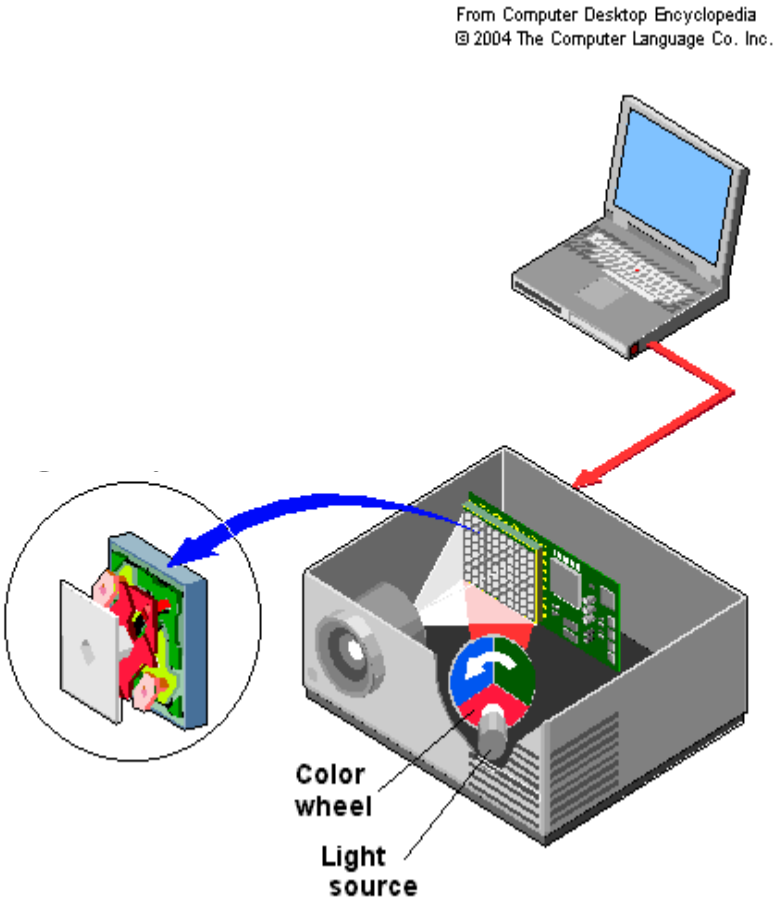
- Digital Light Projection/µ-displays 
- Switches/ µ-mirrors
- Attenuators
- Filters
- µ-lenses

Principle of Digital Light Projection

single pixel of digital micromirror device



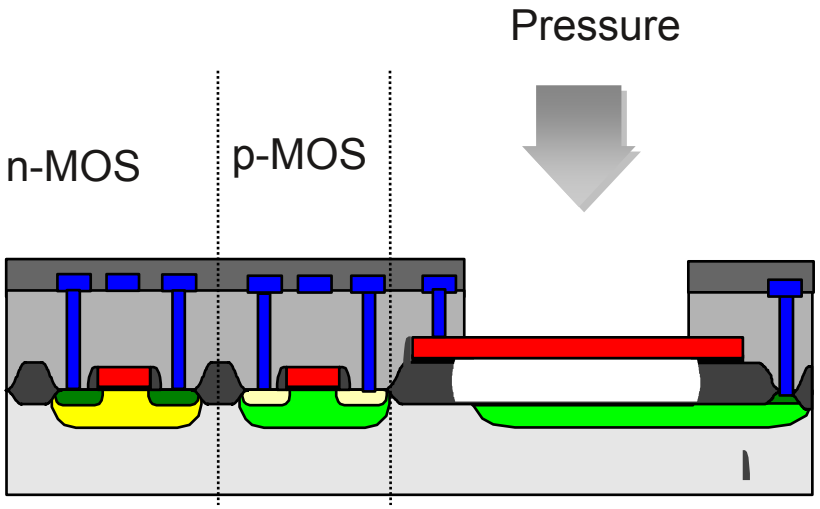
Projection system

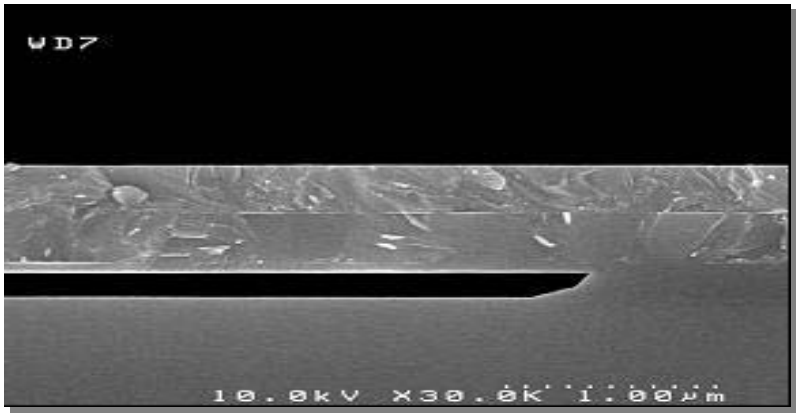


Pressure Sensors
(revenue of 1.6 BUS$ in 2007)

- Side airbag 
- TPMS

Surface Micromachined Pressure Sensor integrated in 0.5µm BiCMOS





0.8µm Poly-Si-Membrane, capacitive sensing

Typically two references and two sensors arranged in a bridge

10mbar overall accuracy

Sensors for 0.1 to 3 bar, side airbag, motor management (intake pressure)

Pressure Sensors
(revenue of 1.6 BUS$ in 2007)

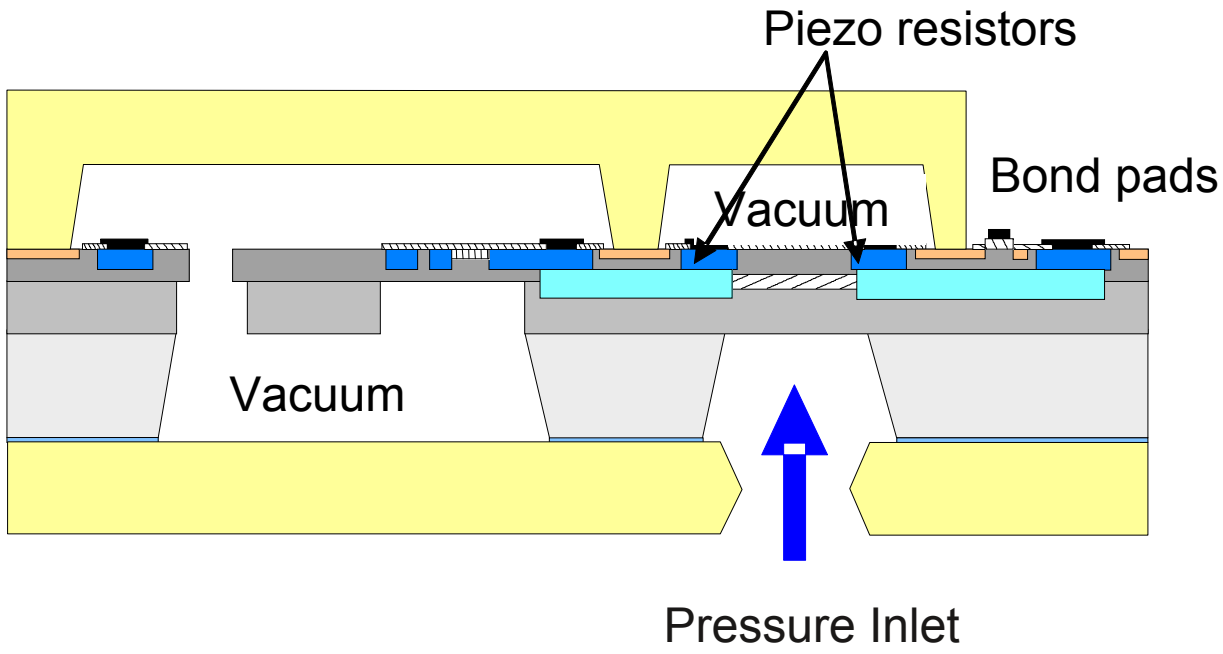
- Side airbag
- TPMS

Bulk Micromachined Tire Pressure Monitoring System (TPMS)

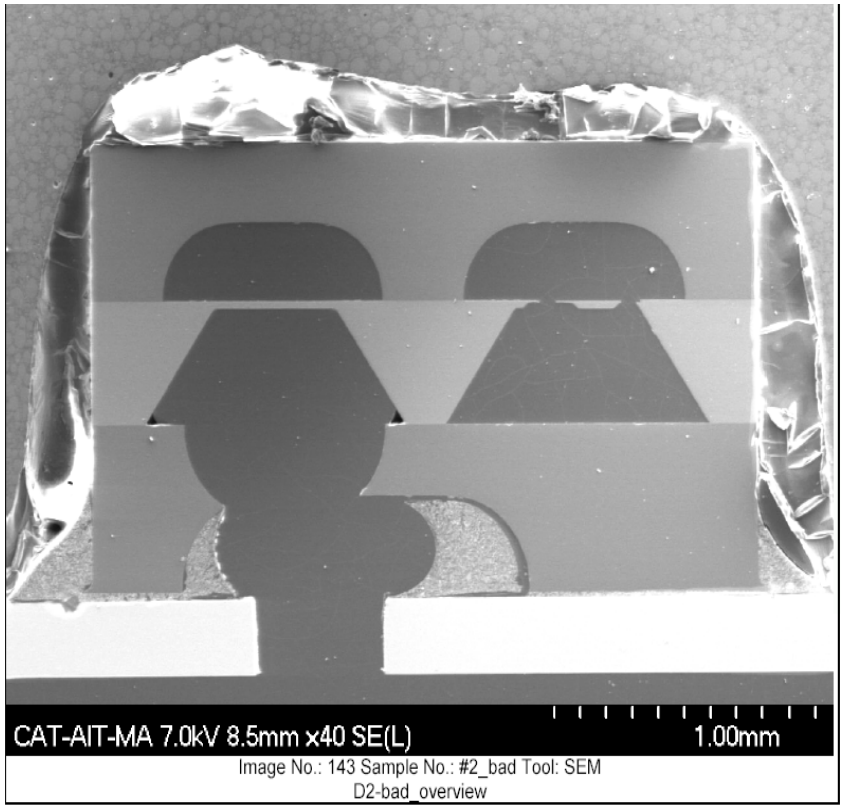
glass-silicon-glass stack

Only silicon oxide exposed to media.

All active parts are placed on the backside of the pressure membrane.



TPMS Device Analysis: X-Ray



Inertia
(revenue of 1.4 BUS$ in 2007)

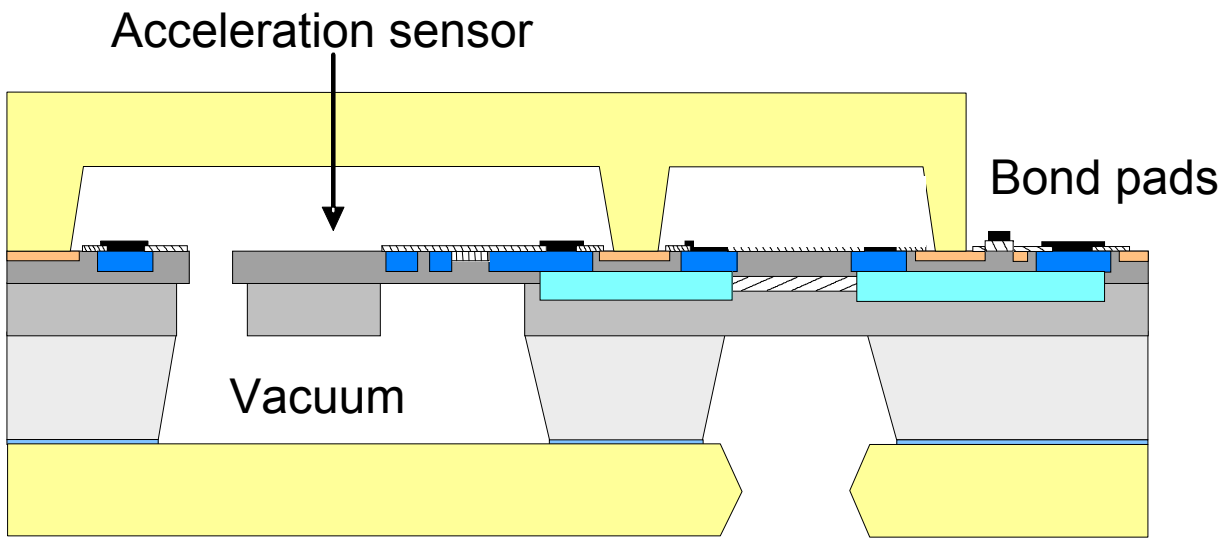
Sensors

- Accelerometer 
- Gyroscope
- Energy scavenging
- Microphone

Acceleration Sensor in TPMS

glass-silicon-glass stack

Only silicon oxide exposed to media.



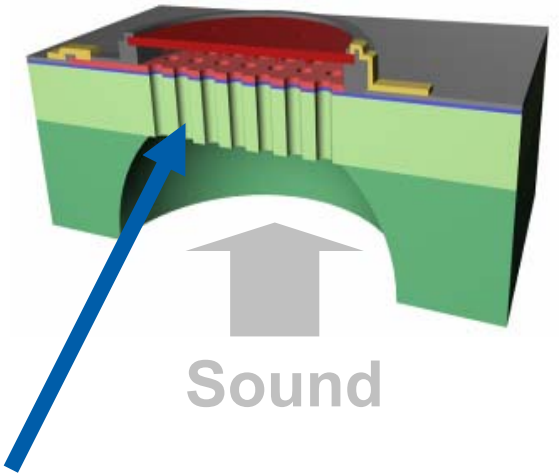
Inertia
(revenue of 1.4 BUS$ in 2007)

Sensors

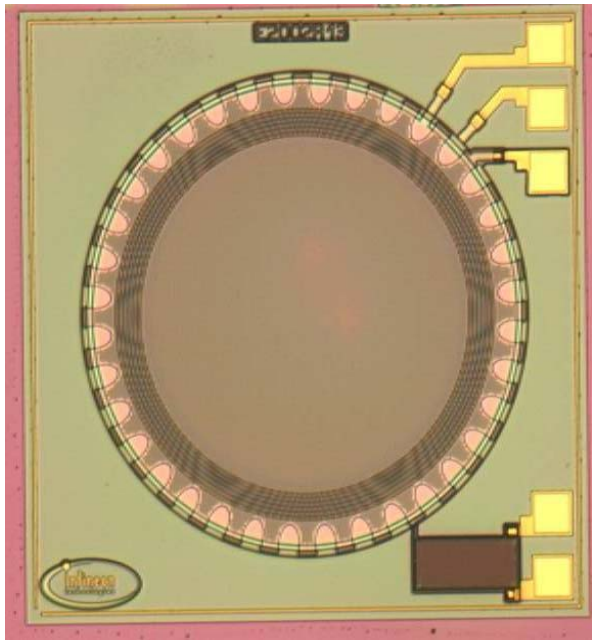
- Accelerometer
- Gyroscope
- Energy scavenging
- Microphone

Microphone

Flexible Membrane

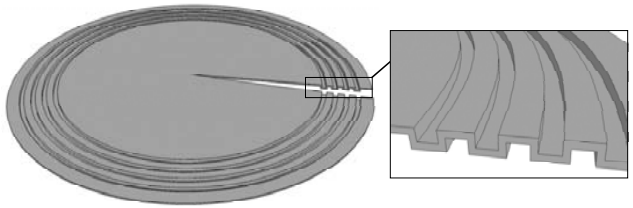


Stiff perforated backplate



Spring supported membrane

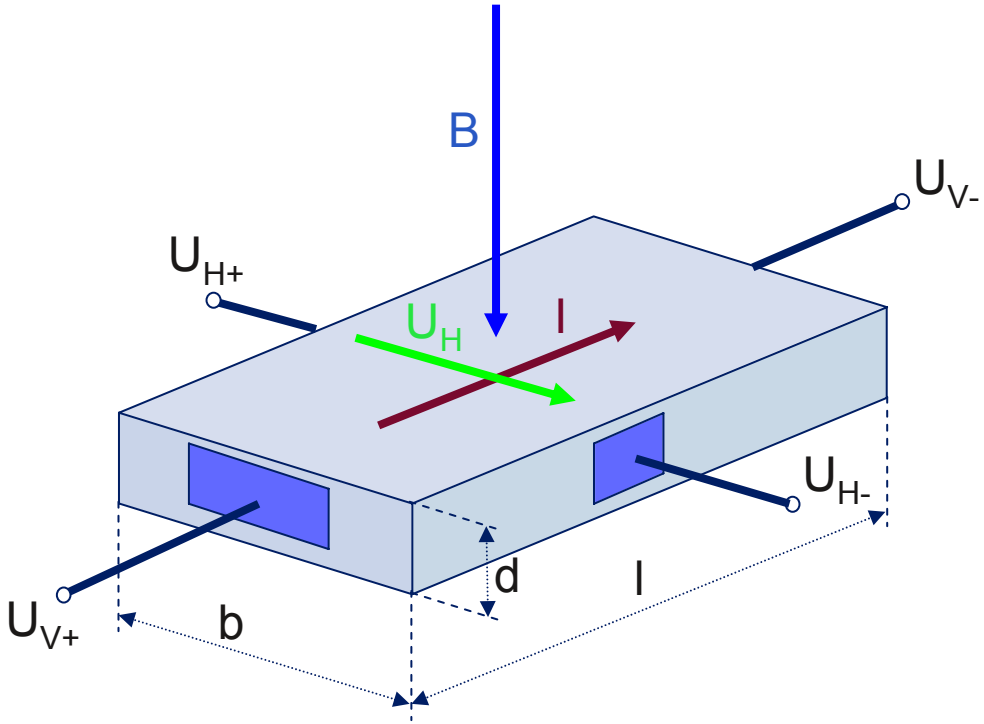
Membrane with corrugations

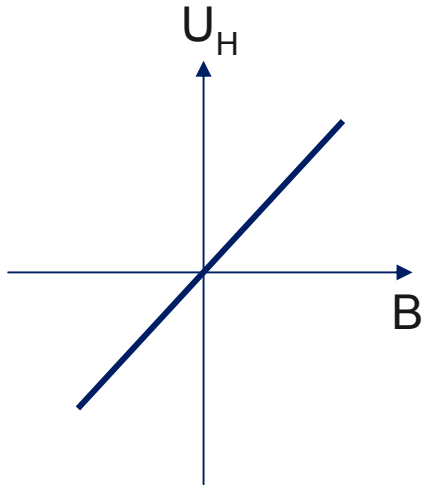


Magnetic Sensors
(revenue of 1.1 BUS$ in 2007)

- Hall sensor
- Giant Magnetic Resistance sensor

Basics of Magnetic Sensing: Hall Effect

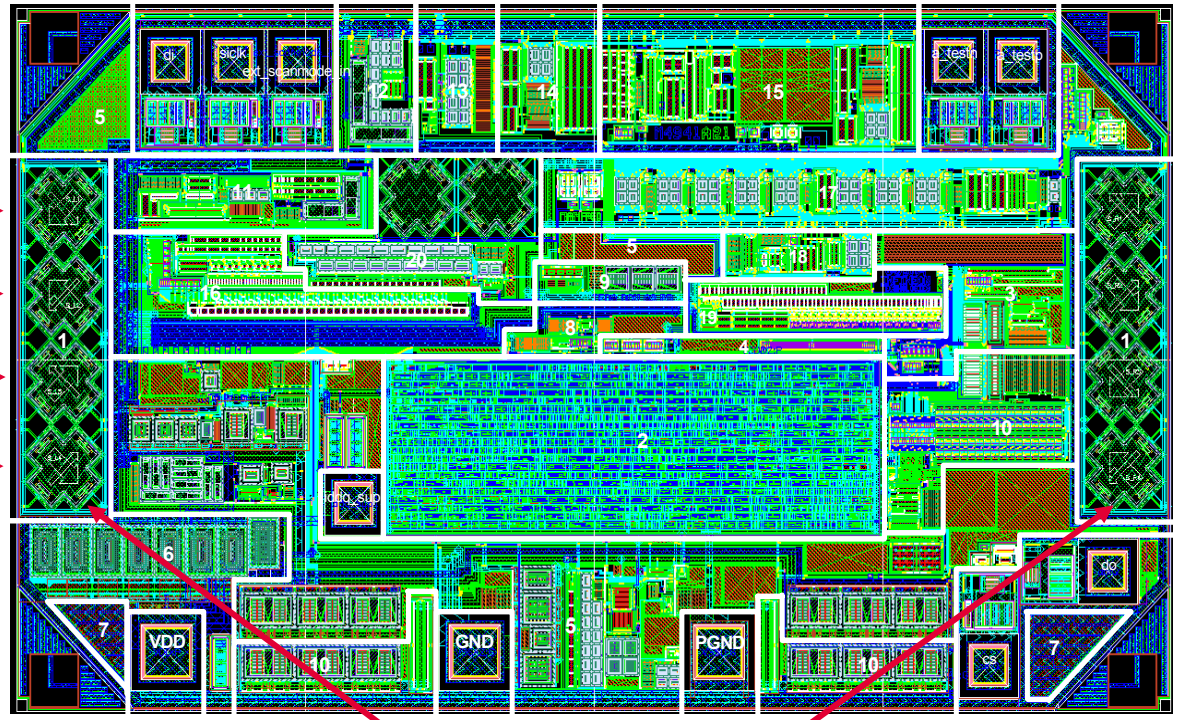


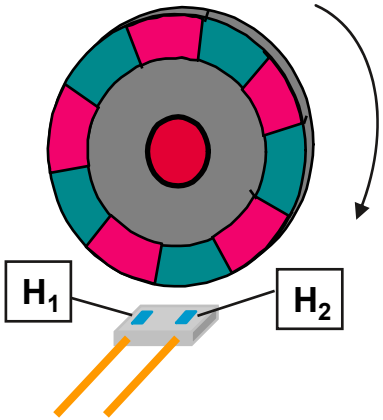


U_v: Supply Voltage for Hall Probe
U_H: Hall Voltage

Hall Probe

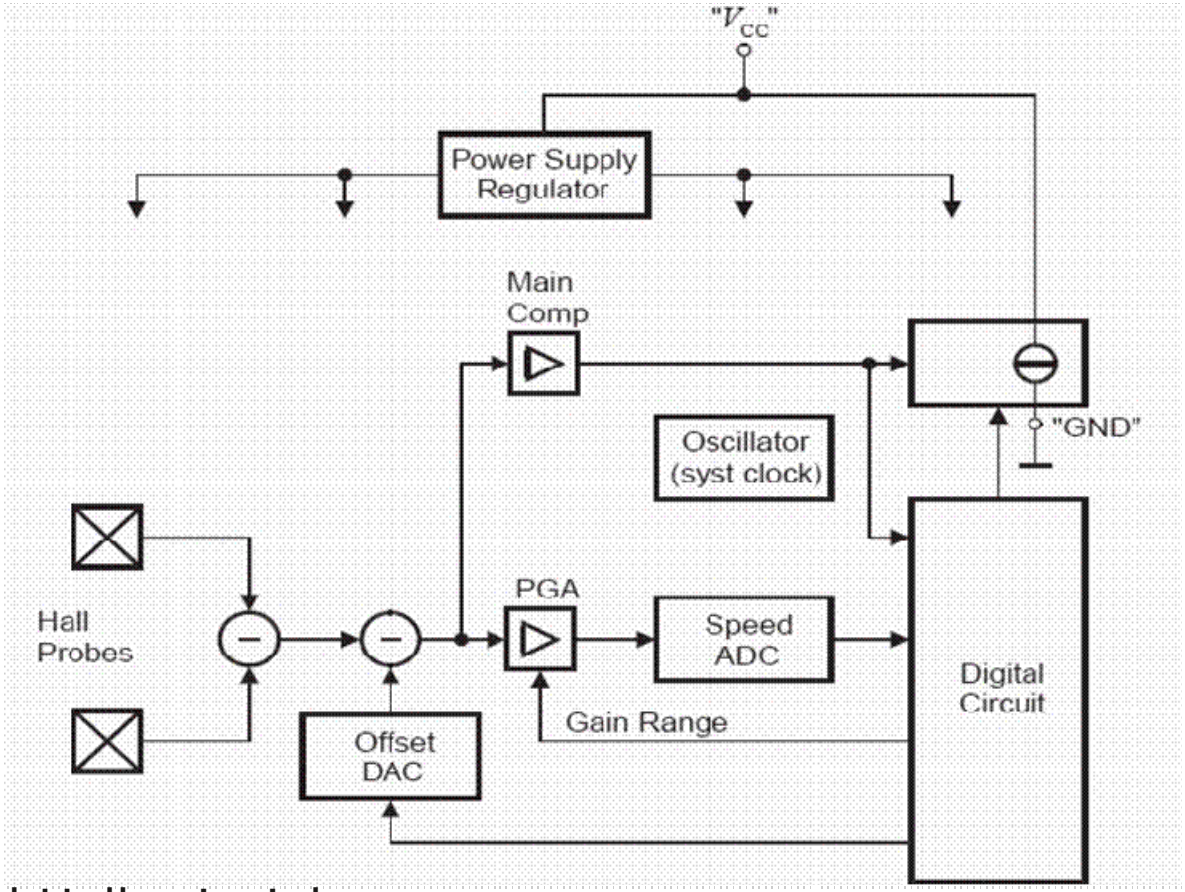
4 Hall plates for
4 directions in
the plain to
compensate for
noise





Distance of Hall plates equals distance of north and south pole of magnet:
2.5mm
(differential principle)

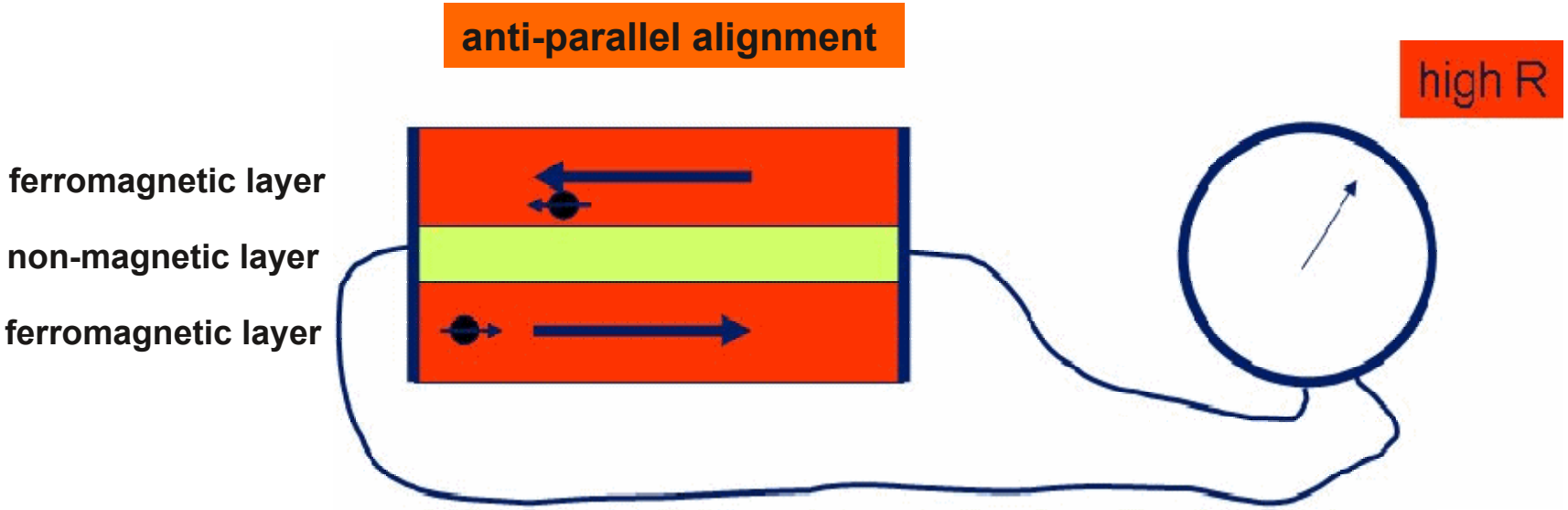
Measurement Principle of Hall Sensor



- Differential Hall principle
- Programmable Gain Amplifier (PGA) to adjust signal level to Analog Digital Converter (ADC)
- Analog offset compensation

Giant Magnetic Resistance (GMR) principle

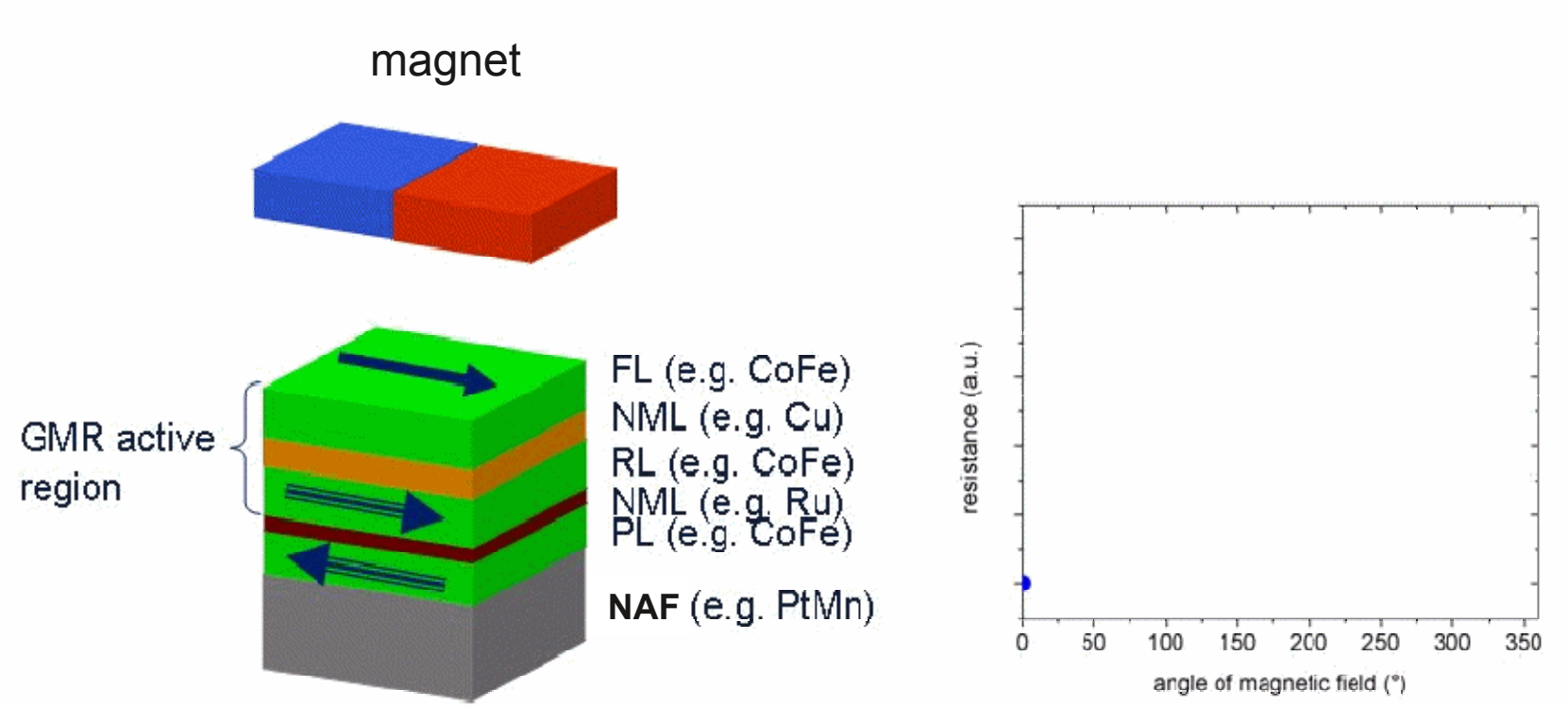
- spin dependent scattering of conducting electrons
- sensitive to in-plane magnetic field components



GMR spin valve system for angle sensing

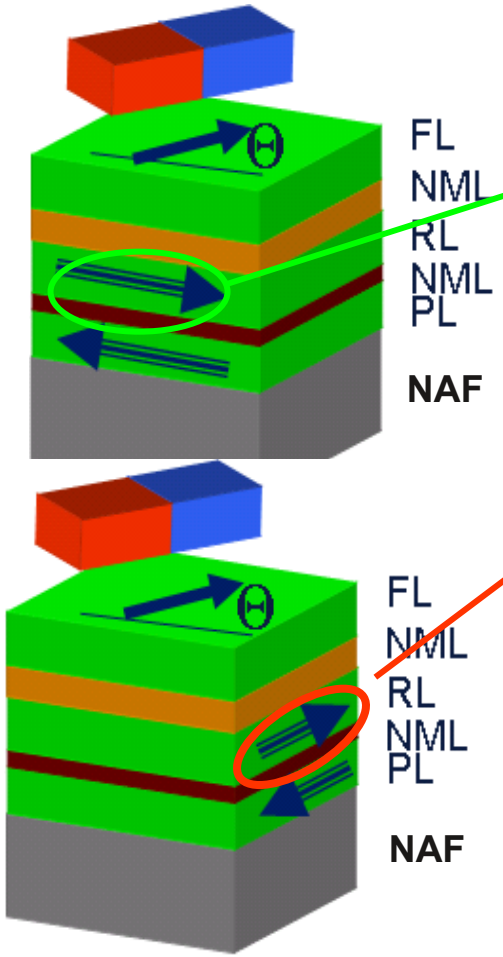
- reference layer (RL) with fixed magnetization direction
- free layer (FL) with ability to follow ideally an external in-plane magnetic field

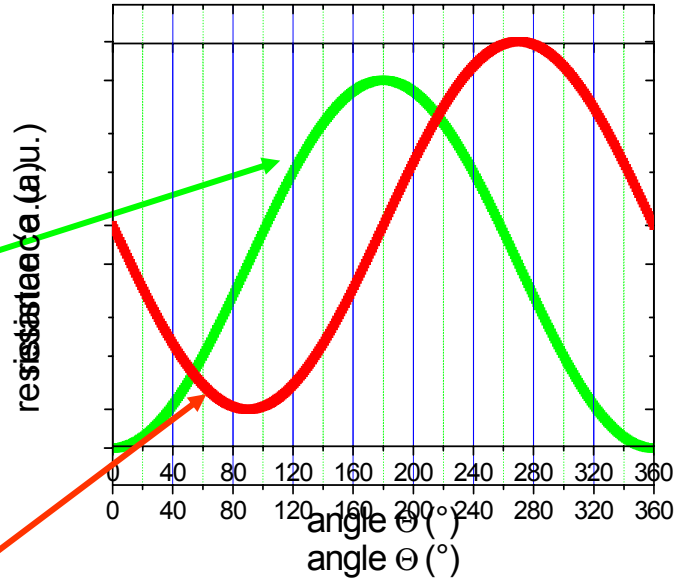
➔ Varying angle between FL and RL magnetization leads to a continuous change in stack resistance



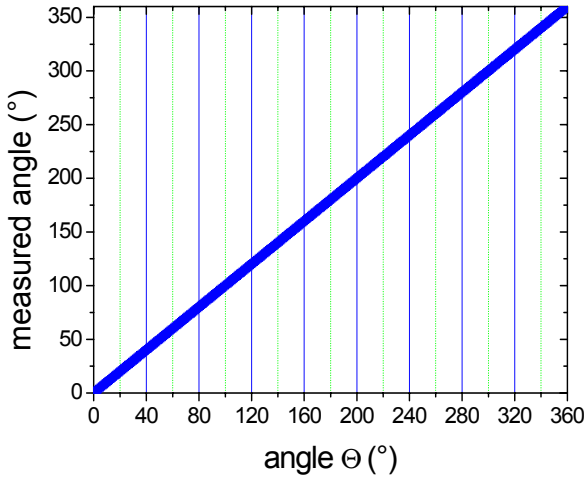
GMR spin valve system for angle sensing

➔ 360° uniqueness by combination of orthogonal RL magnetizations



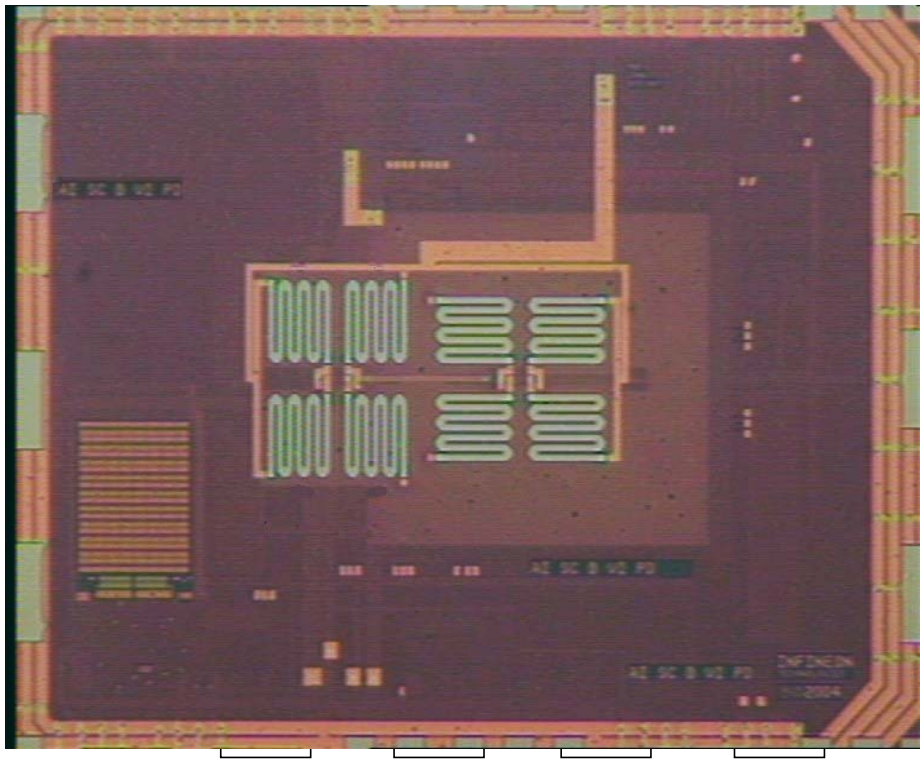


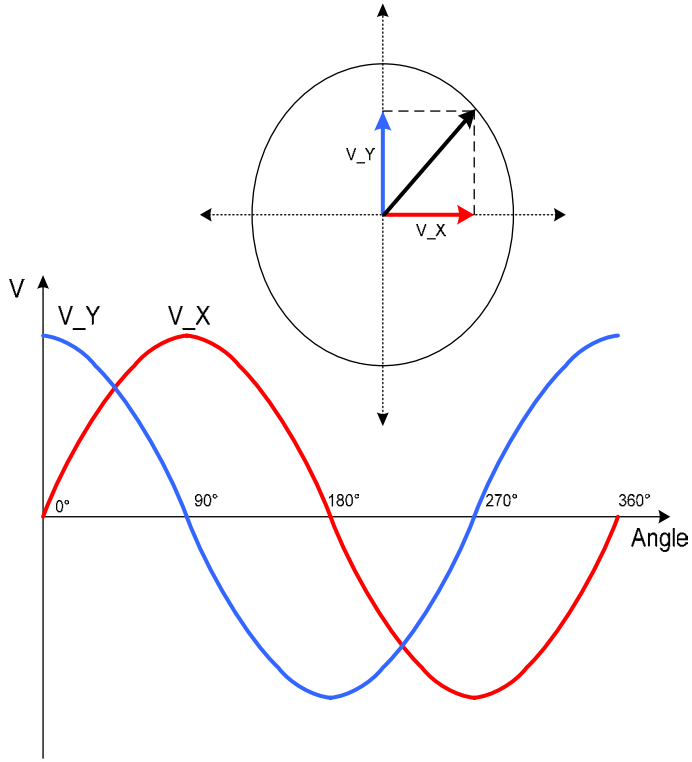
arctan



360° Angular Sensor

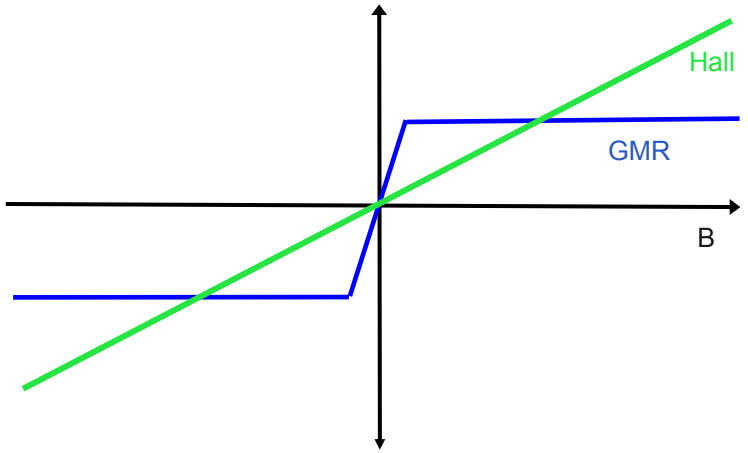
SIN COS



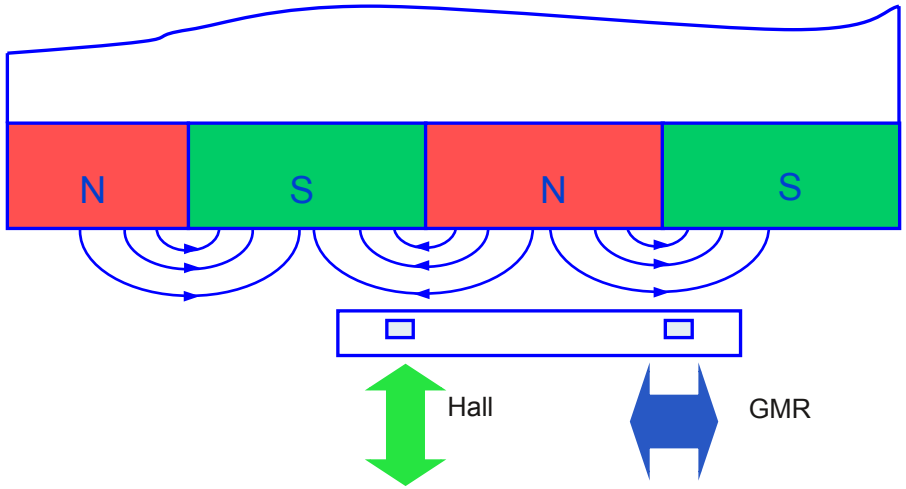


Advantages of GMR compared to Hall

- Higher sensitivity
  - bigger airgap
  - lower jitter



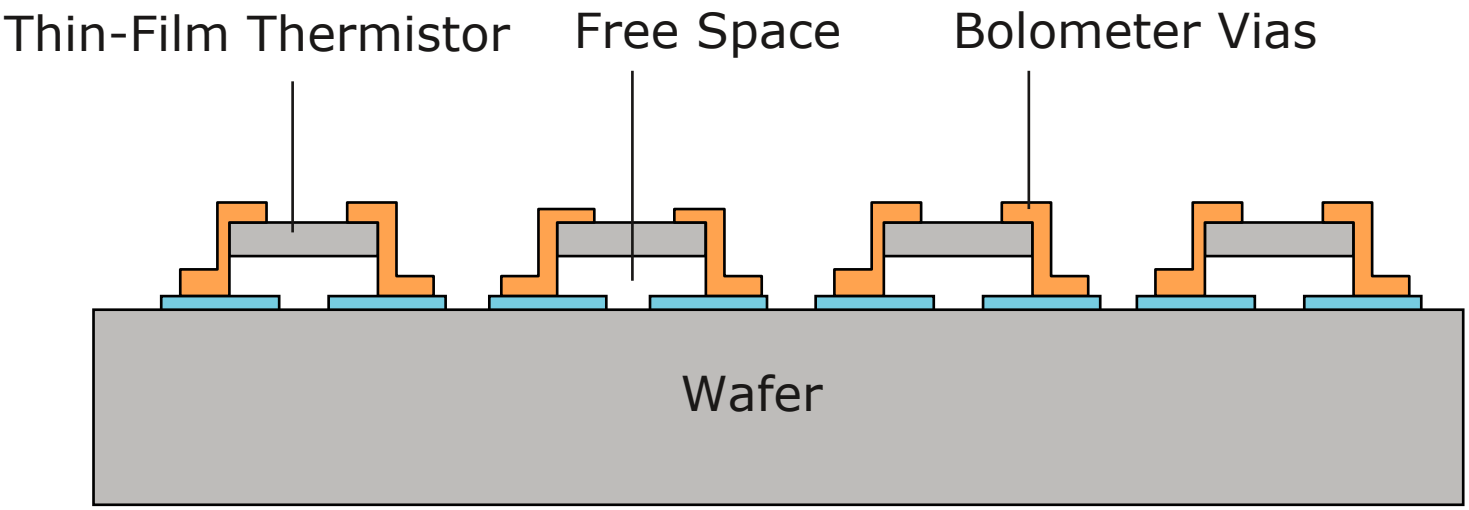
- GMR sensitive only to inplane field
  - bigger airgap
  - independent to back bias field



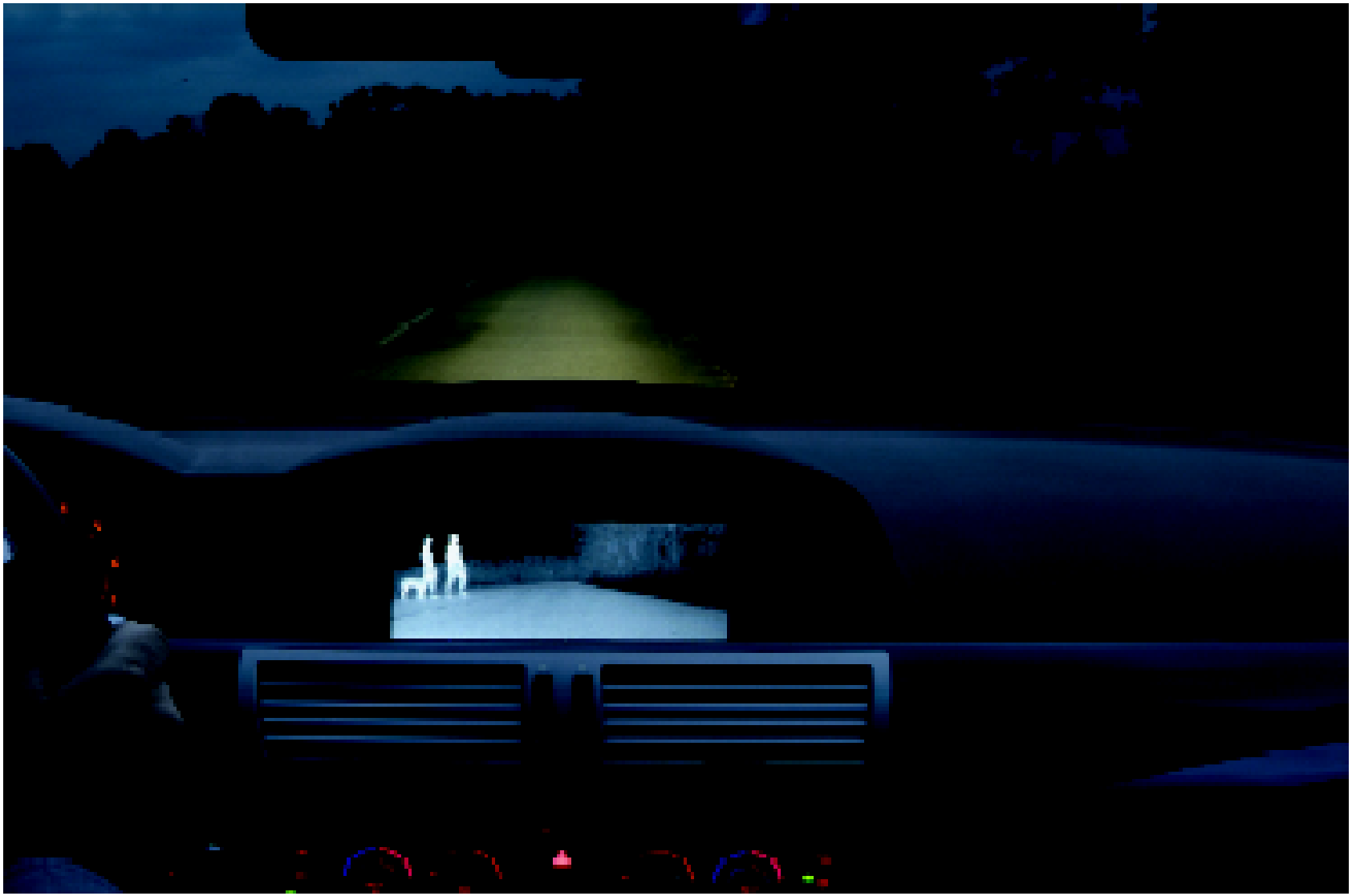
InfraRed Sensors
(revenue of 0.8 BUS$ in 2007)

- IR-temperature
- IR camera arrays

Bolometer Array for Night Vision Systems



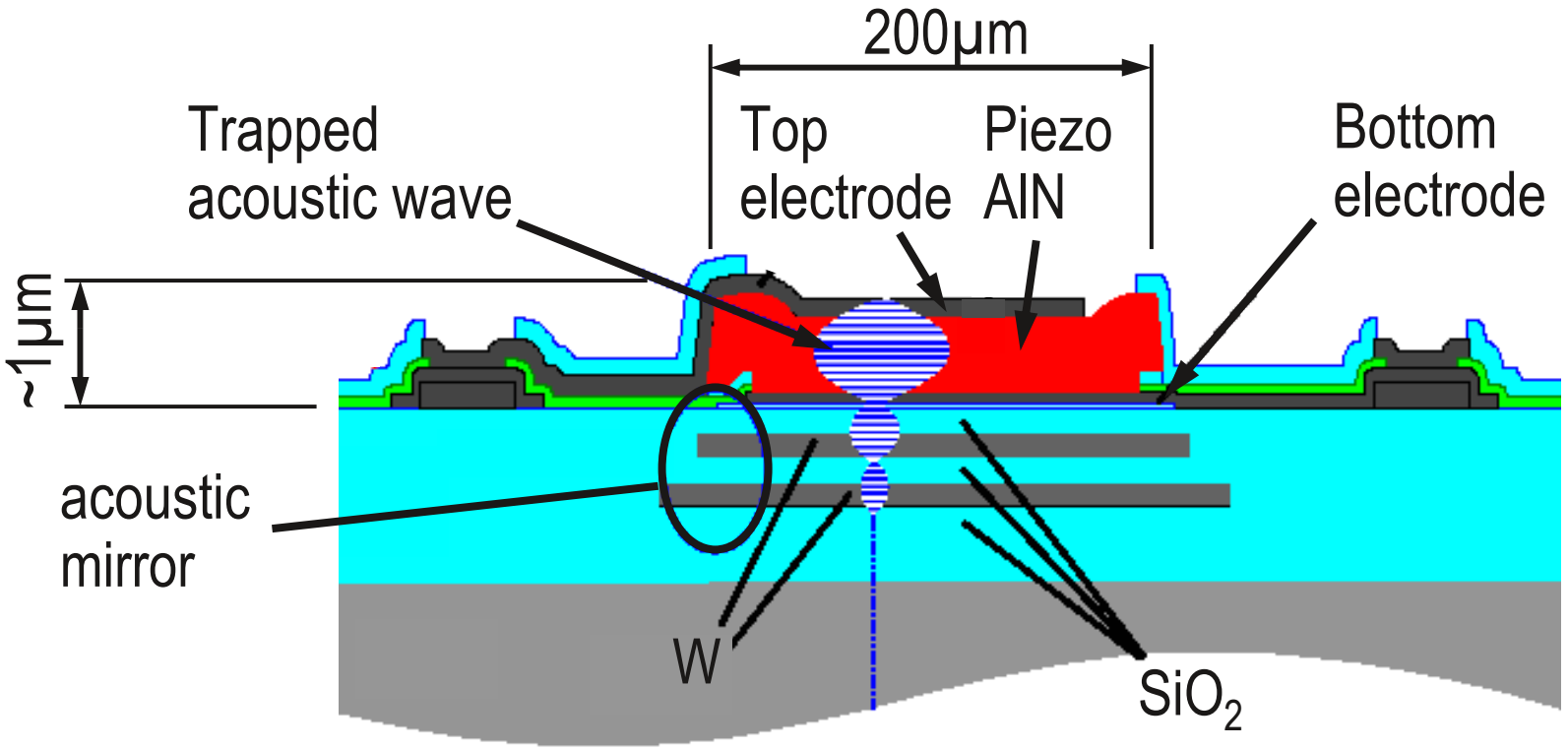
Infrared Night Vision System



RF MEMS
(revenue of 0.7 BUS$ in 2007)

- Inductors
- Capacitors
- Bulk Acoustic Wave (BAW) resonators
- Switches
- µ-mech. resonators

Bulk Acoustic Wave Device



- Si substrate
- Aluminum Nitride (AlN) used as piezoelectric material
- acoustic mirror realized by buried W layers

RF MEMS
(revenue of 0.7 BUS$ in 2007)

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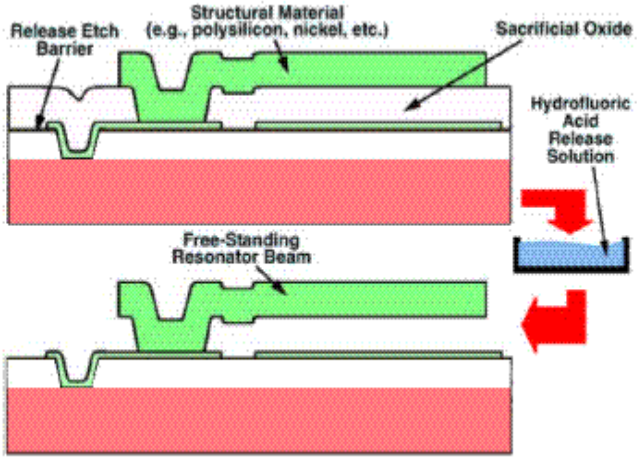
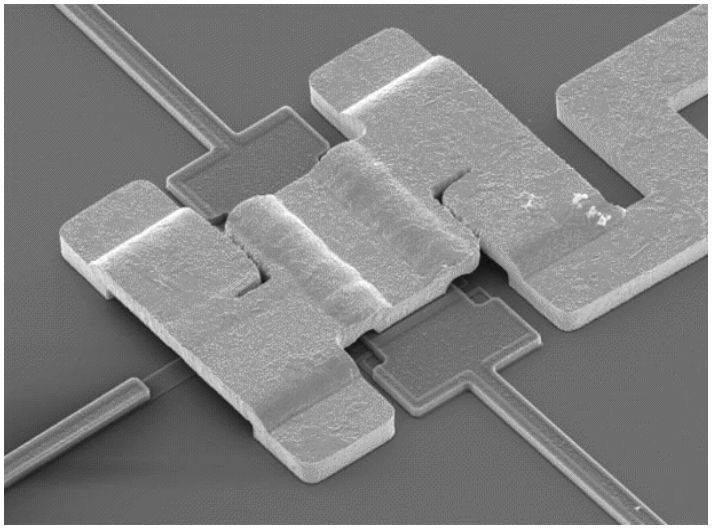
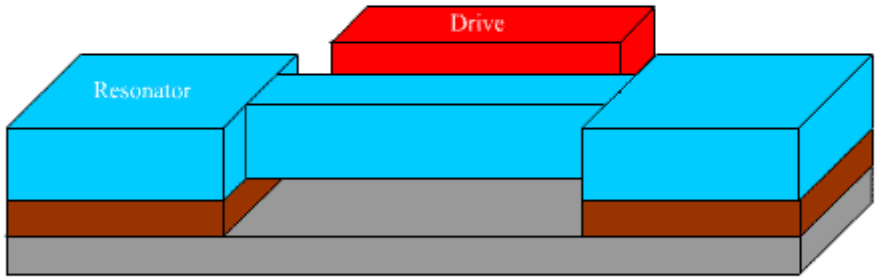
Micro-Mechanical Resonators

Source Discera







Conclusion

- MEMS have developed into a very dynamic field with exiting technical challenges and above-average growth rates
- Some applications have already developed into mature applications
  - Read/Write heads,
  - Digital Light Projection,
  - OptoDevices and Image sensors for cameras and mobile phones
- … others are yet developing
  - Acceleration sensors,
  - Pressure sensors,
  - RF MEMS,
  - Biosensors